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THE GROUND WATER HYDROLOGY OF JACUMBA VALLEY,

CALIFORNIA AND BAJA CALIFORNIA

A Thesis

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Faculty of

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by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

Figure Page

LIST OF PLATES

Chapter 1

INTRODUCTION

Purpose of the Study

The purpose of this study was to develop a qualitative and quantitative understanding of the ground water hydrology of Jacumba Valley, California and Baja California. This study was initially undertaken with the intention of providing ground water information for possible future study of the thermal springs located in the valley. During the course of the study, San Diego County began to institute controls on land development in order to prevent the overuse of ground water resources. These controls, and renewed interest in developing the United States side of the valley, added new importance to this study.

Location

Jacumba Valley and its watershed cover a 307 square kilometer area which straddles the United States-Mexican boundary (Figure 1). The United States' portion, about 30% of the watershed, is located in the southeastern corner of San Diego County, California. The remaining area is located in the state of Baja California, Mexico. The watershed is between longitudes 116° 05' west and 116° 16' west and between north latitudes 32° 30' and 32° 40'. The United States' side of the

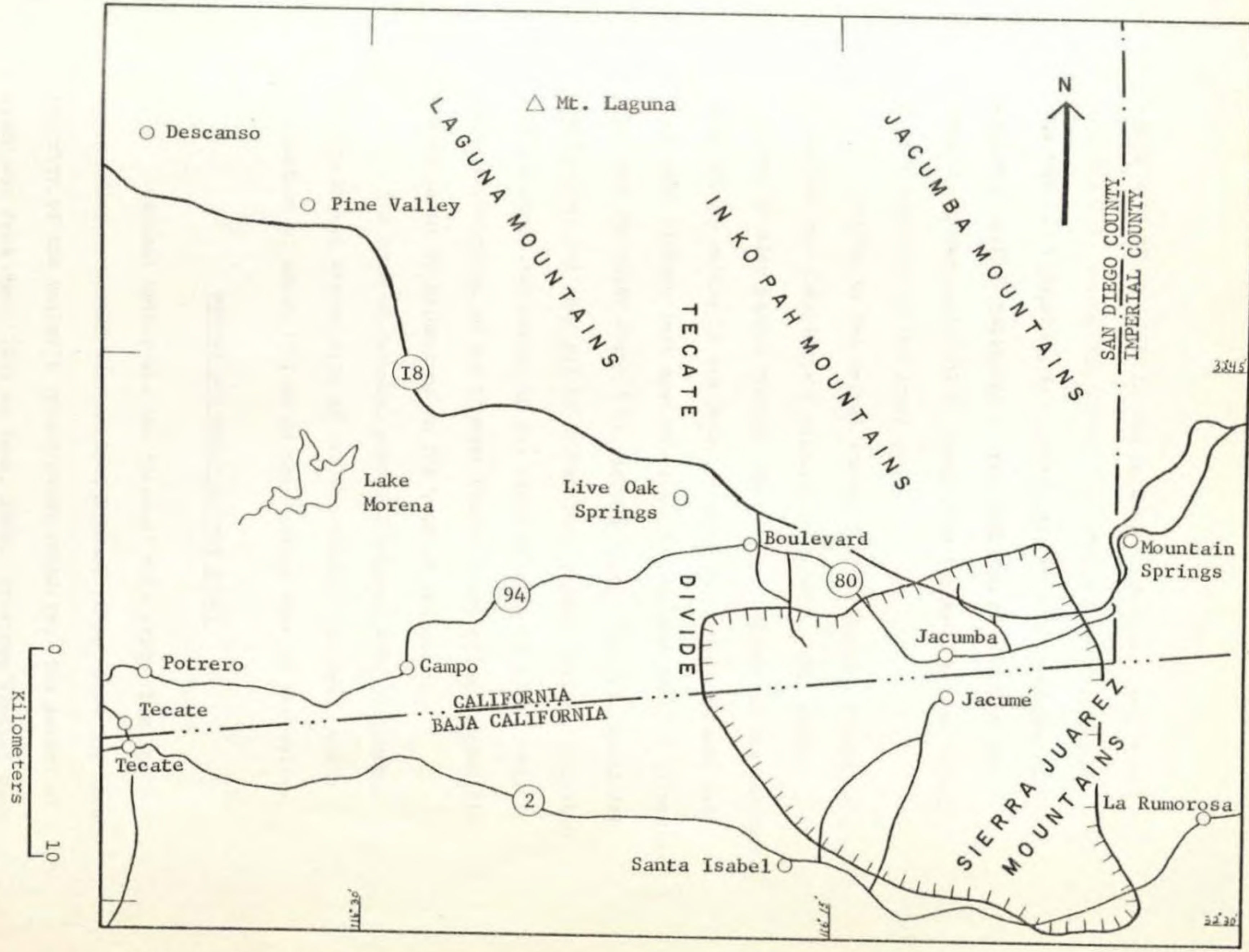

Figure 1. Location of Study Area

study area is included in the In Ko Pah, Jacumba, and Tierra Del Sol U.S. Geological Survey 7.5' topographic quadrangles. The Mexican 1:50,000 scale topographic maps La Rumorosa 111D63 and Neji 111D73, published by the Comision de Estudios del Territorio Nacional (1977), cover both the Mexican and United States portions of the study area.

Access to the United States side of Jacumba Valley is excellent via Interstate 8 exiting at Jacumba. Old State Highway 80 also passes through the valley. Access to the Mexican side of the valley is via Mexican Route 2. Two dirt roads exit from this highway just east of Santa Isabel, one about 1 kilometer east and the other about 5 kilometers east. The dirt roads are maintained, but they can be washed out by heavy rains. Crossing the international border in the study area is illegal. This is very inconvenient, as the closest border crossing is located at Tecate about 60 kilometers to the west of the valley.

The town of Jacumba, population about 400, is located on the United States side of Jacumba Valley. Jacumé, with a population of about 300, is on the Mexican side of the valley.

Method and Scope of the Study

Jacumba Valley was the focus of this study, but the surrounding watershed was included because it provides the great majority of the valley's ground water recharge. The period of study was from June, 1979 to June, 1980. Previous studies that related to the geology and/or hydrology of the Jacumba Valley area were researched. Public and private information on water levels in wells, well logs, meterological data, and personal accounts were collected. This information was supplemented with mapping, electrical resistivity soundings, chemical analysis of ground water, water level measurements, stream discharge measurements, pump tests, and soil tests. From this data the mean annual ground water recharge and the water budget were calculated and the ground water hydrology of the valley and watershed was described.

General Description of the Study Area

Brief History of Jacumba Valley

The following information on the history of Jacumba Valley is from the San Diego Historical Society file on Jacumba Valley in their Library and Manuscript Collection.

The history of Jacumba Valley, as with other areas in the arid southwest, is closely related to its water resources. Indians were the first humans known to inhabit the area. The cold springs on the western side of Jacumba Valley provided them with water and the hot springs and mud baths were attributed with miraculous powers. The most widely accepted translation of the Indian word "jacumba" is "miracle waters" or "magic waters" (Bailey, n.d.). Another translation is "dangerous waters," which is apparently in reference to the reports of sudden rising and falling of the water level of the hot springs. One story claims that several Indians were sucked into the hillside by these sudden rises and falls and their bodies were never recovered (Kelly, n.d.). The present springs show no such activity.

The settlement of Jacumba had its beginning in 1857 as a station on the San Diego-Yuma stage line. The station was established because the cold springs offered a good watering place. In 1877, the stages quit running when the Southern Pacific Railroad laid tracks through the valley. That same year, Burt Vaughn bought the hot springs on the United States side of the valley and started the town of Jacumba (Detzer, 1973).

The abundance of water and a shallow water table in Jacumba Valley were noted by various individuals. A letter from Porte Crayon to the San Diego Union in October, 1868 reports that "Jacumba Valley abounds with grass and water" (San Diego Union, 1868, p. 3). In the notes compiled by C. A. Bailey (n.d., p. 1), "Water is close to the surface. Jacumba flats was of concern to the 'autoist' in the spring before the highway was paved. The flats could bog down the trip." While completing the present railroad line in 1919, the Southern Pacific Railroad had problems with the boggy ground in the valley. Residents report that the railroad remedied the situation by dynamiting a natural dam at the north end of the Valley. In 1923, Brown (1923, p. 211) reported that "Jacumba has long been a prominent watering place on account of its large springs of good water."

The town of Jacumba apparently prospered through the 1950's. During the mid-1950's an attempt was made to commercially grow lettuce, but the cost of irrigation stopped the project. With the construction of Interstate 8, which bypassed the town, in the 1960's the town's economy lapsed. The hot springs, and the spa and hotel which developed around them, continues to be the prime source of income for the town. Recently there has been a renewed interest in the town. A portion of it has been purchased by a group hoping to develop the area.

Geomorphology

Jacumba Valley is located on the eastern side of the Peninsular Ranges of Southern California and Northern Baja California. The valley is located about 20 kilometers east of the drainage divide between the Pacific Ocean and the Gulf of California. According to Minch (1972), the Jacumba Valley watershed is part of an elevated elongate erosion surface that trends to the northwest. It is eastward sloping, about 120 kilometers long, and 20-30 kilometers wide. This erosion surface is bounded on the east by the Salton Trough escarpment and on the west by the drainage divide.

Jacumba Valley is a graben in the paleoerosion surface. The valley is roughly triangular in shape (see the geologic map in the pocket). The only surface discharge from the valley is located in the north end at the head of Carrizo Gorge. The north end of Jacumba Valley is narrowed by numerous hills, whereas the southern portion is wide and unobstructed. The valley is about 11 kilometers long and averages about 7 kilometers wide. The central valley floor is about 850 meters above sea level. The north end of the valley is 790 meters in elevation. The valley gently slopes upward to the south, reaching an elevation of about 920 meters. Hills gradually rise from the valley to the west and southwest to an elevation of about 1070 meters. To the southeast, the Sierra Juarez Mountains climb steeply to 1300 meters. This southeast escarpment ends rather abruptly at the pass through which Interstate 8 leaves the eastern side of the watershed. The hilly topography of the western side of the watershed continues around to the north of the valley where it is cut by Carrizo Gorge.

There are numerous ephemeral streams draining into Jacumba Valley. Their channels extend various distances into the valley, but none of the channels cross the valley to Carrizo Gorge. The drainages on the western side of the watershed are better developed. Boundary Creek is the most prominent drainage. Alluvial fans have developed along the front of the Sierra Juarez Mountains.

Soils

The soils in a watershed play an important role in the hydrologic cycle. A soil's permeability, specific retention, and active rooting depth are controlling factors that determine what portions of the precipitation runoff, satisfy the soil moisture requirements, and recharge the ground water. The soil types present on the United States side of Jacumba Valley and its watershed have been classified and mapped by the United States Soil Conservation Service and Forest Service (1973). The list of these soils and their hydrologic properties are presented in Appendix B. The United States Soil Conservation Service's methods of classification made it difficult to extrapolate the soil types or the hydologic groups into the Mexican portion of the study area. There also appears to be some error in the soil maps. The soils that have developed on the Jacumba Volcanics were classified as Group A soils, those that are very permeable with low water holding capacity. However, the soils on the volcanics have a high percentage of clay, a low permeability, and high specific retention (Appendix B). Because of the above problems, soil tests were made on the soils in the Jacumba Valley area. The locations of the samples are shown on the geologic map in the pocket. The method of collection and testing are in Appendix B. The specific retentions of the eleven samples tested were significantly higher than the water holding capacities listed for the soils by the United States Soils Conservation Service.

Huntley (personal communication, 1980) confirmed that the higher specific retentions were similar to those found in other studies in San Diego County. Consequently, the hydrologic classification of the soils used in this study are based on the soil tests made by the author. Listed as Table 1 are the soil groups used in this report. A generalized soils map is included in Appendix B.

Due to overgrazing, much of the soil on the Mexican side of the valley is poorly developed with both modern and earlier eolian deposits.

Vegetation

The vegetative cover in Jacumba Valley and its watershed is generally sparse and reflects the semiarid environment. The plants of this area are those that can survive the long, dry summers with little or no water, or those that have the ability to tap the zone of ground water saturation. In Jacumba Valley, the amount of cover varies, but averages 30%-50%. It is composed primarily of grasses, low shrubs, and a variety of cactus. There are some localized areas where bushes over 1 meter high are present. The bush vegetation in the Sierra Juarez Mountains is estimated to be 20%-30% cover on the lower slopes and up to 40% cover on the upper slopes. To the west of Jacumba Valley bushes cover an estimated 30%-40% of the ground. Webber (1979) studied two sites to the west of Jacumba Valley (see the geologic map in the pocket for the location of the sites). One site had 55%

Table 1

Soil Groups of the Jacumba Valley Watershed

Group	Specific Retention	Location
W	0.19 centimeters^3/centimeter^3 of soil	Alluvial fans, stream channels, alluvial fill in small mountain valleys, and eolian deposits.
X	0.27 centimeters^3/centimeter^3 of soil	Soil developed on metamorphic and plutonic terrain.
Y	0.38 centimeters^3/centimeter^3 of soil	Soil developed on volcanics and the fine sandy alluvium in Jacumba Valley.
Z	0.59 centimeters^3/centimeter^3 of soil	Clay rich valley alluvium in the northern portion of Jacumba Valley.

plant cover and the other had only 25% cover (Appendix C).

The San Diego County Generalized Vegetation Map (County of San Diego, 1977) shows three types of plant communities in the United States portion of the watershed. Desert Transition covers about 63% of the study area, primarily the eastern sections. Chamise Chapparel is dominant in the western portion, covering about 34% of the area, and Grasslands cover the remaining 3%. For a partial list of the plants found in these communities, see Appendix C.

At scattered locations in Jacumba Valley and in the surrounding watershed there are phreatophytes. In Jacumba Valley they are most abundant at the north end of the valley. The phreatophytes that were identified are cottonwood, mesquite, and salt ceder.

Meterology

Precipitation data for Jacumba Valley and its watershed are available from stations in the town of Jacumba and Boulevard (Appendix A). For Jacumba, daily precipitation records are available beginning in March, 1962, and are complete through the present (County of San Diego, personal communication, 1980). Boulevard is located just to the west of the watershed on the United States side of the international border (Figure 2). Daily records began in December, 1924 and have only a few gaps through the present (National Oceanic and Atmospheric Administration, written communication, 1980; United States Weather Bureau, 1931-1964; United States Environmental

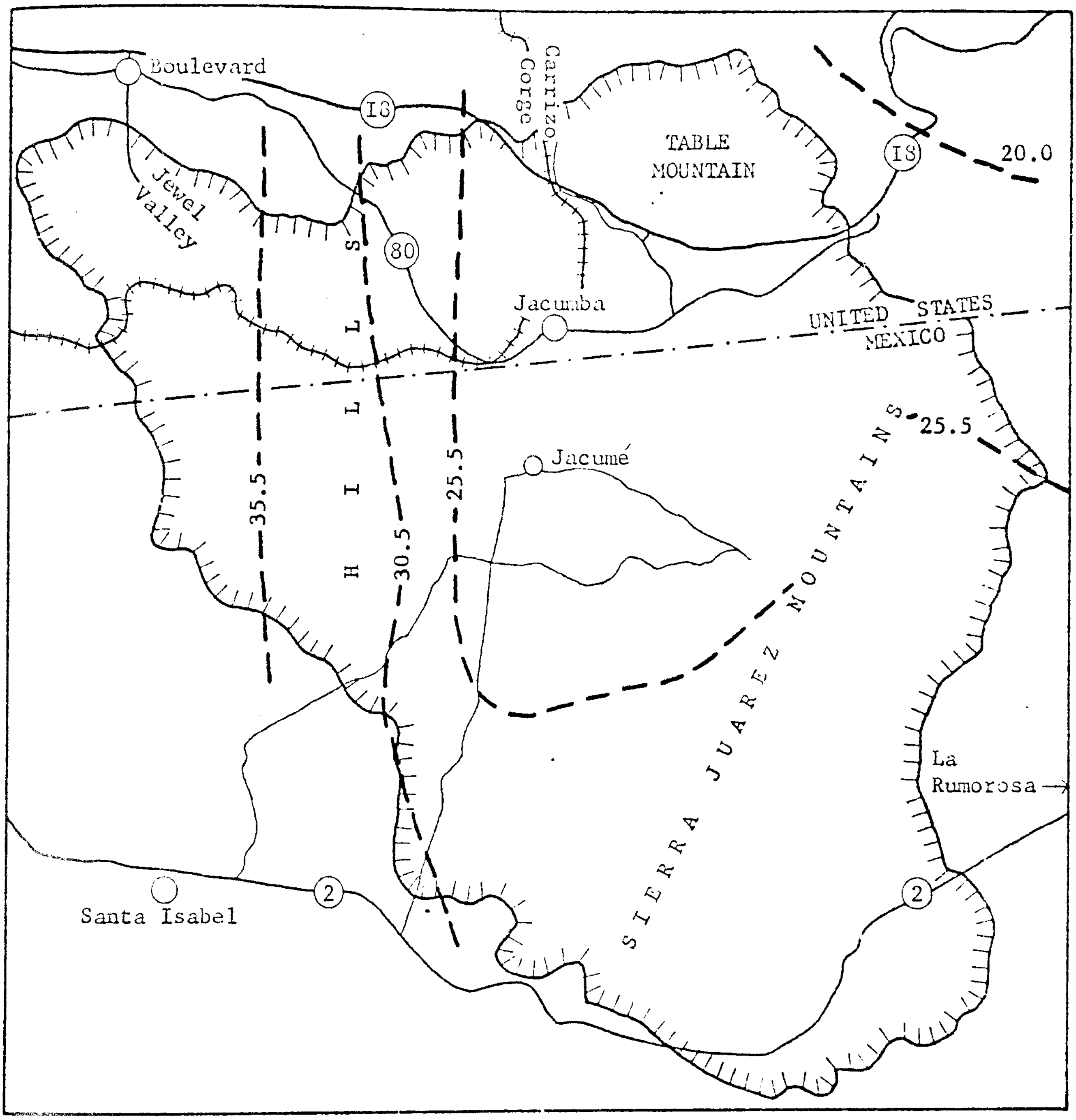

Figure 2. Jacumba Valley Watershed and Isohyetal Map. Dashed lines indicate the mean annual precipitation (centimeters). Isohyetal lines are modified from Hely and Peck (1964). (Scale is about 1:143,000.)

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Sciences Services Administration, 1965-1980). Jacumba's mean yearly precipitation is 24.9 centimeters (9.8 inches) with a range in yearly precipitation from 11.3 centimeters to 44.9 centimeters (Figure 3). Boulevard has a mean yearly precipitation of 38.4 centimeters (15.1 inches), with a range from 14.8 centimeters to 77.6 centimeters (Figure 3).

The monthly precipitation for both Jacumba and Boulevard varies considerably. Figure 4 shows the mean monthly precipitation for the two stations. Commonly the months of May through October have low precipitation and November through April have high precipitation. Each month shows considerable scatter over the years. For example, Jacumba's data show a range in January precipitation from 0-16.7 centimeters and in July from 0-4.5 centimeters. Yearly wet and dry precipitation cycles generally affect the winter precipitation, whereas the variations in the summer months depend on localized storms. Snow occasionally does fall; however, it averages less than 3 centimeters per year in Boulevard.

The Boulevard precipitation record was extrapolated by comparing it to precipitation data from Lake Morena and Lake Cuyamaca, California (Appendix A). Figure 5 is a plot of this extrapolated data covering ninety-three years. The mean yearly precipitation for Boulevard based on the extended record is 40.5 centimeters (16.0 inches). This is slightly higher than the yearly mean based on the available data and may be the

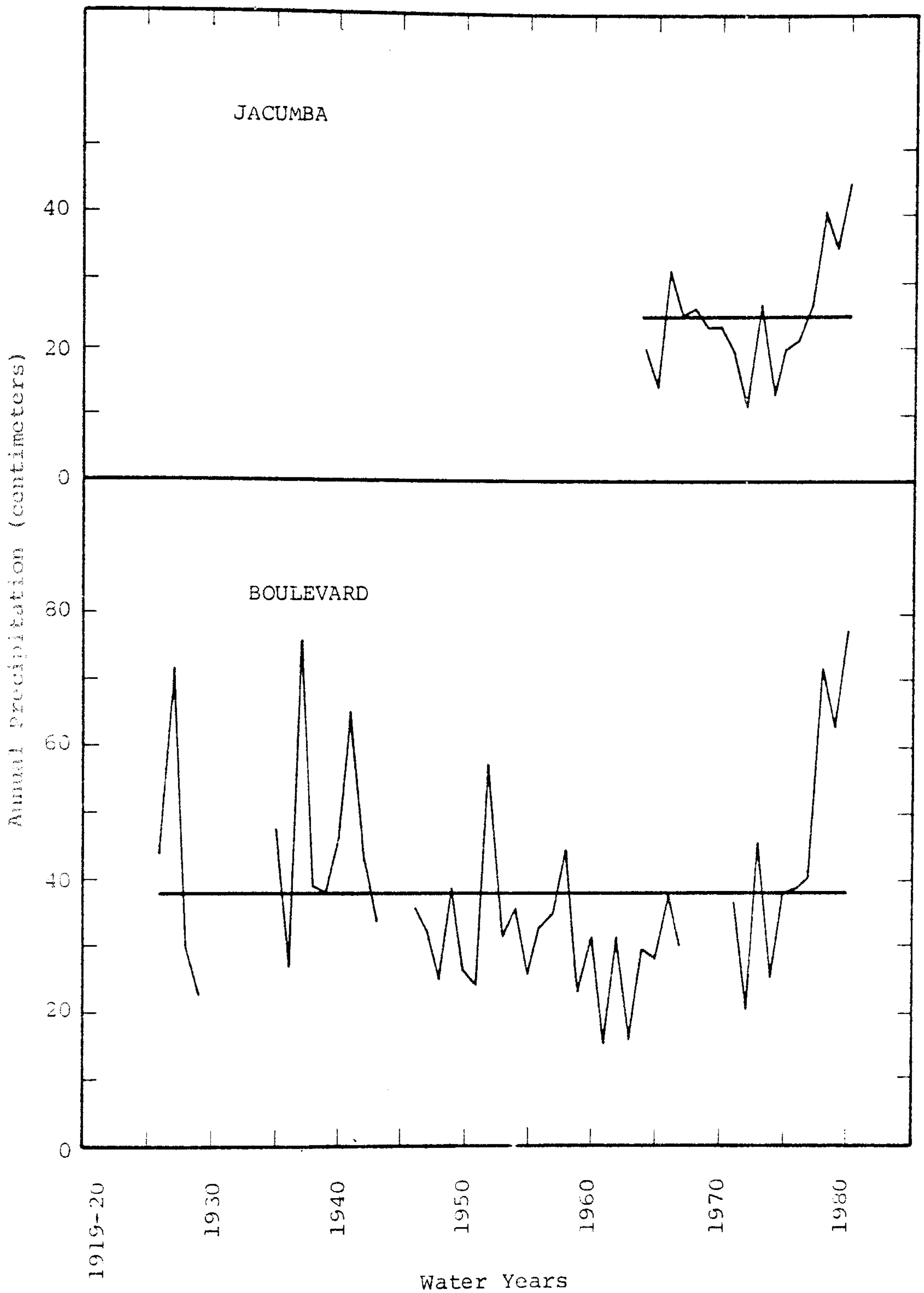

Figure 3. Plot of Available Yearly Precipitation Data for Jacumba and Boulevard

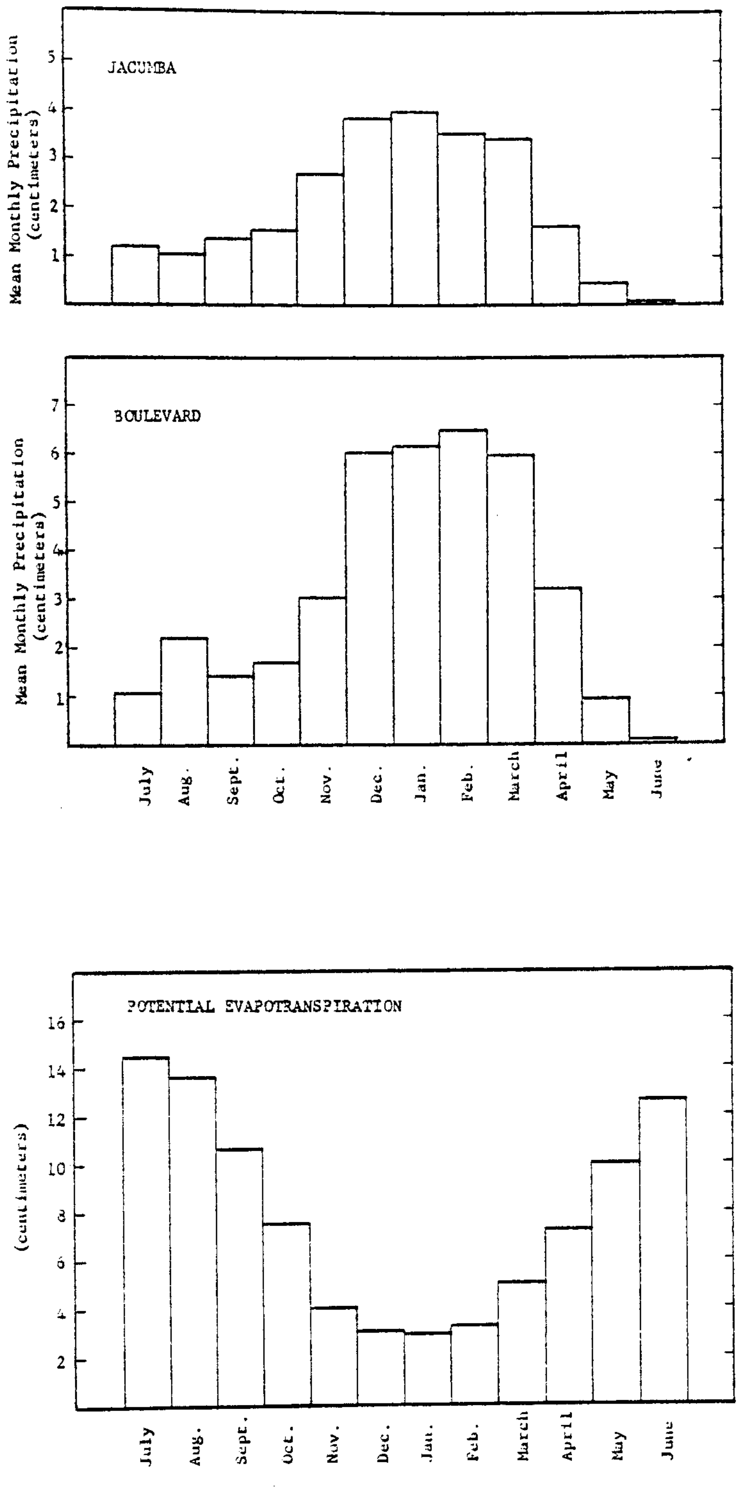

Figure 4. Mean Monthly Precipitation for Jacumba and Boulevard. Calculated mean monthly evapotranspiration for the Jacumba Valley area.

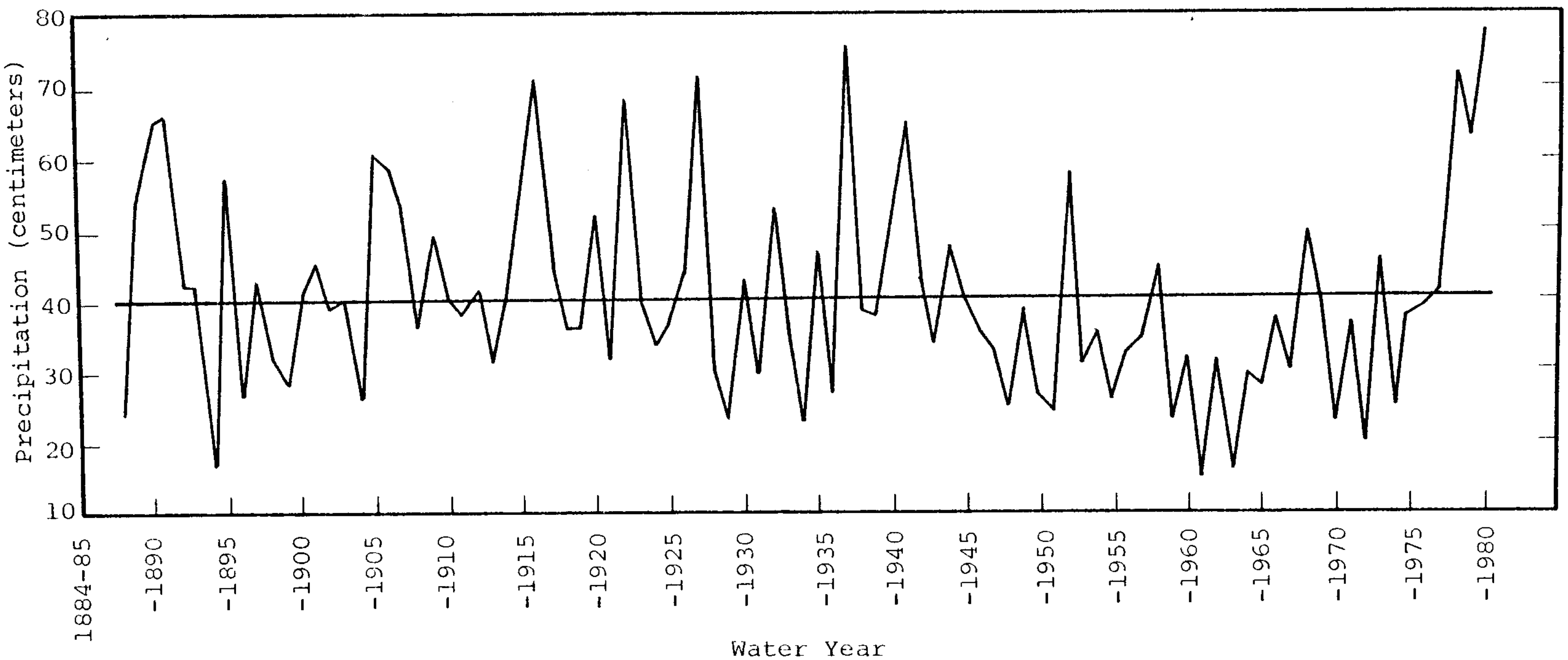

Figure 5. Extrapolated Yearly Precipitation for Boulevard

result of the below-normal precipitation that occurred during much of the time Boulevard kept records. Figure 6 is a plot of this extrapolated data after it was smoothed by averaging seven points for each data point. This smoothed plot clearly shows the wet and dry cycles in the precipitation record. Between the mid-1940's and the mid-1970's, there was a thirty-year period of below-normal precipitation. Prior to that there was a period of forty years, 1905-1945, when precipitation was generally above normal. Superimposed on these long-term cycles are five-to-ten-year fluctuations in precipitation.

Calculations of the probability of occurrence of yearly precipitation are in Appendix A.

Figure 2 (page 12) is an isohyetal map of the Jacumba Valley watershed. The position of the lines generally follows those of Hely and Peck (1964) with some modification based on more extensive precipitation data from Boulevard and Jacumba.

Temperature. There are no temperature records for the Jacumba Valley area. Close (1970) indicated that the mean annual temperature of the Jacumba area is about 16°C. For January, the mean maximum is 14°C-17°C and the minimum is 1°C-2°C. In July, the mean maximum temperature is 36°C-38°C and the minimum is 14°C-17°C.

Evaporation. There are no data on evaporation available for the Jacumba Valley area. Lake Morena, California is the

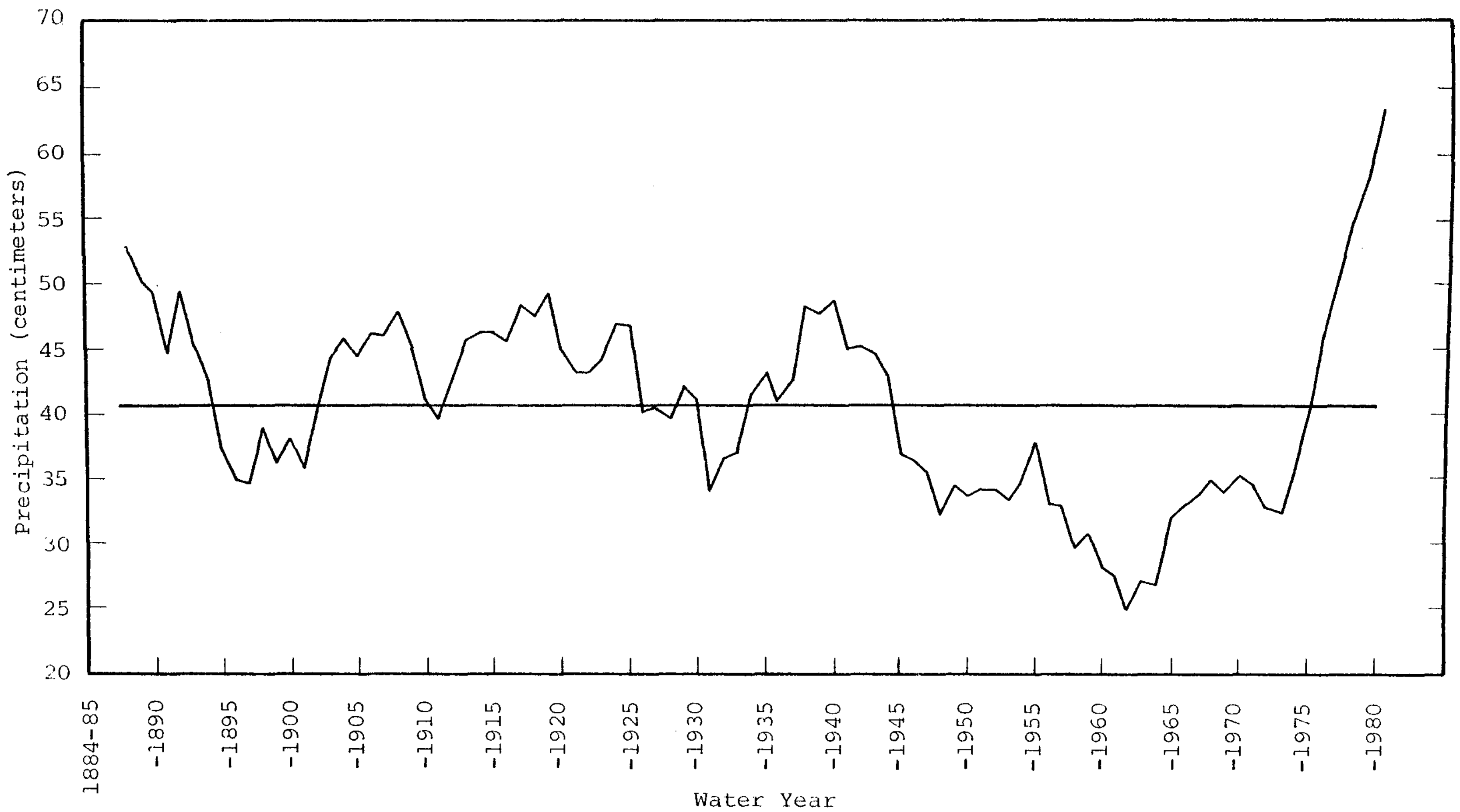

Figure 6. Seven-point Smoothed Plot of the Extrapolated Yearly Precipitation for Boulevard

closest evaporation station with elevation and climate similar to Jacumba's. The mean monthly pan evaporation data for Lake Morena are in Appendix A.

Previous Hydrologic Studies

Little hydrologic work has been done in the Jacumba Valley watershed, probably a result of the rural nature of the area. Much of the work that has been done primarily provided information on the ground water chemistry.

In 1915 Waring described and analyzed the Jacumba Hot Springs. His chemical analysis is included in Appendix K.

In his report on the Salton Sea Region, Brown (1923) briefly described the cold springs in Jacumba. At that time there was a group of cold springs in the same general location as wells J3, J3A, and J4 of this report. Brown describes the cold spring: "The larger one fed a stream that in November 1917 flowed at at least 1 second-foot" (Brown, 1923, p. 211). These springs were located in a

> shallow mountain canyon that enters Jacumba from the west. There is apparently little reason to doubt that the large spring originates from the rise of underflow waters of the arroyo above and is really only a slightly unusual example of flow in an intermittent stream. (Brown, 1923, p. 212)

Brown also mentions the group of warm springs of 32°C sulphur water located just east of the cold springs. He speculates that the warm waters issue along deep fractures. His report includes a chemical analysis of the cold springs (Appendix K).

Burt Babcock (1958), in his study of ground water in San Diego County, was the next author to examine the hydrology of Jacumba Valley. He briefly noted that most of the valley's wells penetrate the sands and gravels of the recent alluvium. He states that below the alluvium there is a thin zone of impermeable clay overlying the Tertiary volcanics. The static water level in the wells he examined varied from 16.8 meters in the middle of the valley to about 6.1 meters along the stream bed of Boundary Creek. The water chemistry of the main Jacumba Cold Spring and two wells was tested (Appendix K). Babcock noted a distinct difference between the spring and the wells; the springs were soft with only two parts per million total hardness and a high percentage of sodium, whereas the wells showed hard water that was high in dissolved solids.

Richard Thesken (1977) performed a chemical study of various wells in the United States portion of the watershed. His study focused on the Jacumba Hot Spring, but his chemical analyses provide good coverage of the United States side of Jacumba Valley (Appendix K).

A few other authors have discussed various aspects of hydrology for areas including or relevant to the Jacumba Valley watershed. Richard Merrian (1951) qualitatively discussed the ground water potential of the various bedrock lithologies in western San Diego County. His work provided the basis for the description of the ground water potential of the bedrock terrain in this report. Hely and Peck (1964) included the entire Jacumba Valley watershed in their study of precipitation, runoff, and evapotranspiration in the Salton Sea area. Some of their data have been used in this report.

Conversations with local residents and well drillers provided some additional information.

Chapter 2

GEOLOGY

Jacumba Valley is a fault-produced valley in the crystalline bedrock of the Peninsular Ranges of southern California and northern Baja California. Most of the mountain valleys in this area have only Quaternary alluvium in them. Jacumba Valley is rather unique in that it also contains Tertiary sedimentary and volcanic formations (Figure 7). A geologic map of Jacumba Valley and its watershed is located in the pocket.

Various authors have studied the geology of the Jacumba Valley area. Minch and Abbott (1973) did a study of the post-batholithic geology of Jacumba Valley, California. Their map and text provided the basis for the geologic work for this study. Geologic maps by Brooks and Roberts (1954), Dibblee (1954), and the Comision de Estudios del Territorio Nacional (1977) cover various portions of the Jacumba Valley watershed in varying degrees of detail. Minch (1972) included the Table Mountain Formation and Hawkins (1970) the Jacumba Volcanics in their regional lithologic studies.

Lithology

Crystalline Bedrock

Crystalline bedrock composes the majority of the Jacumba Valley watershed. These rocks have been mapped as meta-sedimentary

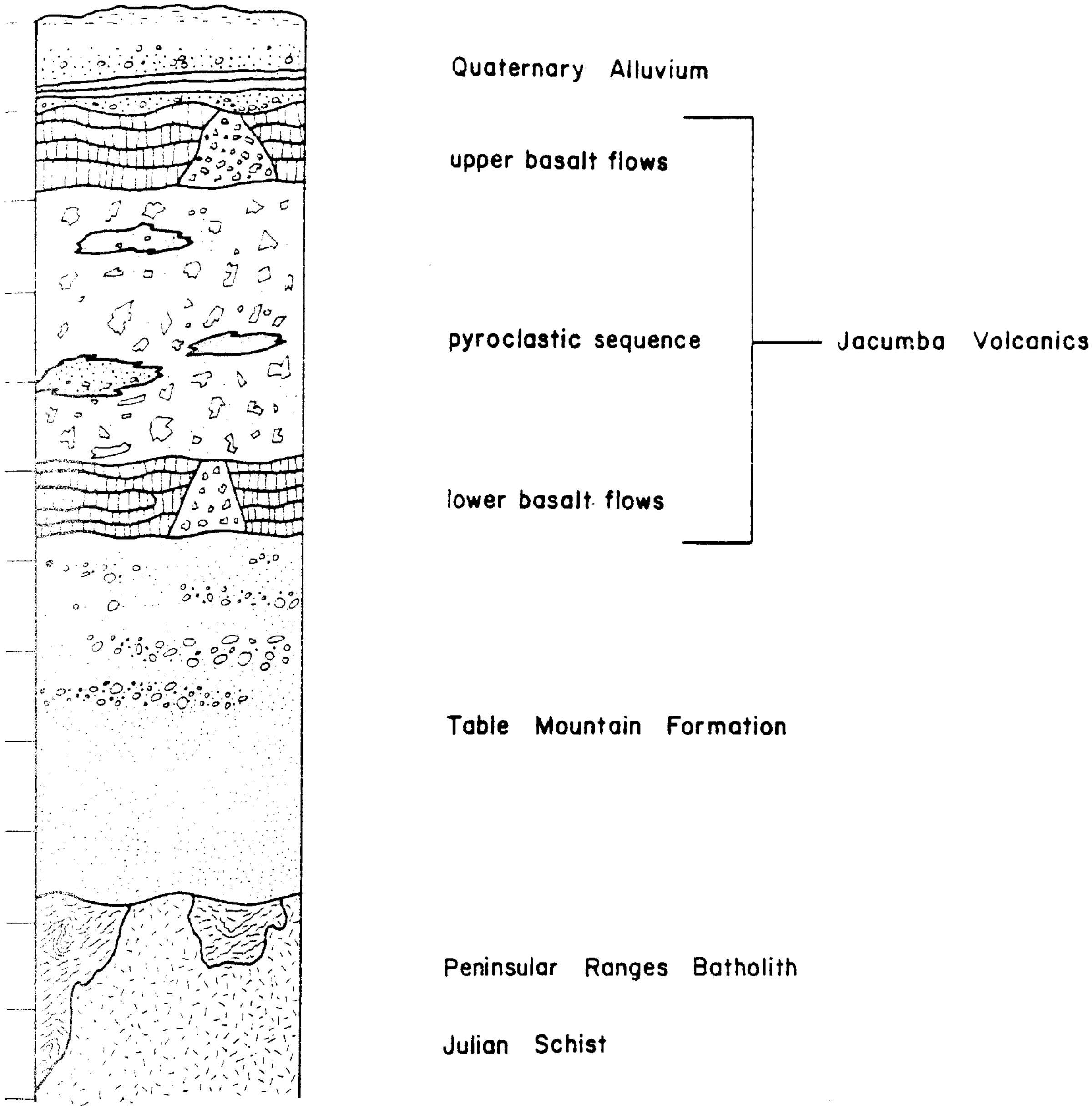

Figure 7. Generalized Stratigraphic Column for Jacumba Valley and Vicinity (Modified from Minch and Abbott, 1973). (50-meter interval scale.)

rocks which were intruded by plutonics of the Peninsular Ranges Batholith. The metamorphic rocks crop out on the United States side of the study area in the hills just west of Jacumba Valley. In Mexico they form the majority of the Sierra Juarez Mountains. The metamorphics, which have been compared to the Julian Schist, are composed of assemblages of schist, quartzite, gneiss, and occasional pods of marble. They appear structurally complex. These rocks are cut by abundant pegmatites and minor plutonic bodies. The age of the metamorphics is unknown, though various authors have suggested a Paleozoic age for the deposition of the sediments (Dibblee, 1954; Peterson, Gastil, and Allison, 1970).

Plutons of the Peninsular Ranges Batholith have intruded the assemblage of metamorphics, pegmatites, and minor plutonics. The compositions of the plutons in the Jacumba Valley area are quartz diorite and granodiorite, with minor pods of gabbro. On the United States side of the watershed, the plutonic rocks crop out to the north and east of the valley and enclose and intrude the metamorphics to the west. In Mexico, the plutonics crop out on the western side of the watershed. Aerial photographs of the plutonic rocks to the west of Jacumba Valley show a closely spaced, well-developed, east-west fracture pattern (Plate I). Radiometric ages for the final consolidation of the southern California portion of the Peninsular Ranges Batholith are between 90 and 100 million years (Peterson, Gastil, and Allison, 1970).

PLATE I

FRACTURES IN THE PLUTONIC TERRAIN TO THE WEST OF JACUMBA VALLEY. (Scale about 1:60,000.) (See Figure 9, page 31, for the location of the plate.) (Photographs courtesy of Gordon Gastil.)

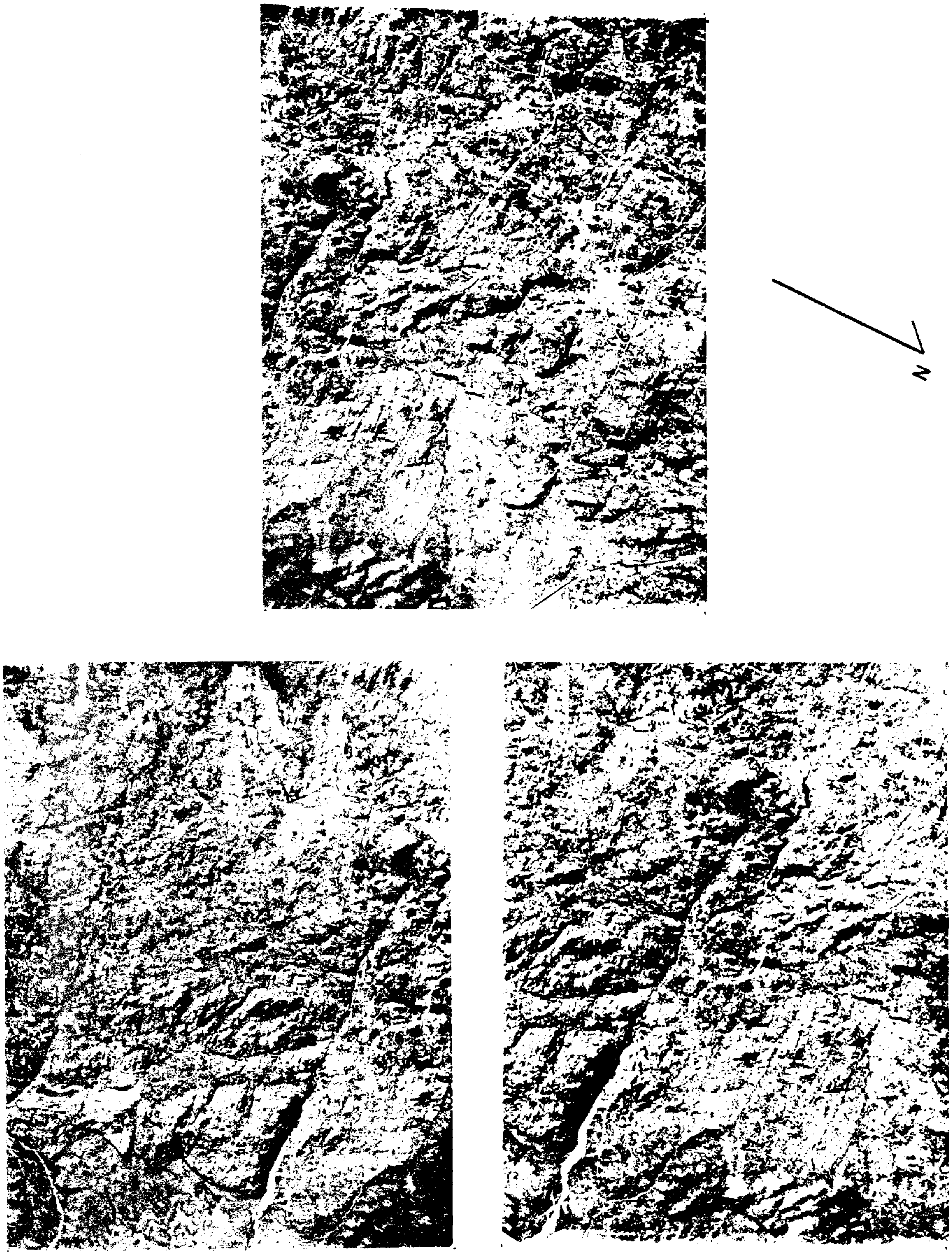

Table Mountain Formation

The Table Mountain Formation is a medium to coarse-grained sandstone and conglomeratic sandstone which unconfromably overlies the crystalline basement. According to Minch (1972), this formation crops out on the east side of the Peninsular Ranges in a belt about 10 kilometers wide and 25 kilometers long. The Jacumba Valley area has some of the best exposures of this formation because they are overlain and preserved by the Jacumba Volcanics. Miller (1935) first defined the Table Mountain Formation from the exposures just northeast of Jacumba Valley. The Table Mountain Formation crops out on the hills throughout much of Jacumba Valley, on the sides of Table Mountain, and in the Sierra Juarez Mountains near La Rumerosa.

Minch (1972) did a detailed study of the formation and much of the information presented below was extracted from his work. The Table Mountain Formation is a white to yellow-brown, fairly well-sorted, friable, medium to coarse-grained sandstone and conglomeratic sandstone. The sandstone is a plutonic lithic arkose with very angular framework grains. Minch reports the following percentages of grain sizes for the sandstone portion of the formation: 27% very coarse sand, 32% coarse sand, 21% medium sand, 10% fine sand, 5% very fine sand, and 5% silt and clay. The 1/2 to 1 meter thick strata of conglomeratic sandstone are generally poorly defined, moderately sorted, and slightly graded. The clast diameter averages 2.5 to 5 centimeters, with clasts up to 10 centimeters common. Clasts up to 30 centimeters in diameter are not uncommon. These clasts are matrix supported. Most surface exposures of this formation are moderately cemented with poikilotopic, very coarsely crystalline calcite. This cement has been leached out of the formation in some exposures. Well cuttings from well R2 showed no evidence of calcite cement in the subsurface of the formation.

The thickness of the Table Mountain Formation varies considerably in and around Jacumba Valley. The measured thickness ranges from 0 to 90 meters (Minch and Abbott, 1973). The Table Mountain Formation is present in the subsurface of Jacumba Valley. An electrical resistivity sounding near Round Mountain, sounding #2 in Figure 8 and Appendix J, indicated that the formation is about 200 meters thick. Resistivity sounding #3 also indicates that the Table Mountain Formation is thicker in the subsurface than in the surface exposures.

During the summer of 1979, a 150-meter well was drilled and backfilled in the Table Mountain Formation near well R2 (Figure 8). The log for this abandoned well is shown in Table 2. Well R2 was drilled about 30 meters from the well described above. According to the drillers, the log was similar down to 120 meters where drilling was terminated. The 50 meters of moderate to well sorted, medium to coarse-grained, arkosic sandstone between 100 meters and 150 meters had no conglomeratic fraction. This indicates a significant change in the lithology

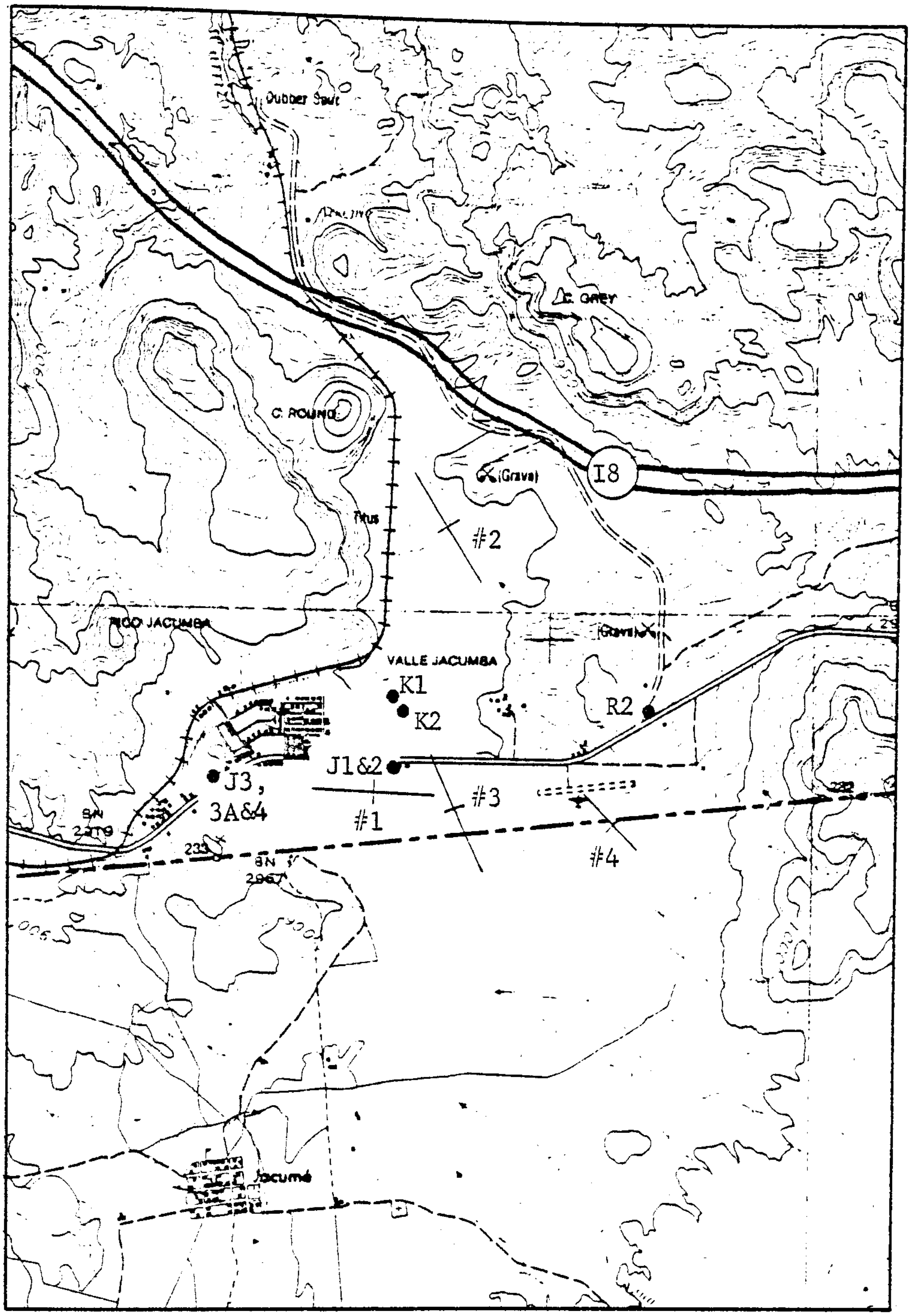

Figure 8. Location of Electrical Resistivity Soundings and Wells with Logs (Scale 1:50,000)

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——+—— Location and alignment of Schlumberger array.

● Location of wells.

Table 2

Log for the Abandoned Well near Well R2

Depth	Lithology
The first 35 meters were not logged.	
35-45 meters	Arkosic sandstone
-55	Conglomeratic sandstone and sandstone
-70	Sandstone and conglomeratic sandstone
-100	Conglomeratic sandstone and sandstone
-150	Arkosic sandstone

of the formation that is nowhere present in surface exposures.

Surface exposures of the Table Mountain Formation indicate that the unit thins rapidly to 20 meters and less at the north end of Jacumba Valley. This thinning is particularly evident at the north end of the long flat hill to the west of Round Mountain (see the geologic map in the pocket). In the southern portion of the valley, outcrops and electrical resistivity sounding #4 (Figure 8 and Appendix J) suggests that the formation thins to less than 100 meters thick just south of the international border (Figures 9, 10, and 11).

Minch (1972) and Minch and Abbott (1973) state that the Table Mountain Formation is probably a remenent of an extensive fluvial deposit on the paleoerosion surface. The outcrop pattern in the vicinity of Table Mountain supports this. However, the rapid thinning of the formation at the north end of Jacumba Valley and just south of the international border suggests that a channel or graben developed on the paleoerosion surface prior to and/or during the depositon of the Table Mountain Formation. There is no evidence for fault controlled thinning at the north end of the valley; therefore, this author prefers a model of a paleochannel (Figures 10 and 11). Cobble imbrication studies by Minch (1972) indicate a paleocurrent flowing in a southwesterly direction. This roughly conforms to the suggested channel in the subsurface of the valley. Faulting has preserved the thicker section of the formation in the valley.

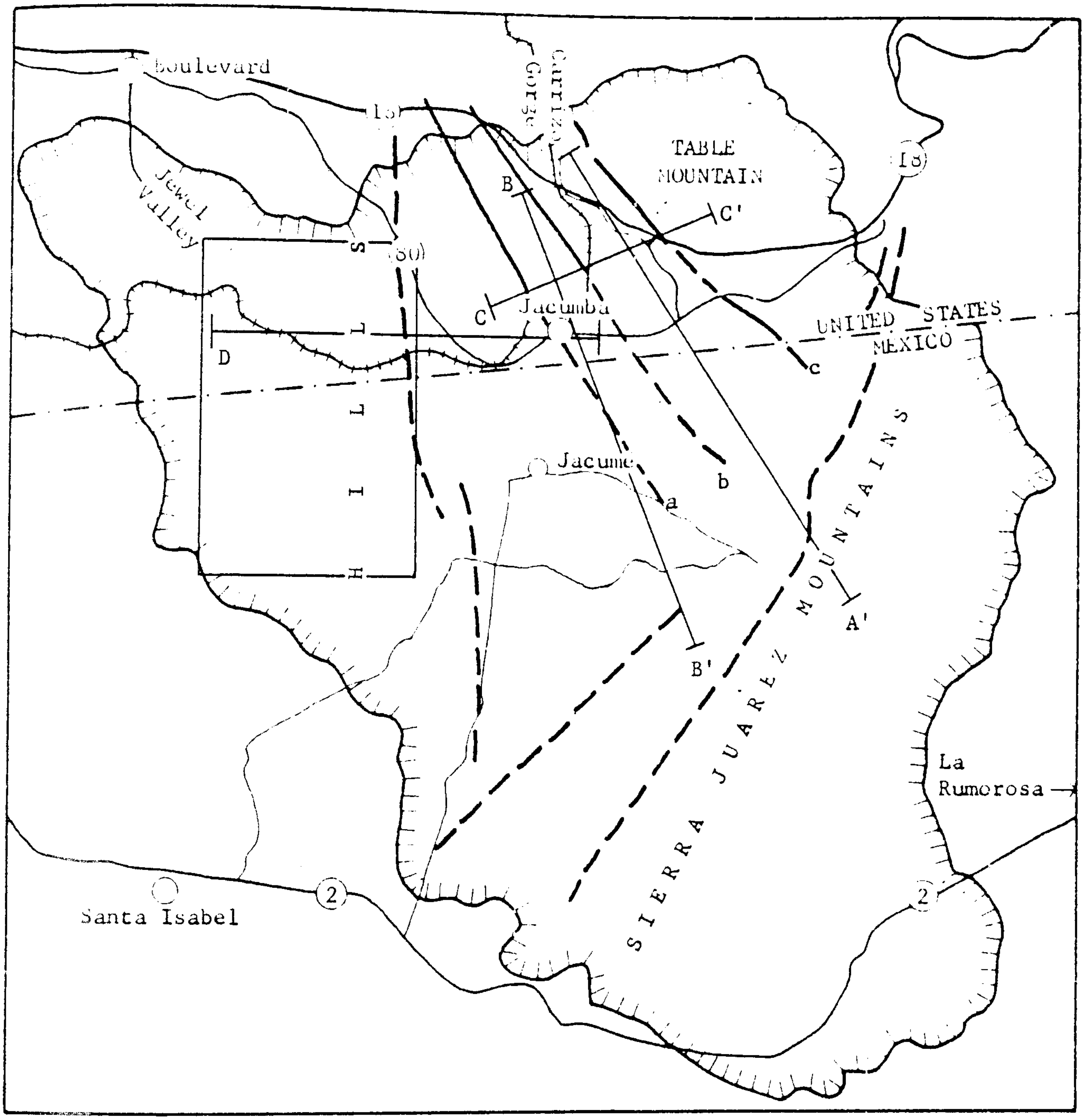

Figure 9. Location of Faults, Cross Sections, and Plate I. Thick lines indicate principal faults. Thin lines indicate cross sections. The area enclosed by the rectangle is the area shown in Plate I. (Scale is about 1:143,000.)

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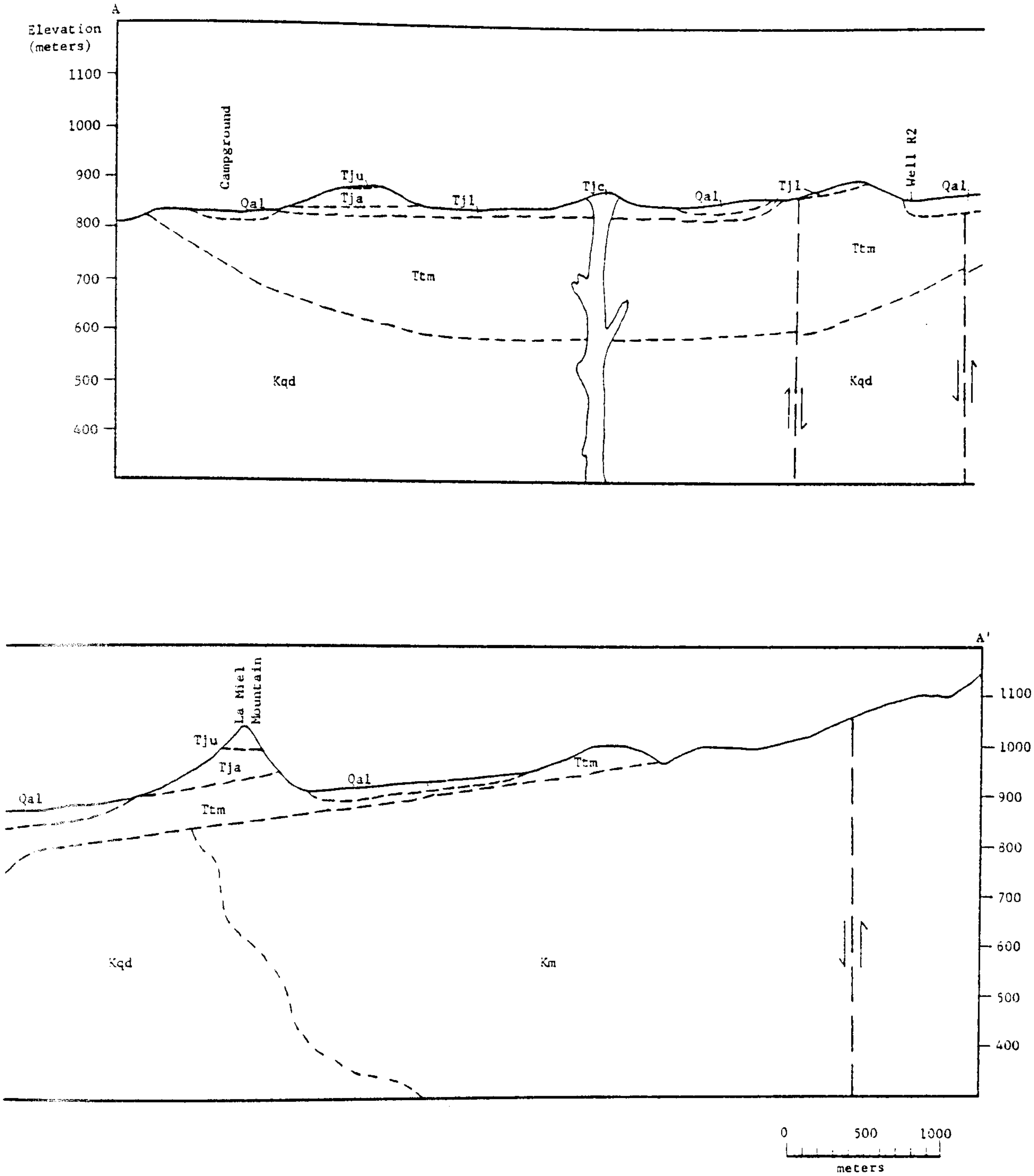

Figure 10. Geologic Cross Section A-A'

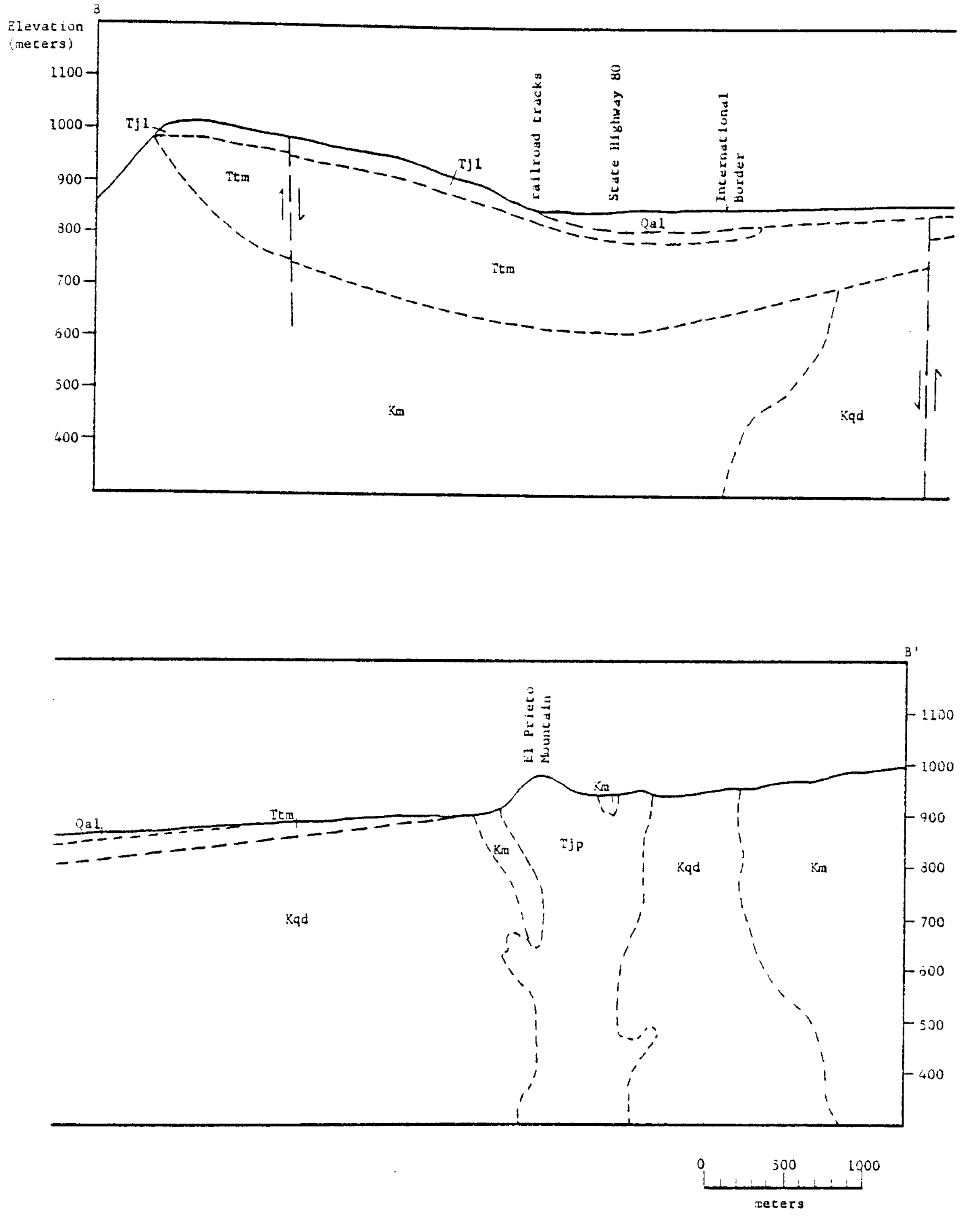

Figure 11. Geologic Cross Section B-B'

The two different lithologies found in the subsurface of Jacumba Valley indicate that the depositional history of the Table Mountain Formation is more complicated than suggested by previous authors. The change in lithology, from sandstone to sandstone and conglomeratic sandstone, may record the initiation or an increased rate of tectonic activity, possibly related to the faulting and volcanics in the area.

Minch (1972) suggests that the Table Mountain Formation was highly eroded prior to the deposition of the Jacumba Volcanics. Hawkins (1970) believes that there was only minor subflow relief. This author agrees with Hawkins. There is little evidence for much relief in the Table Mountain Formation and Jacumba Volcanic contact. The absence of about 100 meters of sandstone in the surface exposures surrounding Jacumba Valley could indicate that that portion of the formation was completely eroded prior to the deposition of the conglomeratic portion.

Minch (1970, 1972) assigns a tentative age for the Table Mountain Formation of late Cretaceous to early Eocene on the basis of clast composition. According to him, some of the clasts are similar to those in the Cabrillo Formation of San Diego, which is late Cretaceous. Also, the absence of "Poway clasts" suggested an age of no later than early Eocene. Although the age of the Table Mountain Formation was not studied during this project, it came to the attention of this author that some of the clasts in the formation are nearly identical in hand specimen to the lavas of the Jacumba Volcanics. Both have reddish-brown phenocrysts of olivine, amphibole and/or pyroxene surrounded by a gray groundmass. These clasts are quite unlike other volcanic clasts found in the Table Mountain Formation. The Miocene Jacumba Volcanics overlie the Table Mountain Formation; however, there are other volcanics of similar age in the Salton Trough area (Dibblee, 1954). In addition, if the Table Mountain Formation were deposited prior to the mid-Eocene, they were deposited during a time believed to be characterized by intense humid weathering (Peterson and Abbott, 1973). The arkosic sandstone of the formation shows no evidence of humid weathering, yet the granitic bedrock in the Peninsular Ranges does. These data suggest that the formation was deposited after the mid-Eocene, probably in the Miocene or Oligocene.

Jacumba Volcanics

The Jacumba Volcanics are composed of basaltic and andesitic pyroclastics sandwiched between two lava flow sequences. According to Minch and Abbott (1973), the volcanics are present in a belt about 20 kilometers by 55 kilometers roughly parallel to the axis of the Peninsular Ranges. They are best exposed in and around Jacumba Valley. From these exposures Miller (1935) defined the formation. In the Jacumba Valley area, the volcanics overlie the Table Mountain Formation.

Hawkins (1970) and Minch and Abbott (1973) have studied the Jacumba Volcanics and much of the information presented below was extracted from their work. The two lava flow sequences average about 35 meters thick. The maximum thickness is 40 meters and individual flows are about 4 meters thick. These flows occur at the base and top of the volcanic section. The lavas are composed of platy to massive, dark to light gray, porphyrtic aphanitic basalt, andesitic basalt, and andesite. The bases and tops of the individual flows are commonly vesicular to scoracious. The centers are massive. Platy jointing due to thermal contraction and flow orientation of minerals is more abundant in the lower flow sequence. The lower flows crop out in the Table Mountain area, along the ends of the low hills at the southwestern base of Gray Mountain, on the long flat hill and Jacumba Peak north of the town of Jacumba, and along the northern portion of La Miel Mountain. The lower flows are missing from the stratigraphic sequence along the western and southern sides of La Miel Mountain. This outcrop pattern suggests that in the subsurface of Jacumba Valley, the lower flows terminate just south of the international border. Outcrops of the upper lava flows are restricted to a small area on Table Mountain, the low hills southwest of Gray Mountain, and the top of La Miel Mountain.

Sandwiched between the two sets of flows is a heterogeneous sequence of breccias, lahar deposits, and volcanoclastic sandstones. These deposits average about 90 meters thick. Their maximum thickness is 150 meters (Minch and Abbott, 1973). The breccias and lahar deposits generally show no signs of stratification or sorting except in the few areas where they were apparently reworked by fluvial action. Partical size ranges from silt to boulders. Some of the fluvial deposits contain up to 50% plutonic derived material. There are also some eolian volcanoclastic sandstones with large planar-wedge cross-laminae.

A number of cinder deposits, that are suggestive of eruptive centers, are scattered about on the United States side of the study area. One obvious cinder cone is exposed in a gravel pit on Table Mountain. Most of the cinder deposits contain abundant calcite cement. This suggests that the calcite cement found in the Table Mountain Formation was not penecontemporaneous with the deposition of that formation, but may have been leached from the volcanics.

There are a series of andesite plugs in Jacumba Valley. The Round Mountain plug is younger than the breccias and lahar deposits that it intrudes. The other plugs in the valley may be of similar age.

As discussed earlier, there appears to have been only minor relief associated with the lower contact of the volcanics. In Jacumba Valley, the lower flow sequence may be limited to the same area as the Table Mountain Formation paleochannel and the deposition of the lower flows may have been controlled by the channel. Most of the present topographic relief of the volcanics is due to faulting that occurred during and since the volcanism.

The volcanics have been dated as early Miocene, around 18.7 $\pm$ 1.3 million years, by Hawkins (1970). This volcanism roughly correlates with the early rifting of the Gulf of California.

Quaternary Alluvium

Jacumba Valley has received considerable alluvial material since the deposition of the Jacumba Volcanics. The Quaternary alluvium consists of modern material (15-20 centimeters of fine sand was deposited over a small portion of the valley during floods in February, 1980) and older material that is currently being eroded. The alluvium occurs as slope wash, alluvial fans, and valley fill. In the center of the valley, the alluvium has accumulated to a thickness of 35-45 meters, but this material thins toward the sides and ends of the valley (Figures 10 and 11, pages 32 and 33).

The lithology of the slope wash and older alluvium exposed in stream cuts is moderately to poorly stratified coarse sand and gravelly sand. It is moderately sorted and unlithified. Clast sizes range up to cobble, but are predominantly gravel and pebble. Deposits on the surface of the valley range from predominantly clay and silt at the north end, sand in the southern portion, and gravel and coarse sand in some of the stream channels. South of the international border are some eolian sands as both a thin modern cover and thick dune deposits that are now being eroded by streams.

Logs from wells that penetrate the alluvium in the center of the valley are presented in Table 3. See Figure 8 (page 28) for the location of the wells.

The alternating layers of clay and gravelly sand in the well logs appear to be lacustrine deposits. Similar deposits, of rhythmic layers of silty-clay and fine to medium sand, occur in the stream cut banks at the north end of Jacumba Valley. There are abundant small gastrapod shells in these deposits. Above the lacustrine sediments the well records generally show a fining upward trend.

The wells on the western edge of Jacumba penetrate the alluvium to a depth of 18 meters (County of San Diego, Department of Public Health, personal communication, 1980).

Well J3A		Well J4	
Depth (Meters)	Lithology	Depth (Meters)	Lithology
- 9.1	Clay and silt	-12.2	Layers of clay and gravel
-15.2	Coarse sand and gravel	-18.3	Gravel and boulders

In general, the lithology of the Quaternary alluvium varies both with depth and laterally, as would be expected in an alluviated valley in the arid southwest.

Table 3

Logs for Wells J1 and J2[a] and Wells K1 and K2[b]

Depth (Meters)	Lithology	Depth (Meters)	Lithology
	Well J1		Well J2
0-3.0	Soil and clay	0-3.0	Soil and clay
-11.6	Clay	-11.6	Clay
-12.2	Fine sand	-12.2	Fine sand
-15.2	Medium sand	-15.2	Medium sand
-26.8	Coarse sand and small gravel	-26.8	Coarse sand and small gravel
-30.5	Coarse sand and coarse gravel	-30.5	Coarse sand and small gravel
-36.6	Layers clay and coarse sand	-36.6	Layers clay and coarse sand
-37.8	Volcanic formation	-42.7	Layers clay and coarse sand
	Well K1		Well K2
0-1.5	Clay and topsoil	0-6.1	Clay and silt
-9.1	Silt and fine sand	-6.4	Cobbles
-12.2	Fine sand	-12.2	Fine sand
-13.7	Sand	-13.7	Sand
-15.2	Boulders and sand	-15.2	Rocks and sand
-19.2	Sand and gravel	-21.3	Sand and gravel
-19.5	Black silt and clay	-28.0	Rocks and sand
-20.7	Sand and gravel	-31.4	Large rocks and sand
-21.3	Black silt and clay		
-29.9	Sand and gravel		

Table 3 (Continued)

Depth (Meters)	Lithology	Depth (Meters)	Lithology
	Well K1		Well K2
-31.4	Boulders and cobbles		
-32.3	Sand and gravel		
-33.5	Red clay		

[a]Taken from County of San Diego, Department of Public Health, personal communication, 1980.

[b]Taken from William Ketchum, personal communication, 1980.

Structure

The structure of Jacumba Valley and its watershed is dominated by faults. The valley is a graben on a paleoerosion surface. There are three basic orientations of faults in Jacumba Valley and its watershed: (1) an active northeasterly trending fault which forms the scarp of the Sierra Juarez Mountains, (2) a group of faults which trend to the northwest, and (3) a north-south trending fault to the west of the valley (Figure 9, page 31, and the geologic map in the pocket).

The Comision de Estudios del Territorio Nacional (1977) mapped the northeast trending fault. Their map suggests that the fault either splits into two parallel faults in the northeast and southwest portions of the study area or the fault has accompanying parallel faults. The geology and topography of Jacumba Valley and the Sierra Juarez Mountains near La Rumorosa suggest that at least 300 meters of vertical offset has occurred. Earthquakes of up to Richter Magnitude 4 have occurred in the vicinity of the fault trace during the last twenty years (Hileman, Allen, and Nordquist, 1973).

The northwest trending faults show considerable variation in length and relative movement. Three of these faults, labeled "a," "b," and "c" in Figure 9 (page 31) helped to form Jacumba Valley (Figure 12). The southwestern fault "a" does not show any clear surface trace, but its presence is suggested by the

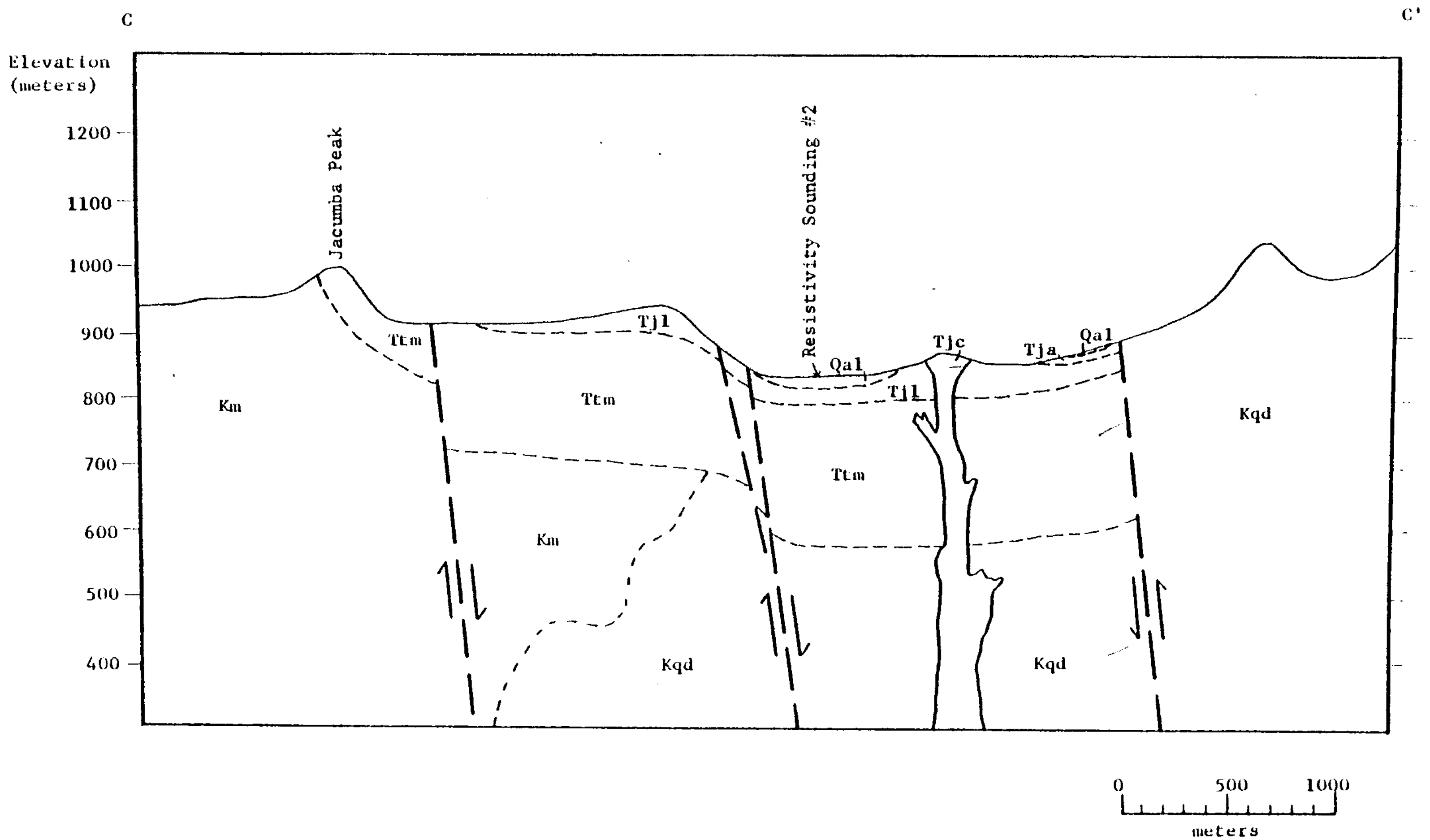

Figure 12. Geologic Cross Section C-C'

topographic saddle between Jacumba Peak and the long flat hill to the east and by the outcrop pattern of the Table Mountain Formation there (pocket geologic map, Plate III). The small knob of volcanics and the Table Mountain Formation located just south of Jacumba indicates that those units are tilted, possibly the result of drag along a fault. Also, the surface exposure of the Table Mountain Formation on the Mexican hill south of Jacumba is thin while the same unit is at least 90 meters thick in the subsurface of the valley. The fault is inferred to pass through the saddle just east of Jacumba Peak, through the town of Jacumba, and in the subsurface of the valley to the east of El Prieto Mountain (Figure 9, page 31). The northeast side of this fault has moved down relative to the southwest side.

Northwest trending fault "b" is actually two faults where it cuts the saddle between Round Mountain and the long flat hill to the west (Figure 9, page 31). This fault probably also continues into the southern portion of Jacumba Valley, but it is covered by alluvium. The faults in the saddle by Round Mountain show normal offset with the northeast side down (Figure 12). Electrical resistivity sounding #2 indicates that the lower contact of the Jacumba Volcanics is about 43 meters below the surface of the valley (Figure 8, page 28, and Appendix J). The elevation of the same contact west of the fault on the long flat hill indicates a vertical offset of roughly 115 meters along this fault. There may have been some rotational movement along this fault. The lower lava flows crop out on the small hill that is north of the airport, yet the flows are not present at the surface of the valley to the west of that hill. Electrical resistivity sounding #4 suggests that the lower flows are about 40 meters below the surface (Figure 8, page 23, and Appendix J). This evidence indicates a vertical offset with the southwest side down, opposite the offset on the fault near Round Mountain.

The third northwest trending fault "c" is located at the southwestern base of Gray Mountain. Its trace is clearly visible there and can also be found on the northeastern side of La Miel Mountain (Figure 9, page 31, and pocket geologic map, Plate III). The trace of the fault suggests that the dip of the fault plane is vertical or slightly toward the northeast. The southwest side is down with at least 400 meters of vertical offset (Figure 12, page 43). This estimated offset is based on the relative elevations of the bedrock-Table Mountain Formation contact in the subsurface of Jacumba Valley and in the vicinity of Table Mountain.

There are a number of prominent northwest trending faults in the Table Mountain area. One of these faults shows right lateral separation (Minch and Abbott, 1973).

The fact that the Table Mountain Formation is close to 200 meters thick in the subsurface of Jacumba Valley, yet only 90 meters thick in the surrounding hills indicates that some of the movement on the northwest trending faults occurred prior to and/or contemporaneous with the deposition of the Table Mountain

Formation. Movement along these faults also occurred following the deposition of the Jacumba Volcanics.

The Comision de Estudios del Territorio Nacional's (1977) geologic map of the La Rumorosa quadrangle shows a north trending fault to the west of Jacumba Valley (Figure 9, page 31). The topography associated with this fault, a ridge 50-100 meters high, continues into the Unied States side of the study area along the western side of the drainage that Old State Highway 80 follows. Because of this topography, this fault has been inferred to continue into the United States.

Chapter 3

GROUND WATER

Surface Manifestations

It has been long recognized that ground water manifests itself at the surface in the form of springs and variations in the type and density of vegetation. Jacumba Valley and its watershed have both springs and variations in vegetation.

Springs

During the early history of Jacumba Valley, the most prominent nonthermal springs in the watershed were the group of springs located on the western edge of the valley at the mouth of Boundary Creek. Wells J3, J3A, and J4 on Figure 13 are now located at the site of the springs. These springs supplied stage travelers and the residents of Jacumba with water until the mid-1950's. The only information available on the flow rate of these springs is from Brown (1923), who described the larger spring as flowing at a rate of "at least 1 second-foot," and a report in the files on the private water company of Jacumba (County of San Diego, Department of Public Health, personal communication, 1980), which reported a flow rate of 757 liters/minute in February, 1953. Long-time residents of Jacumba reported that the flow rate of the springs varied with the seasons.

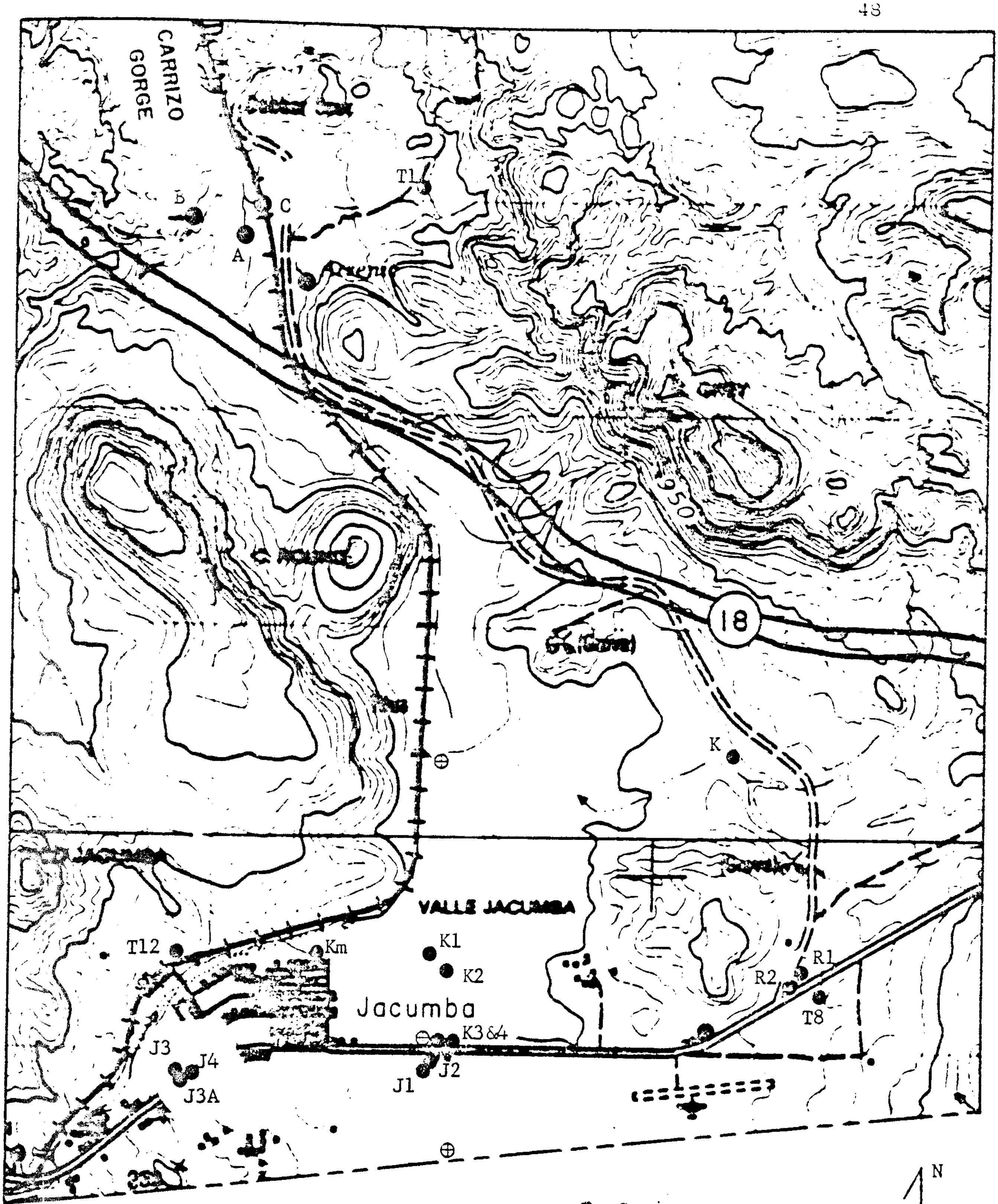

Figure 13. Location of Springs and Wells on the United States Side of Jacumba Valley (Scale 1:28,000)

Springs
Active or open wells
⊕ Abandoned and filled wells

Jacumba's town wells J3, J3A, and J4 were drilled in the area where the springs were located. According to residents, the area around these wells was dry for a number of years, but the springs became active again two years ago. During this study, wells J3A and J4 were surrounded by about 10 centimeters of water. These springs are the result of the subsurface flow from Boundary Creek being forced toward the surface by shallow bedrock. Bedrock crops out in the vicinity of the springs.

Similar springs occur to the west of the town of Jacumé in Mexico (Figure 14). These springs still supply the residents of Jacumé with water. During the fall of 1979, the Jacumé springs were feeding a stream that was flowing at 300-400 liters/ minute.

Topographic maps of Jacumba Valley indicate springs at the north end of the valley. Arsenic Spring is located in an old horizontal excavation in the lower flows of the Jacumba Volcanics (Figure 13, page 48). This spring was not actively flowing during the period of study, though the ground around the mouth of the excavation was damp and vegetation was denser.

Springs are also indicated just south of the old dam at the head of Carrizo Gorge (Figure 13). Spring "A" is located in the main drainage, Spring "B" is located in a tributary branching to the west, and Spring "C" is located under a railroad trestle to the east. Spring "A" discharges from alluvium, the Table Mountain Formation, and fractured bedrock. This spring was not

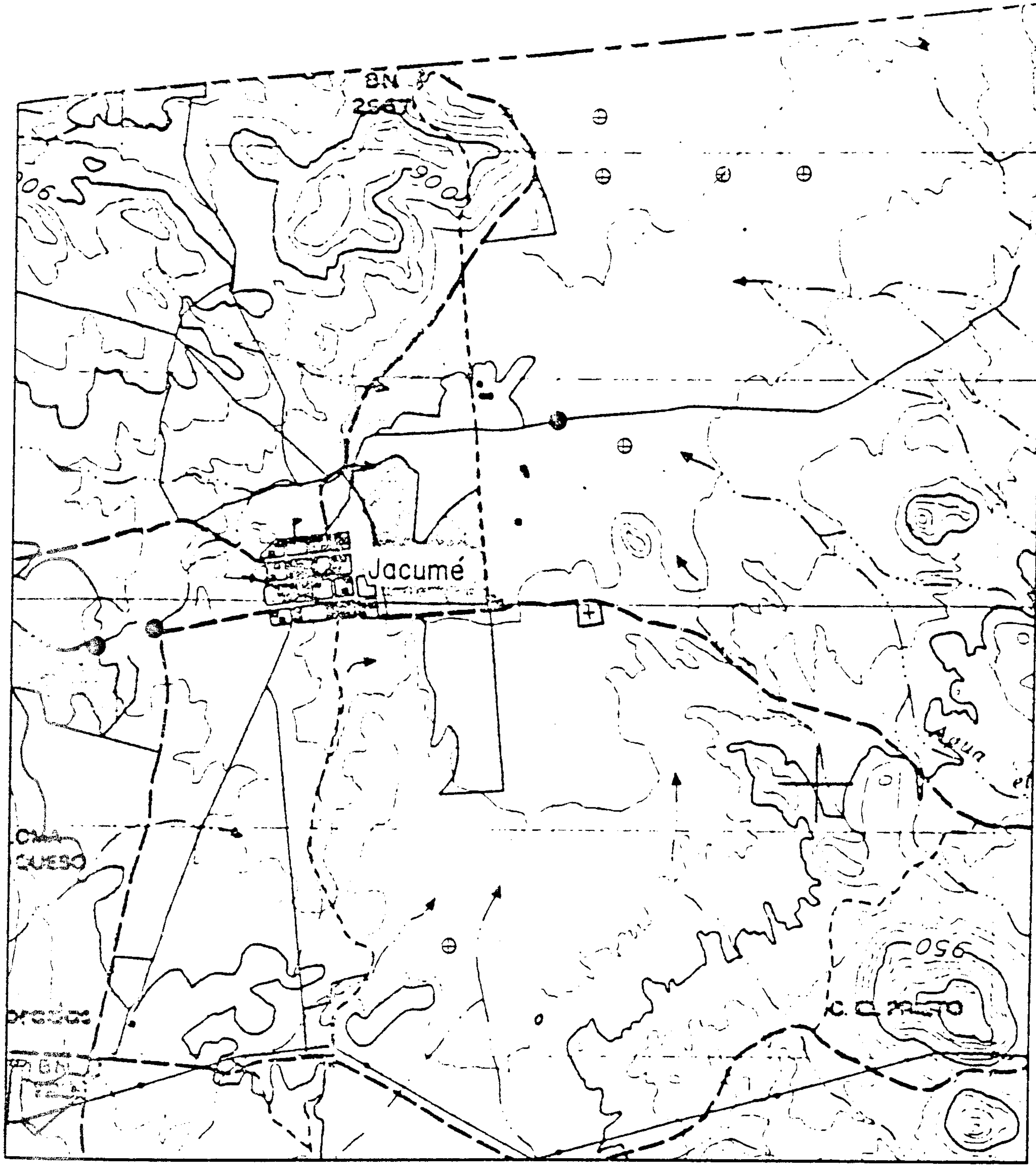

Figure 14. Location of Cold Springs and Wells on the Mexican Side of Jacumba Valley (Scale 1:28,000)

Springs and seeps

⊕ Abandoned and filled wells

N

active between June, 1979 and April, 1980. It began to flow during April. The flow of the spring increased with time and by late May, the estimated combined flow rate from the numerous seeps was on the order of 200 liters/minute. By early September, 1980, the flow rate was reduced so that only pools and damp ground were present. Abundant caliche in the area indicated that considerable evaporation had occurred during the summer.

Spring "B" is a group of springs located in the channel of the tributary. It was inactive throughout the summer and fall of 1979 and began to flow during the period of surface runoff in February and March, 1980. By the beginning of May it was flowing at a rate of about 75 liters/minute, but it had decreased to about 10 liters/minute by the end of the month. When examined at the beginning of September, 1980, these springs consisted of standing pools and damp ground. There was no surface flow. These springs issue from alluvium.

Spring "C" issues from allluvium under a railroad trestle. During much of the period of study, this spring flowed at about 8 liters/minute. During February, 1980, the flow increased slightly to about 20 liters/minute. By September, 1980, the flow rate had risen to roughly 50 liters/minute.

Springs "A," "B," and "C" showed only minor activity during the summer and fall of 1979. They became markedly more active during the spring and summer of 1980. The fact that the precipitation for the water years 1978-1979 and 1979-1980 was above average and occurred only during the winter months indicates that the spring activity is not directly dependent on precipitation. During the period November, 1979 to September, 1980, the ground water table in the alluvial aquifer rose over 4 meters in the center of the valley. As of September, 1980, the elevation of the water table in well K3 was 30 meters above the elevation of the springs. This rise in the water table appears to be the cause of the renewed activity of the springs. (A portion of the springs' discharge measured between February and May, 1980 may have been the result of the winter's precipitation draining from soil in the vicinity of the springs.) The springs "A," "B," and "C" appear to be the result of ground water discharge from Jacumba Valley's aquifers. In the past, when the water table in the valley was significantly higher, the springs were probably more active and played a major role in draining the ground water from Jacumba Valley.

Topographic maps of the Jacumba Valley watershed show springs in the hills and mountains surrounding the valley. The drainages downstream from these springs were occasionally checked from June, 1979 to May, 1980 and none had any surface flow. Time restrictions prevented the actual inspection of these springs.

A discussion of the thermal springs in Jacumba Valley will be presented in a later section.

Vegetation

In arid regions, vegetation can indicate the presence of ground water at or near the surface. Vegetation is denser in the vicinity of springs and shallow ground water. Phreatophytes are also common indicators of areas of shallow ground water. In Jacumba Valley, where vegetation is generally sparse, there are a few locations where phreatophytes and/or denser vegetation growth indicates ground water. At the present time, there is considerable growth of grasses and reeds in the vicinity of the wells J3A and J4 (Figure 13, page 48). Aerial photographs from the 1950's show numerous trees in the vicinity of the Jacumba Cold and Hot Springs and throughout much of the western side of Jacumba (Plate II). Many of the trees, cottonwoods, are still present in town, but most are gone from the area immediately around the springs.

In the same aerial photographs, there is a large stand of trees at the northeast corner of Jacumba where well Km is now located (Figure 13, page 48). Today, only a couple cottonwoods remain. Cottonwoods can have a root depth of as much as 9 meters, but 3-4 meters is more common (Meinzer, 1927). There is no spring at the northeast corner of Jacumba. However, the presence of the cottonwoods there, with few between that spot and the western side of Jacumba, suggests that this is a localized spot of shallow ground water. In May, 1980, the static water level in well Km was 7.5 meters below the surface. A possible cause of the shallow water table may be the lower lava flows which dip below the

PLATE II

PHOTOGRAPH OF THE TOWN OF JACUMBA SHOWING THE GROWTH OF TREES ON THE WESTERN SIDE OF THE TOWN AND THE LARGE GROVE OF TREES IN THE VICINITY OF WELL KM AT THE NORTHEAST CORNER OF THE TOWN. The photograph was apparently made in the 1950's. (Scale about 1:18,000.) (Photograph courtesy of Gordon Gastil.)

PLATE II

PHOTOGRAPH OF THE TOWN OF JACUMBA SHOWING THE GROWTH OF TREES ON THE WESTERN SIDE OF THE TOWN AND THE LARGE GROVE OF TREES IN THE VICINITY OF WELL KM AT THE NORTHEAST CORNER OF THE TOWN. The photograph was apparently made in the 1950's. (Scale about 1:18,000.) (Photograph courtesy of Gordon Gastil.)

alluvium just to the north (Figure 11, page 33). The volcanics may act as an aquitard and cause a perching effect on the ground water.

The Mexican cold and hot springs do not have as many trees associated with them as their American counterparts, but vegetation is denser around them.

On the floor of Jacumba Valley to the north of Round Mountain there is a gradual increase in the density of vegetation until a thick growth, primarily of salt ceder and mesquite, occurs just north of the old dam (Figure 13, page 48). Both salt ceder and mesquite are phreatophytes and they can send their roots to depths over 15 meters (Meinzer, 1927; Robinson 1958). The elevation of the ground water table in the center of Jacumba Valley, well K3, roughly corresponds to the elevation of the valley floor north of Round Mountain. This elevated water table in the valley suggests that the phreatophytes north of Round Mountain have probably found water at depths of less than 5 meters. These phreatophytes cover an estimated 30%-50% of the area between Round Mountain and the old dam, roughly 240,000-390,000 square meters (55-95 acres).

In the bedrock terrain surrounding Jacumba Valley, aerial photographs show occasional clumps of vegetation, often coinciding with the springs indicated on topographic maps. Some of the small alluviated valleys in the watershed, such as Jewel Valley located to the west of Jacumba Valley (Figure 2, page 12), show dense vegetation and trees at their discharging ends.

Wells and Water Level Records

Wells

Available records show that wells have been the prime source of water for the town of Jacumba since the mid-1950's. Until that time most of the residents of Jacumba obtained their water from the cold springs on the western edge of town. In 1956, the town owner drilled a 38-meter well into the valley alluvium east of town, well J1 (Figure 13, page 48). This well was used to supply water to the town. In 1963, well J2 (43 meters deep) was drilled 46 meters from well J1, apparently because a continually declining water table was reducing the supply from well J1. As the water table continued to decline, the town owner drilled wells J3 (24 meters deep), J3A (15 meters deep), and J4 (18 meters deep) in the vicinity of the cold springs. Well J4 was drilled in the early 1970's. The above information on Jacumba's wells comes from the file on the town at the County of San Diego, Department of Public Health (Personal communication, 1980). At the present time, wells J1 and J3A supply about 170 hookups with water. J2 has been abandoned, but is still open. J3 is a standby well and J4 has been active, but is apparently being contaminated by standing water around the well head.

Well Km (Figure 13, page 48) is being used to supply four houses and two service stations. No information is known about the well, though based on the water chemistry and the flow rate of the well, it is apparently receiving water from the valley alluvium. During the 1950's, there was an attempt to grow lettuce commercially on the United States side of the valley. To provide water for irrigation at least six wells were drilled. Of these, four remain open. They are K1 (33.5 meters deep), K2 (30.5 meters deep), K3, and K4 (Figure 13, page 48). All of these wells were drilled into the alluvium. During the 1960's a well was drilled into the alluvium just south of Round Mountain for use by the California Highway Department while building Interstate 8. This well has been abandoned and is now filled to a depth of 10.4 meters. There is an active well located next to the airport cafe, T5, but there is no information on it. Two wells, R1 (about 41.8 meters) and R2 (122 meters) tap the Table Mountain Formation and are used to supply one household and irrigate a garden. No information is available on well T8; however, the water chemistry suggests that it also taps the Table Mountain Formation. It supplies water to one house. William Ketchum (personal communication, 1980) had well K drilled in the 1960's and he reports that it penetrated the lower flows of the Jacumba Volcanics at about 31 meters. It is unused and capped. Well T1 serves the campground at the north end of Jacumba Valley and is reportedly between 60 and 90 meters deep. The location of the well and the water chemistry suggests that it is tapping the Table Mountain Formation. A few residents of Jacumba reported that a well had been attempted in the alluvium to the east of La Miel Mountain, but little water was found.

On the Mexican side of the Jacumba Valley there are numerous abandoned wells, some completely and some partially filled (Figure 14, page 50). According to residents, the four wells just south of the border produced good amounts of water, but were improperly built and collapsed. There are numerous hand-dug wells on the Mexican side of the valley, some of which are still being used.

There are active wells in the bedrock terrain to the west of Jacumba Valley on the United States side of the border. Most of the wells are in the small drainage along Old Highway 80 (Figure 15). These wells are between 22 and 97 meters deep, and, according to residents, supply ample water for individual households. Jim Holes (personal communication, 1980) reported the log for well H2 as: 0-12 meters sandy alluvium, 12-38 meters schist, 38-82 meters hard granitics both weathered and unweathered. There were fractures around 55 meters and 61 meters. An owner along the west side of the valley reported fractured bedrock to a depth of 41 meters. Water occurred in fractures at 15 meters, 24 meters, and below 28 meters.

The presence of wells in the bedrock terrain in Mexico was not investigated.

Water Level Records

Records of water levels in wells in Jacumba Valley prior to this study are very scanty (Appendix H). During the mid-to-late 1950's the California Department of Water Resources sporadically

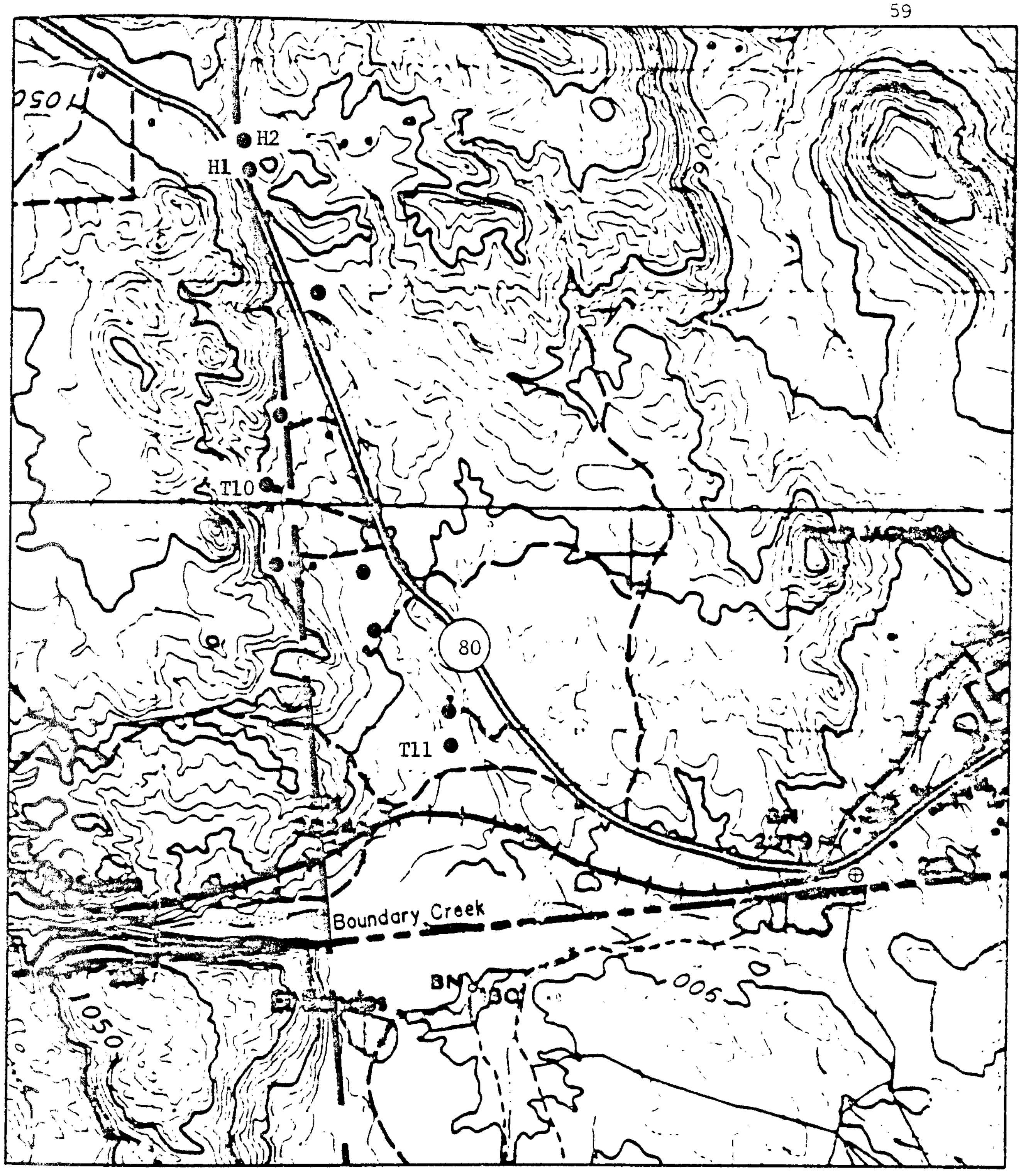

Figure 15. Location of Wells in the Metamorphic Terrain to the West of Jacumba Valley (Scale 1:28,000)

● Active and open wells

⊕ Abandoned and filled wells

▬ Fault

N

monitored four wells. The few available well logs list the static water level at the time the well was drilled. There are no known water level records for the bedrock terrane or for the Mexican side of the watershed.

When well K3 was drilled in July, 1955, the water table in the alluvium was recorded at 841.3 meters above sea level (Ketchum, personal communication, 1980). When well J2 was drilled in 1962, the water level was at 829.1 meters (County of San Diego, Department of Public Health, personal communication, 1980). The available water level records generally show a continuously declining water table throughout the period 1955-1962 (Appendix H). This was a period when ground water recharge was below normal and there was a heavy demand on the ground water supplies because of the attempt to grow lettuce. During the 1960's the water levels apparently continued to fall due to the continued below-normal ground water recharge and the heavy pumping for the construction of Interstate 8. In 1966, a memo was placed in the County of San Diego, Department of Public Health (personal communication, 1980) files of the Jacumba water company stating that the heavy pumping for the highway construction was lowering the water table and probably making the ability of wells J1, J2, and J3 to supply sufficient water doubtful. When well J3A was drilled, in 1966, in the vicinity of the Jacumba Cold Springs, the static water level was at 859.8 meters, 6.7 meters below the ground surface.

From November, 1979 to September, 1980, the water levels in wells J2, K1, K3, Km, J3, R1, and H1 were monitored (Appendix H). When well K3 was first measured in November, the water level was at 831.7 meters and rising. The water level in well J2 was at 831.3 meters and in well K1 it was 829.3 meters. Water was at the surface around well J3A and the water level in well J3 was 866.8 meters. All of the wells monitored, except J3 and R1, showed continuously rising water levels throughout the monitoring period (Figures 16 and 17). By September, 1980, the elevation of the water table in well J2 was 835.5 meters, in well K3 was 835.9 meters, and in well K1 was 834.9 meters. The total rise of the water levels between November, 1979 and September, 1980 was 4.2 meters in well J2, 4.3 meters in well K3, and 5.6 meters in well K1. The water level in well J3 did not continue to rise because the springs next to it were active. Well H1 in the bedrock terrain west of Jacumba Vlley showed a rise of 1.5 meters between November, 1979 and September, 1980.

The rate of rise on the water levels increased significantly in February, 1980 due to infiltration from heavy surface flow that entered the valley from the western drainages. The surface flow in Boundary Creek flowed to the north of Jacumba and close to well Km. This well reacted sooner and more dramatically to the increased recharge than wells K1, K3, and J2. A ground water mound was formed in the vicinity of well Km that measurably influenced the water levels in the valley (Figure 16).

During April and May, 1980, the water level in well R1, which taps the Table Mountain Formation, was at a higher elevation

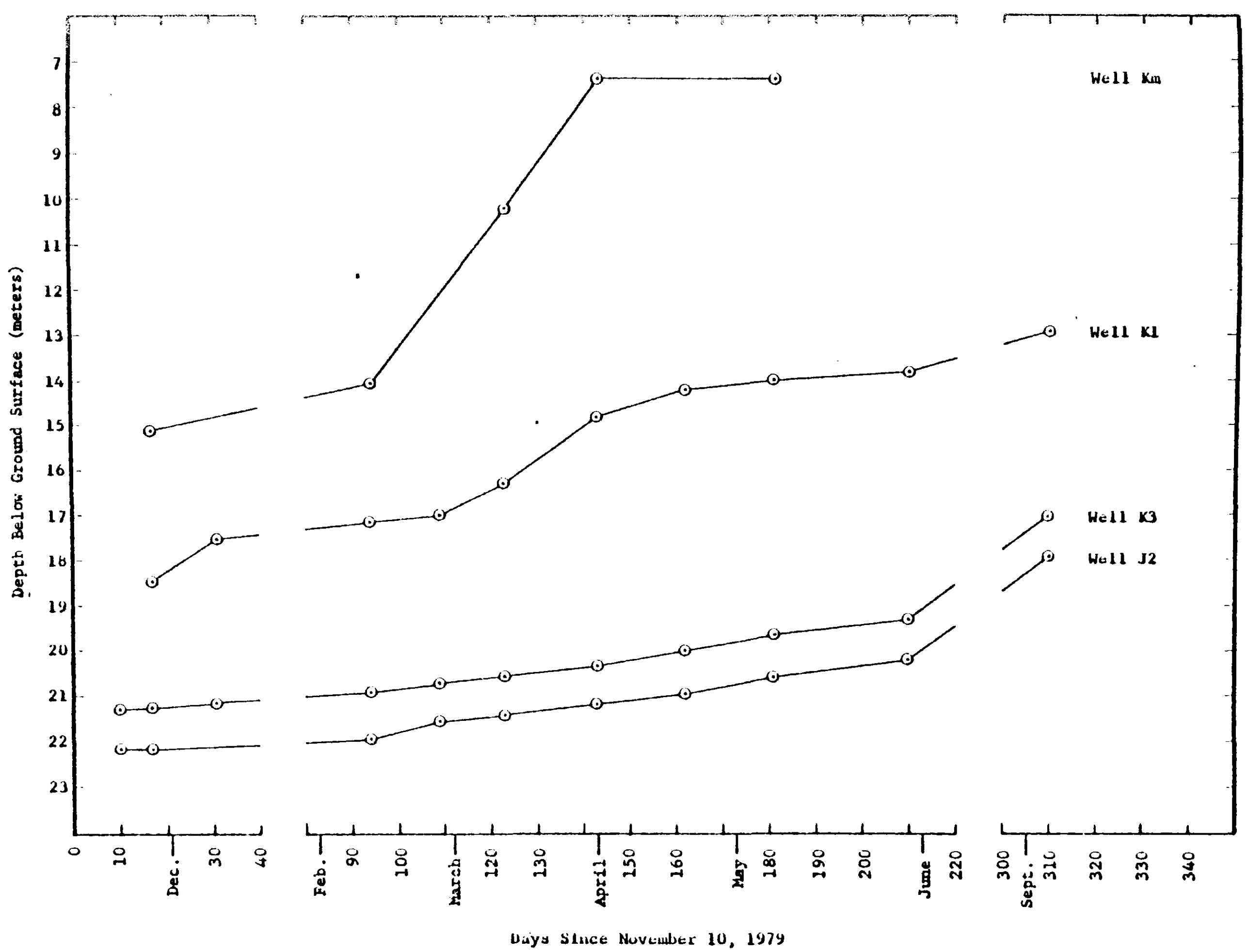

Figure 16. November, 1979 to September, 1980 Water Level Records for Wells Km, K1, K3, and J2

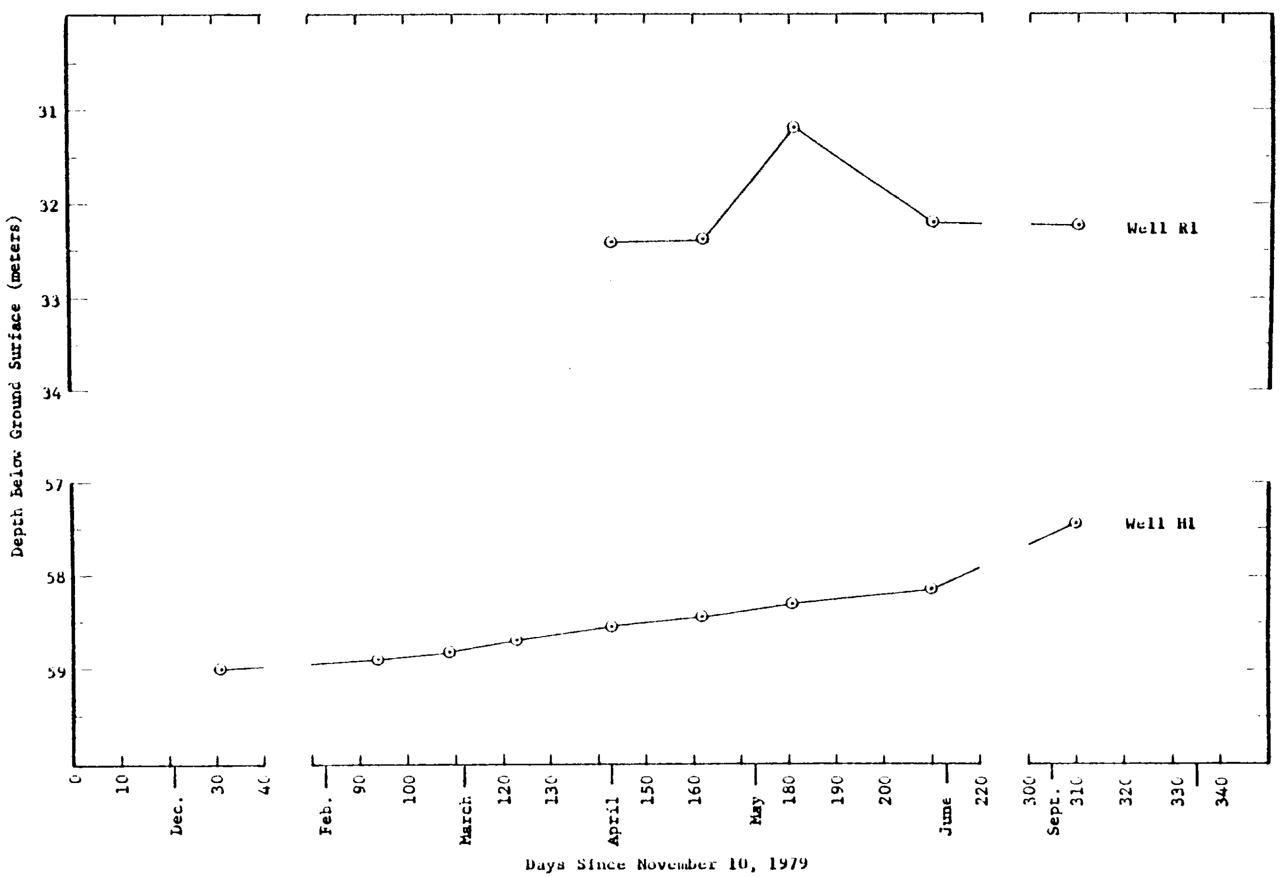

Figure 17. November, 1979 to September, 1980 Water Level Records for Wells R1 and H1

than the water levels in the alluvial aquifer in the center of Jacumba Valley. By September the elevation of the alluvial water table was above that in well R1.

Aquifers

The wells in the Jacumba watershed tap three of the four lithologies present. In the crystalline bedrock terrain, water is being pumped from the metamorphic and plutonic rocks. In Jacumba Valley, the Quaternary alluvium is an important aquifer. In the valley there are a few wells that draw water from the Table Mountain Formation. Each of these lithologies has different hydrologic properties which will be discussed below. The Jacumba Volcanics is the only lithology that does not provide water to wells in the valley.

Crystalline Bedrock

Because of the large area covered by crystalline bedrock and the limited period of study, the information on the hydrologic parameters and the use of the crystalline bedrock aquifers is primarily based on field reconnaissance and previous hydrologic work. The previous hydrologic work is mainly qualitative. Merrian (1951) presented qualitative information on ground water in the various types of bedrock found in western San Diego County. His statements can be used to describe the bedrock aquifers in the eastern portion of the county as the rock types are similar. According to Merrian, the metamorphic rocks generally weather deeply with the exception of quartzites. This weathering, as well as the schistosity and the closely-spaced joints, aid the permeability and increase the storage capacity of the rocks. The yields from the metamorphic rocks in western San Diego County are erratic and the success of a well depends on local conditions and characteristics of a particular phase of the metamorphics. According to Davis and DeWiest (1966), the average well yields in most metamorphic rocks is 38-95 liters/minute, though local variations can be considerable. The metamorphics in the Jacumba Valley watershed are quite variable in lithology and are cut by numerous pegmatites. The pegmatites and quartzite layers resist weathering, while the schists and gneisses show evidence of considerable weathering. These factors undoubtedly cause variations in well yields. Conversations with residents and local drillers seemed to confirm this.

The wells in the metamorphic terrain on the United States side of the Jacumba Valley watershed are located in the drainage which parallels Old State Highway 80 to the west of Jacumba (Figure 15, page 59). All of these wells are domestic wells and no pump tests have been performed on them. No household indicated that they were restricted by their water supply. Some of the households have automatic washers and irrigated gardens. In this drainage there appears to be two different areas of wells, based on the depth to water. The wells along the western edge of the drainage range in depth from about 22 meters to 41 meters, with static water levels between 6 and 15 meters. The other set of wells, located in the center of the drainage, have depths between 45 meters and 97 meters and water levels between 30 meters and 61 meters. The data on well depths and water levels was obtained from conversations with the residents of the area. This discrepancy between the two portions of a rather small drainage may be the result of the north trending fault which is inferred to follow the western edge of the drainage (Figure 15, page 59). This fault may be acting as a ground water barrier causing an elevated water table on the western side.

The water level monitoring of well H1 from November, 1979 to September, 1980 showed an increase in the rate of rise of the water level following the heavy precipitation of January and February, 1980 (Figure 17, page 63). The water level in early February was 58.9 meters below the surface. The increased rate of rise of the water level was first recorded in the well 44 days after the initiation of heavy precipitation in January. This indicates that the minimum velocity of the ground water migrating down to the zone of ground water saturation is about 1 meter/day.

The other area of metamorphic terrain in the Jacumba Valley watershed is located in the Sierra Juarez Mountains of Mexico. The presence of wells in this area was not investigated due to communication problems.

The quartz diorite and granodiorite plutons in western San Diego County are very dependent on jointing to provide permeability and storage capacity for ground water (Merrian, 1951). Merrian concluded that these rock types were a moderate to poor source of water compared to other types of basement rock. Where good jointing exists these rocks can be a good source of water. Weathering does not seem to improve the water bearing ability of the fractures. Where fractures are not common, the surface-weathered material will form a fair source of water.

There are few wells in the Jacumba Valley watershed that have been drilled in the plutonic bedrock. There are, however, many wells in the mountainous areas of San Diego County that are drilled in similar rock types. They reportedly provide ample water for domestic use.

Aerial photographs of a portion of the plutonic terrain to the west of Jacumba Valley show a well-developed. closely-spaced, east-west pattern of fractures (Plate I, page 25). Such a regional fracture system will extend to greater depths than the stress-relief fractures related to erosion, and could be zones of good permeability and storage capacity.

Ganus (1973) suggested that a dual ground water system may exist in the bedrock areas of San Diego County. One system is located in shallow stress-relief fractures and residuum and the other system is in deeper regional fractures. Such a dual system would be most pronounced in topographically high areas and may merge in low areas (Figure 18). Discussions with local drillers seemed to support this model. They often claimed to find water

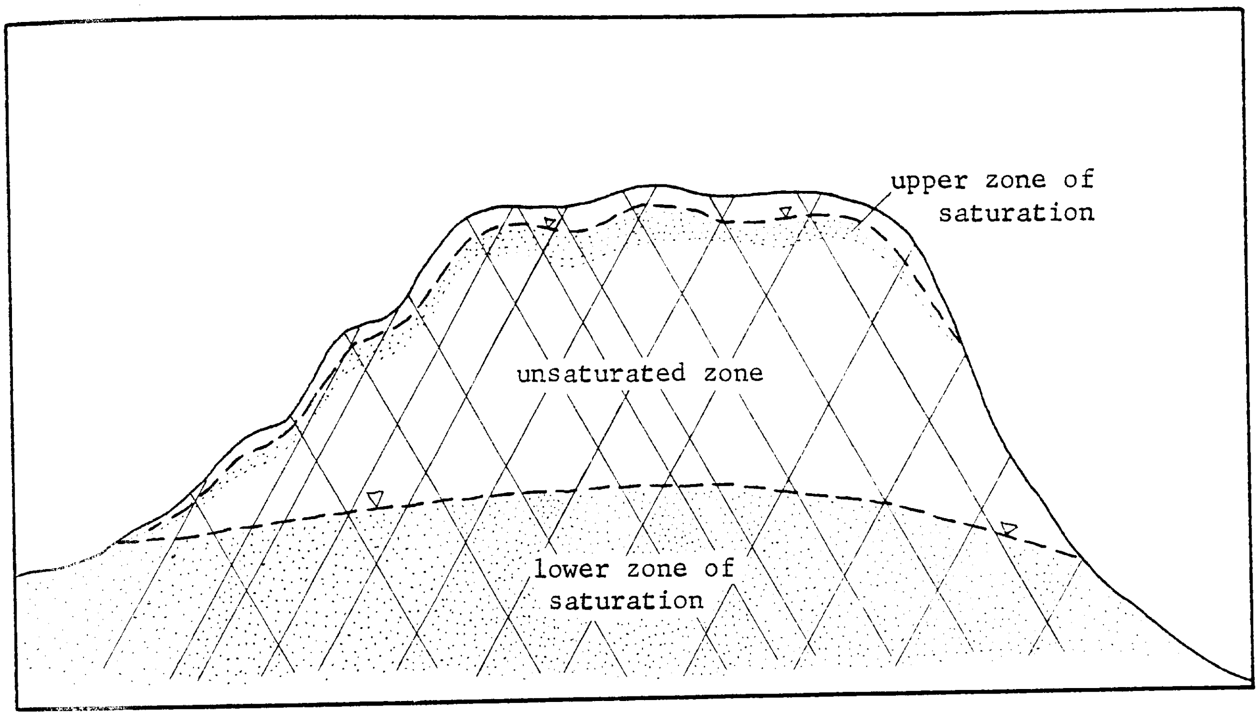

Figure 18. Ganus' Concept of a Dual Ground Water System in Fractured Crystalline Rock Highlands (After Ganus, 1973)

near the surface and then more water at significantly greater depths. Some of the local drillers claimed that the best wells in the area between Jacumba and Campo, located to the west of Jacumba, are between 105 and 135 meters deep. Some of the deep fractures reportedly contain confined water (McGuffie, personal communication, 1980).

The crystalline bedrock of the Jacumba Valley watershed is capable of providing ground water for domestic use. It is unlikely that the storage capacity is great enough for more extensive development. Further studies to identify and map regional fractures and the degree of weathering of the metamorphics would aid in the siting of future wells.

Table Mountain Formation

The Table Mountain Formation forms the largest aquifer in Jacumba Valley. The Table Mountain aquifer is bounded on the northeast and southwest by two of the northwest trending faults that form the valley (faults "a" and "c" in Figure 9, page 31, and Figure 12, page 43). At the north end of the valley the formation thins rapidly to 10-15 meters and crops out at the surface. To the south of the international border, evidence suggests that the formation thins to 75-90 meters and eventually crops out at the southern end of Jacumba Valley (Figure 10, page 32). Throughout most of the United States side of the valley the Table Mountain aquifer is overlain by the lower flows of the Jacumba Volcanics and the Quaternary alluvium. Electrical resistivity soundings and well logs indicate that the volcanic-Table Mountain Formation contact is between 45 meters and 80 meters below the surface of the valley. The 80-meter value is based on a 40-meter thickness of alluvium and a 40-meter thickness of the lower flows as measured on the long flat hill north of Jacumba. Using these approximate boundaries and the elevation of the ground water table in May, 1980, the estimated saturated volume of the Table Mountain aquifer is 2.07×10^9 cubic meters (Appendix F). It was not possible to determine the specific yield of this aquifer with the information available. The specific yield of the alluvial aquifer was conservatively estimated to be between 5% and 10%. Because the lithology of the Table Mountain Formation and the Quaternary alluvium are grossly similar, a range of the specific yield from 5% to 10% is an acceptable estimate for the Table Mountain aquifer. With this assumed specific yield, the Table Mountain aquifer has between 1.0×10^8 and 2.1×10^8 cubic meters (84,000-169,000 acre-feet) of recoverable water stored in it. This is obviously a crude estimate and is not a value that should be used for detailed planning of water development.

There are three wells known to be drilled into the Table Mountain aquifer: R1, R2, and K (Figure 13, page 43). Two other wells, T1 and T8, may tap this aquifer. A limited pump test was performed on well R2 in May, 1980 (Appendix I).

The transmissivity was determined as 4.3×10^{-4} meter^2/minute (4.6×10^{-3} feet^2/minute). This low transmissivity reflects the 20% fine sand to clay that composes the generally homogeneous lithology of the Table Mountain aquifer. Though no calcite cement was detected in the drill cuttings from well R2, the low transmissivity may indicate the presence of some cement in the subsurface.

The pump test on well R2 did not last long enough to attempt to calculate the specific yield of the aquifer. With data from the water level measurements made on well R1 during the spring of 1980 and knowledge that surface flow from the mountains surrounding Jacumba Valley first entered the valley on February 14th, an attempt was made to calculate the storage coefficient of the aquifer (Appendix F). Infiltration from the surface flow initiated a recharge pulse which propagated through the valley's aquifers. The velocity of propagation of the recharge pulse through the aquifer was related to the diffusivity of the aquifer by modeling it after the propagation of heat through a semi-infinite solid. Carslaw and Jaeger (1951) provided the theory and equations for the velocity of propagation of heat through a semi-infinite solid:

$$V = Ae^{-kx}\text{Cos}(\omega t - kx - \varepsilon) \qquad \text{Equation 1.}$$

"A" is the amplitude of the periodic fluctuation of the surface temperature, "k" is the diffusivity of the medium, "x" is the distance into the medium, and $\omega = \frac{2\Pi}{\text{Period}}$. From this basic equation comes the equation for the velocity of propagation of the crest of the periodic fluctuation of the surface temperature through the medium: $V = (2K\omega)^{1/2}$. By assuming that the propagation of the ground water recharge pulse in the aquifer is similar to the propagation of a heat pulse in a semi-infinite solid, the velocity equation can be used to calculate the diffusivity of the aquifer. The recharge pulse reached well R1 within eighty-five days. The ground water recharge for the Table Mountain aquifer probably occurred in the area between Jacumé and the international border, an area where the Table Mountain aquifer is not overlain by the Jacumba Volcanics. The surface flow entered Jacumba Valley through the drainage to the west of Jacumé. The distance between the recharge point and well R1 is 2100-3000 meters. This gives a velocity of propagation of the recharge pulse of 25-36 meters/day. The period of the recharge pulse, as estimated from the records of well Km (Figure 16, page 62) and stream flow measurements on Boundary Creek (Appendix D), was about fifty days. The diffusivity "k" of the aquifer was determined to be 2500-5100 meter^2/day. The diffusivity of an aquifer is equal to the transmissivity divided by the storage coefficient. The transmissivity of the Table Mountain aquifer is 0.62 meters^2/day as determined by the pump test on well R2. The calculated storage coefficient is 1.2×10^{-4} to 2.5×10^{-4}. This value indicates that the aquifer is responding elastically to hydraulic stresses.

Throughout much of the United States side of Jacumba Valley the Table Mountain aquifer is overlain by the lower flows of the Jacumba Volcanics. There is some evidence that the volcanics act as an aquitard and partially confine the ground water in the Table Mountain aquifer. The rather high rate of propagation of the recharge pulse, 25-36 meters/day, suggests that the water is confined. The recharge pulse passed well R1 as a wave would, causing the water level to rise and then fall back to near its original elevation. The recharge pulse did not cause a permanent rise in the elevation of the water level as it did in the wells of the unconfined alluvial aquifer (Figures 16 and 17, pages 62 and 63). This wave-like behavior of the recharge pulse is characteristic of a confined aquifer. Finally, the fact that during the spring of 1980 the elevation of the water level in well R1 was higher than the water level in the alluvial aquifer suggests that the Table Mountain aquifer is partially confined. The lower flows of the Jacumba Volcanics develop a clay-rich soil where they are exposed at the surface. Babcock (1958) reported a thin clay layer in the subsurface of Jacumba Valley just above the volcanics. The presence of clay with the volcanics may indicate that the volcanics are altered in the subsurface of Jacumba Valley and are capable of acting as an aquitard.

Quaternary Alluvium

The Quaternary alluvium filling Jacumba Valley provides the great majority of the ground water currently used in the valley.

The relatively shallow water table, the good hydraulic conductivity of the sediments, and the ease of well drilling have encouraged the use of this aquifer.

The thickness of the Quaternary alluvium and the depth to water in Jacumba Valley varies considerably. North of Round Mountain the alluvium is estimated to be only 5-10 meters thick and the water table is probably within 5 meters of the surface. In the vicinity of Old State Highway 80, the water table as of May, 1980, was about 20 meters below the surface and the alluvium is up to 45 meters thick. The alluvium thins further to the south and toward the sides of the valley, though in areas such as the mouth of Boundary Creek, it is about 20 meters thick (Figures 10 and 12, pages 32 and 43, respectively). The estimated saturated volume of the alluvial aquifer based on November, 1979 water levels was 7.89×10^7 cubic meters (Appendix F). The estimated saturated volume based on the higher water levels recorded in 1955 was 1.20×10^8 cubic meters. It was not possible to determine the specific yield of the alluvial aquifer from the information available. The specific yield was, therefore, conservatively estimated as between 5% and 10%. Based on these values there was an estimated 3.9×10^6 to 7.9×10^6 cubic meters (3200-6400 acre-feet) of recoverable water in the alluvial aquifer as of November, 1979. The volume of recoverable water in the aquifer in 1955 was between 6.0×10^6 and 1.2×10^7 cubic meters (4800-9700 acre-feet). The alluvial aquifer has a very small storage capacity compared to the

Table Mountain aquifer. This low storage capacity was undoubtedly a major factor in the drastic decline of the water table during the 1950's and 1960's.

During the fall of 1979 a limited pump test was performed on well J1 (Appendix I). The test was limited to four hours because it was necessary to maintain the town's water supply. The transmissivity of the alluvial sediments was determined to be 2.0 $meter^2$/minute (21 $feet^2$/minute). The pump test did not last long enough to determine the specific yield. This high transmissivity is primarily the result of the coarse sand and gravel which is present between 15 meters and 30 meters in the well. Similar coarse sediments are also present in the well logs of wells K1 and K2, so the transmissivity of the alluvium in the vicinity of those wells is probably comparable to that measured in well J. However, because of the heterogeniety of the alluvial sediments, particularly in the northern portion of the valley, the transmissivity undoubtedly varies. A pumping test was performed on wells K1 and K2 when they were drilled in the mid-1950's (Ketchum, personal communication, 1980). About 3400 liters/minute was pumped from each well for an unspecified period of time and the nonstatic water level was measured at the end of the test. Well K1 showed 5.8 meters of drawdown and well K2 showed 3.0 meters of drawdown. This difference in drawdown is an indication of the variation in transmissivity that is present in the alluvial aquifer.

An attempt was made to calculate the specific yield of the alluvial aquifer using the propagation of the recharge pulse through the aquifer (Appendix F). The first method of calculation is identical to the method used for the Table Mountain aquifer. Using the well records of wells Km, K1, K3, and J2 (Figure 16, page 62), the velocity of propagation of the recharge pulse was determined to be about 9 meters/day. This velocity resulted in a calculated speculated yield that is unreasonably high (Appendix F).

The second method used was also modeled after the propagation of heat through a semi-infinite solid. The amplitude of the pulse declines as the pulse propagates through the medium. Carslaw and Jaeger (1951) provided the equation:

$$A_d = A_s e^{-x\sqrt{\frac{\omega}{2k}}} \qquad \text{Equation 2,}$$

relating the change in amplitude to the diffusivity of the medium. A_d = amplitude at depth, A_s = amplitude at the surface, x = distance into the medium, k = diffusivity, and $\omega = \frac{2\Pi}{\text{Period}}$. Using this method, the calculated diffusivity varied considerably from 5,700 to 13,400 meter^2/day. The specific yield varied from 50% to 21% (Appendix F). The results of these calculations are not reliable and therefore were not used.

The lack of accurate values for the various variables involved in the above calculations was probably a factor in rendering them unreliable. The large periods of time between water level measurements made it difficult to accurately determine the velocity of propagation and the change in amplitude of the recharge pulse. Another factor may be the fact that the transmissivity used was determined for a very coarse portion of the aquifer, while the recharge pulse passed through a much larger and probably more varied portion of the aquifer.

Ground Water Chemistry

It is evident that the chemistry of the ground water has been the most studied aspect of the Jacumba Valley hydrology. So as not to break tradition, this author also performed chemical analyses of the ground water. The results of all available chemical analyses performed in the area are in Appendix K.

Waring (1915) analyzed the Jacumba Hot Springs. Brown (1923) analyzed the Jacumba Cold Springs. Babcock (1958) presented analyses of a Jacumba cold spring and two wells showing an increase in concentration of total dissolved solids toward the center of the valley. The private water company of the town of Jacumba has tested each of the wells they own and the Jacumba Hot Springs (County of San Diego, Department of Public Health, personal communication, 1980). Richard Thesken (1977) analyzed water from eleven wells on the United States side of the Jacumba Valley watershed. His study focused on the hot springs and their relationship to the cold waters in the area. No chemical studies of wells or springs on the Mexican side of the study area are known.

The chemical analyses performed for this study were made in order to compare and contrast the water in the two aquifers in Jacumba Valley. For this purpose, three wells located in the alluvial aquifer, J3A, Km, and J1, were sampled (Figure 13, page 48). The only active well that is known to draw water from the Table Mountain aquifer is R2, so it was sampled. Water from the Jacumba Hot Spring (well JHS) and two Mexican thermal springs were also sampled. The chemical analyses of the thermal springs will be presented in a later section of this report. The details of the method of collection and analysis of the water samples will be found in Appendix K.

Swenson's Analyses

In the analyses performed for this study, chemical similarities and differences were found within the alluvial aquifer and between the alluvial and Table Mountain aquifers. In the alluvial aquifer, the calculated total dissolved solids show an increase toward the center of Jacumba Valley, from about 500 milligrams/liter in well J3A to over 800 milligrams/liter in well J1. The Table Mountain aquifer, in its one sample, shows a calculated total dissolved solids concentration similar to well J3A. On a Piper diagram, samples Km, J3A, and R2 are grouped together and not dominated by any single ion (Figure 19). Sample J1 plots apart from the others, but also shows no dominance by a single ion. The

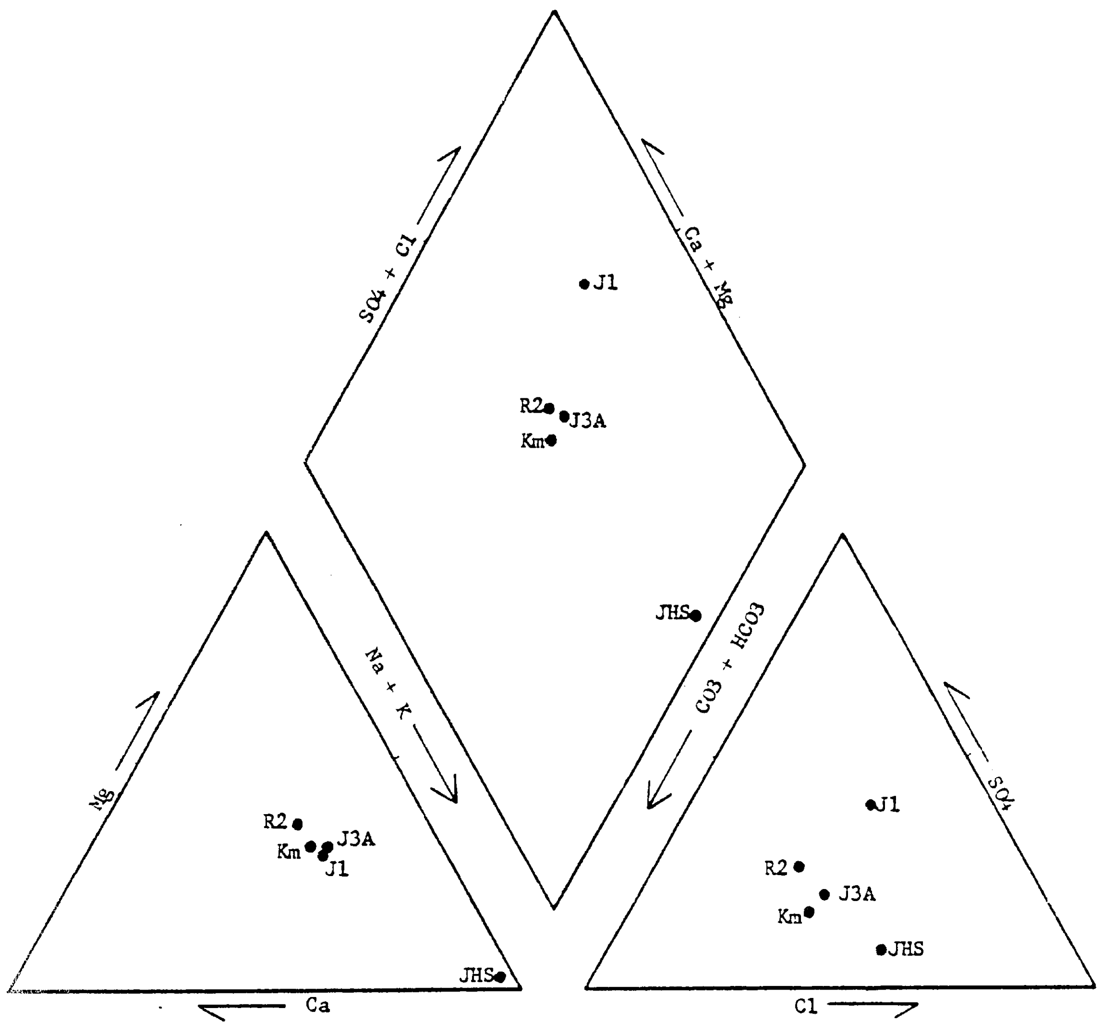

Figure 19. Piper Diagram of Ground Water Analyses Performed by the Author

relative abundances of the cations sodium, magnesium, calcium, and potassium in the three wells in the alluvial aquifer all show the same pattern (Figure 20). Sodium is the most abundant cation. Sample R2 from the Table Mountain aquifer shows a different pattern of relative cation concentration with magnesium the most abundant cation. Potassium is significantly increased and sodium decreased in sample R2. The anion concentrations of samples J3A, Km, and R2 show the same pattern of relative abundances with bicarbonate the most abundant anion (Figure 20). Sample J1 shows a different pattern with sulfate the most abundant anion and chloride also high. This difference in anion concentrations causes sample J1 to plot apart from the other alluvial aquifer samples on the Piper diagram (Figure 19).

Samples J3A and Km from the alluvial aquifer show similar patterns of relative concentrations of all major constituents. The only difference between the samples is that Km has a higher concentration of each anion and cation. These two wells are supplied with water entering the valley alluvium from the Boundary Creek drainage. The change in ground water chemistry between the two wells is a result of the flow through the alluvial sediments between the wells.

Of the sampled wells in the alluvial aquifer, well J1 has the highest calculated total dissolved solids. This would be expected for a well farthest from the source of ground water recharge. The cation concentrations of all the alluvial aquifer

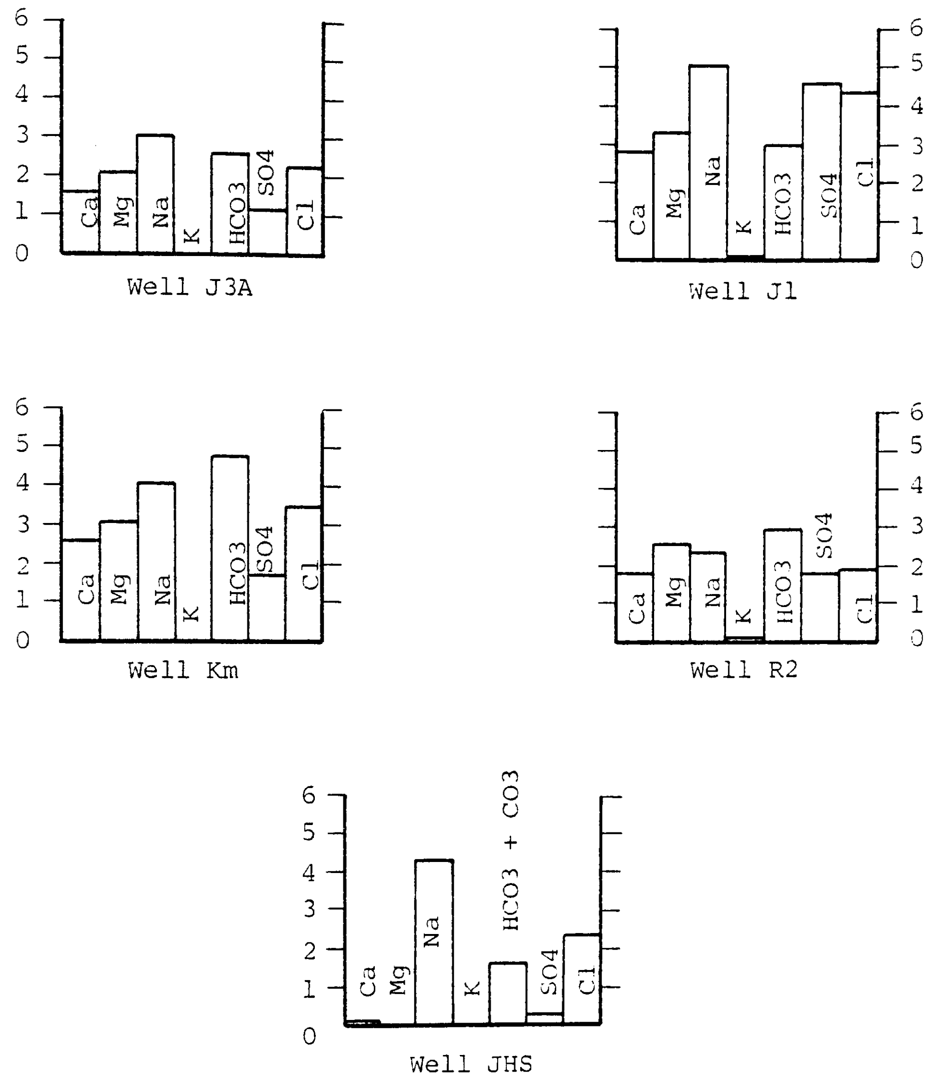

Figure 20. Histogram of Major Cations and Anions in the Ground Water Analyses Performed by the Author. Scales are in milligrams per liter.

samples are similar, but the anion concentrations of well J1 are significantly different from those of wells J3A and Km. Well J1 has sulfate and chloride as the most abundant anions, while the bicarbonate is the most abundant anion in samples J3A and Km. Under normal recharge conditions the ground water that supplies well J1 comes from the Mexican side of the valley. The change in anion concentration, from bicarbonate in the wells on the edge of the valley to sulfate and chloride in the center, is characteristic of ground water as it moves farther from the point of recharge. Chebotarev (1955) developed the sequence

$$HCO3 \rightarrow HCO3 + Cl \rightarrow Cl + SO4 \rightarrow (\text{or } SO4 + Cl) \rightarrow Cl$$

describing the chemical changes that occur as the ground water chemistry becomes progressively more like that of sea water. This trend towards a composition of sea water is apparently occurring in Jacumba Valley as the ground water from the bedrock terrain surrounding the valley migrates through the alluvial sediments.

The one well in the Table Mountain aquifer, R2, has low concentrations of the major anions and cations and a low calculated total dissolved solids. There is no apparent source of ground water recharge in the immediate vicinity of well R2; therefore, the ground water in the well probably had to migrate through the aquifer. A later discussion will show that the ground water recharge for the Table Mountain aquifer probably originates in the bedrock terrain to the west and south of the valley. If it is assumed that sample J3A is representative of much of the ground water entering the valley from the bedrock, then sample R2 suggests that the Table Mountain aquifer does not greatly alter the chemistry of the water it receives as recharge.

There is an indication that the waters in the alluvial aquifer may receive some contamination from the thermal waters in the valley. Wells J3A, Km, and J1 all have rather high concentrations of sodium and both Km and J1 have high concentrations of fluoride. All of the thermal waters tested show high concentrations of these two constituents (Appendix K). The Mexican thermal springs are undeveloped and undoubtedly mix with the cold ground water to some degree. This would explain the contamination in well J1 which is down gradient from these springs. Well J3A is located about 100 meters from the Jacumba Hot Spring well and well Km is located down gradient from the hot spring well (JHS). The hot spring well is cased through the alluvium to prevent mixing, but excess water from it is piped into a nearby pond. Contamination could come from this pond or from thermal waters in the area that are not tapped by the hot spring well.

Thesken's Analyses

Richard Thesken (1977) analyzed eleven ground water samples from the United States side of the Jacumba Valley watershed. His analyses included two wells located in the metamorphic terrain to the west of the valley. His sample T4 is the Jacumba Hot Spring well (JHS) and will be discussed in a later section.

Thesken's (1977) samples T3 and T6 correspond to wells J3A and Km, respectively. Histograms of these samples show that they have slightly different concentrations of cations and anions (Figure 21). A Piper diagram plot shows that sample T3 is dominated by sodium and has high chloride, while T6 is not dominated by any particular ion (Figure 22). The position of sample T3 on the Piper diagram, between sample T6 and the hot spring sample T4, suggests that well J3A was being contaminated by the hot spring at the time of sampling.

Sample T7 is from well R1, which taps the very upper portion of the Table Mountain aquifer (Figure 13, page 48). The relative concentrations of cations and anions shown in the histograms (Figure 21) and the position of the sample on the Piper diagram (Figure 22) indicate that the chemistry of this sample is different from the alluvial samples T3 and T6. Sample T8 is from a well of unknown depth located to the south of well R1 (Figure 13, page 48). The histogram and Piper diagram plots of this sample indicate that its chemistry is very similar to that of T7 (Figures 21 and 22). T1 is the well that supplies the campground at the north end of Jacumba Valley (Figure 13, page 48). Its relative concentration of cations and anions shows that it, too, is chemically similar to well R1 (Figures 21 and 22). The chemical similarities of wells T8 and T1 to well R1 strongly suggest that those wells also tap the Table Mountain aquifer.

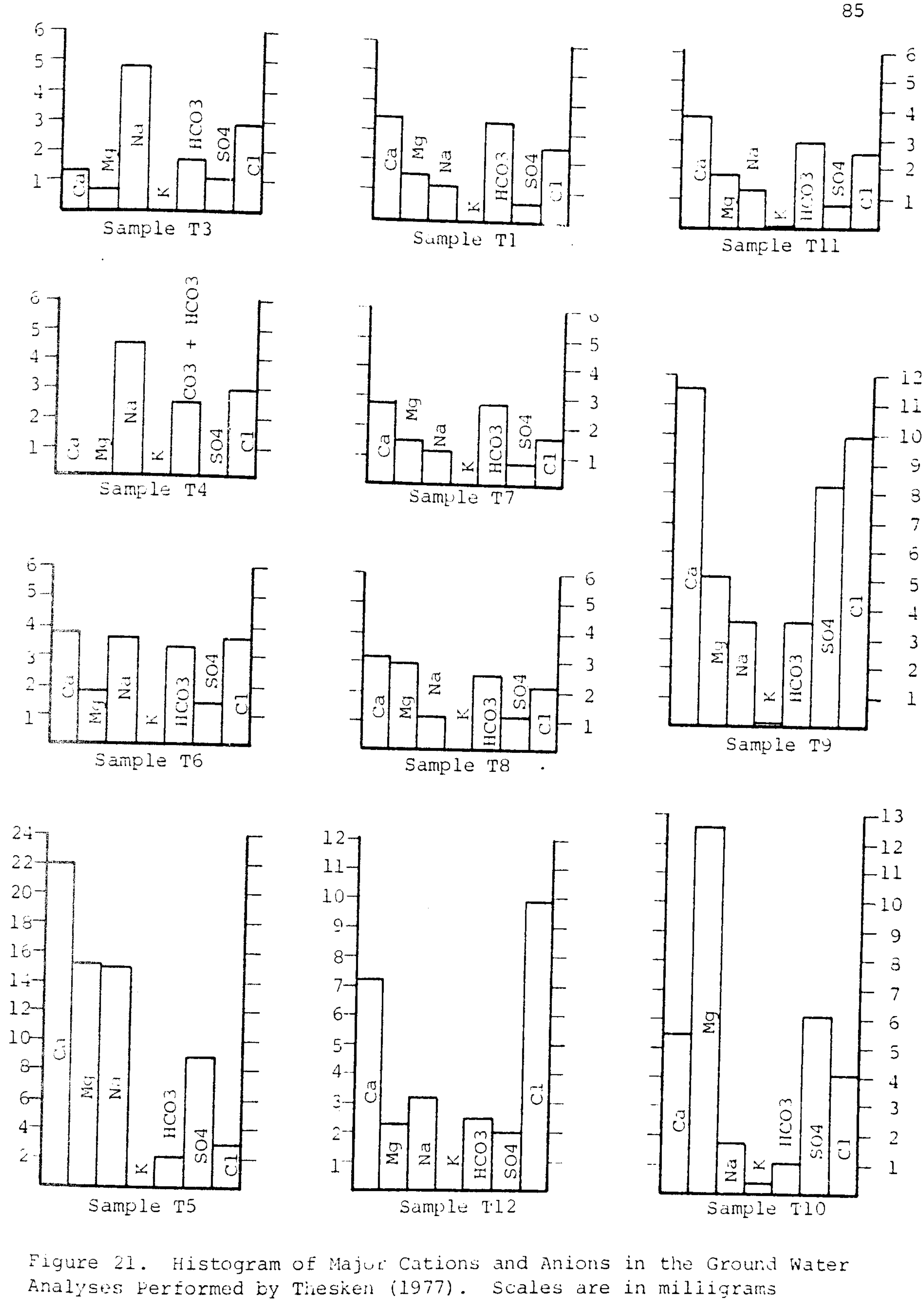

Figure 21. Histogram of Major Cations and Anions in the Ground Water Analyses Performed by Thesken (1977). Scales are in milligrams per liter.

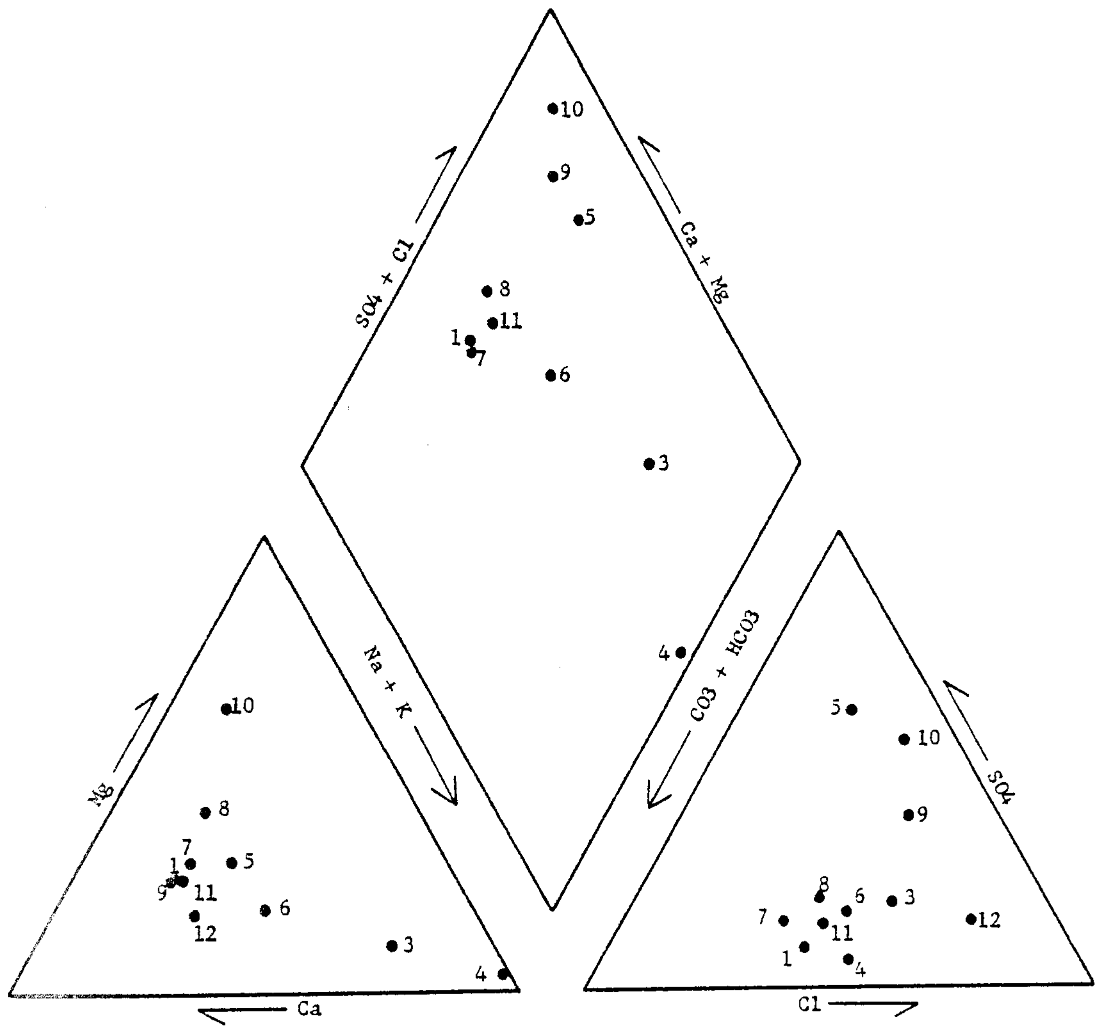

Figure 22. Piper Diagram of Ground Water Analyses Performed by Thesken (1977)

Sample T5 is from a well near the airport (Figure 13, page 48). The ground water chemistry of this well is very anomolous and does not suggest a source in any particular aquifer. No information about the well is available.

Richard Thesken's (1977) samples T9, T10, and T11 are from wells in the drainage along Old State Highway 80 to the west of Jacumba (Figure 15, page 59). Sample T9 is from well H1. Sample T10 is from a well to the west of the north trending fault along the western side of the drainage. Both wells are in the metamorphic terrain. Well T11 is located in alluvium at the junction of the drainage and Boundary Creek. The relative concentrations of cations in T9 and T11 are similar (Figures 21 and 22). Sample T10 is quite different with a very high magnesium content. The relative anion concentrations of both T9 and T10 are alike with low concentrations of bicarbonate. T11 has a higher concentration of bicarbonate, probably a reflection of its source in alluvium rather than bedrock. The combined anion and cation chemistry of samples T9 and T10 are similar as evidenced by their plotting on the Piper diagram (Figure 22). The chemistry of sample T11 is closer to the chemistry of the Table Mountain aquifer sample T7 (Figure 22). The differences in chemistry of the two bedrock samples may be due to differences in lithology, well depths, and/or ground water flow patterns. There is not enough known about the bedrock areas or the wells to determine the significance of the chemical differences.

Sample T12 is from a well located along the northern edge of the town of Jacumba (Figure 13, page 48). According to the owner's description, the well drilled through, and cased, the alluvium and is drawing water from either granitic bedrock or the Table Mountain Formation at a depth of about 45 meters. The chemistry of the sample is fairly similar to samples T9 and T10, though the anions are dominated by chloride, suggesting that its source may be in bedrock (Figures 21 and 22, pages 85 and 86, respectively).

The ground water samples collected during this study and by Thesken (1977) do not reliably sample either of the two aquifers to the north or south of the center of Jacumba Valley. As a result, the chemical analyses can only give an estimation of the overall chemistry and chemical changes within the aquifers. Both sets of analyses do indicate that there are some differences between the alluvial aquifer and the Table Mountain aquifer and between different portions of the alluvial aquifer. It is likely that with the northward flow of the ground water in the valley, the ground water continues to increase in total dissolved solids toward the head of Carrizo Gorge. One driller reported that the water in the alluvium at the north end of the valley is stagnant. If T1 does draw water from the Table Mountain aquifer, as its chemistry suggests, then there is only a slight increase in the total dissolved solids as the ground water in that aquifer moves through the valley.

A comparison of the analyses performed for this study and those performed by Richard Thesken (1977), particularly for wells J3A and Km, indicates that there are certain discrepancies. Varying rates of ground water recharge at the time of sampling and/or error in analysis are the probable causes of the differences.

The nonthermal waters sampled by this author and Thesken are within the guidelines set by the United States Public Health Service for public water supplies. However, wells J1 and Km did have fluoride concentrations that exceeded the limits in the 1980 tests.

Previous Analyses

The Jacumba Cold Springs and some of the wells in Jacumba Valley have been sampled numerous times since 1923 (Appendix K). The Jacumba Cold Springs were sampled by Brown (1923), the town of Jacumba in 1951, and Babcock (1958). When wells J3, J3A, and J4 replaced the springs, each well was tested by the town of Jacumba. Well J3 was tested in 1964, well J3A was tested in 1966, and well J4 was tested in 1972. Well J3 was also tested by Thesken (1977) and during this study in 1980. Well J1 to the east of Jacumba was tested by the town in 1957, by Babcock (1958), and during this study. Well J2 was sampled by the town in 1963. The analyses of all of the tests performed by the town are in the County of San Diego, Department of Public Health files.

Figure 23 presents histograms of the major anions and cations for each of the chemical analyses made prior to Thesken's

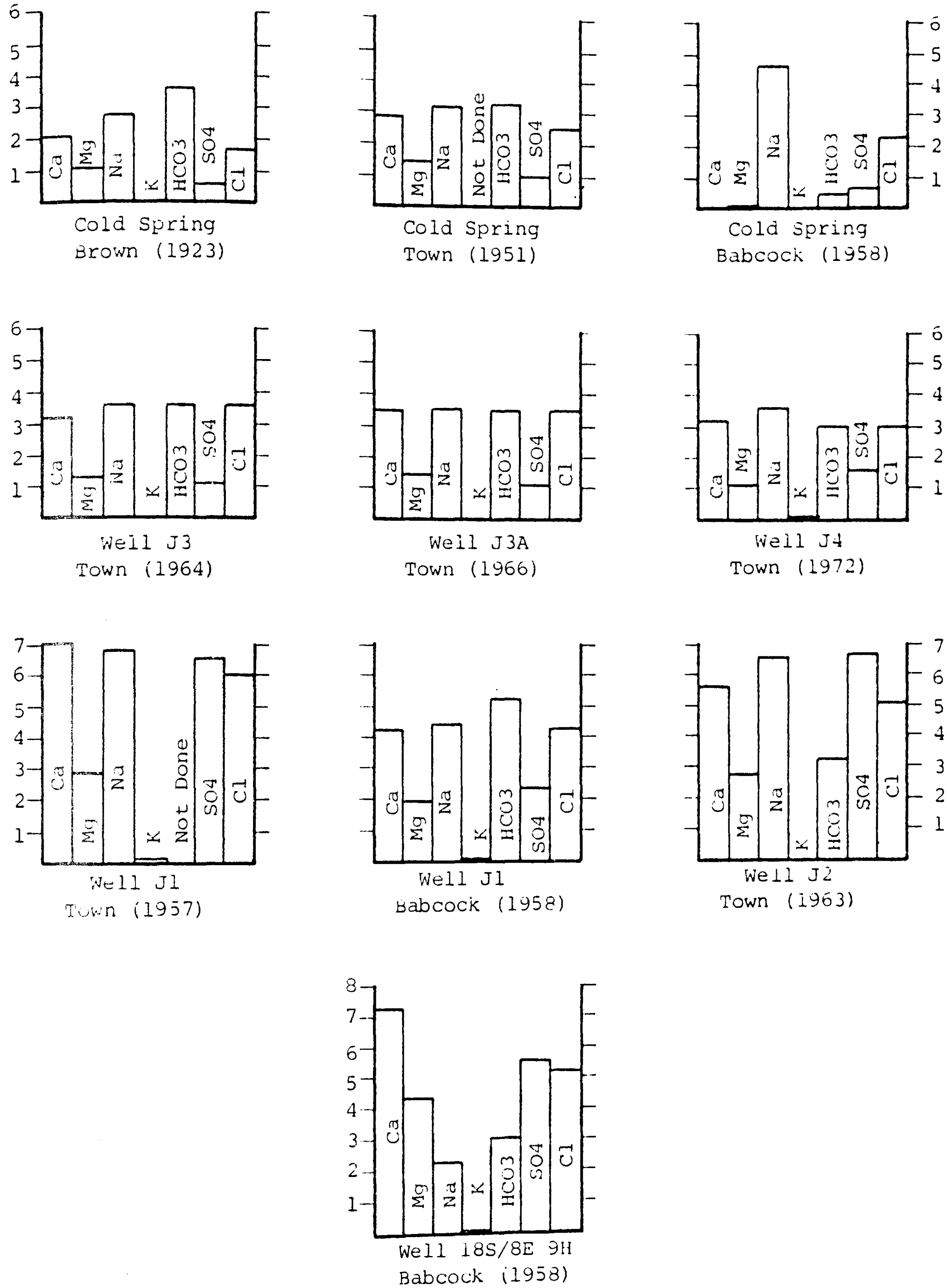

Figure 23. Histogram of Major Cations and Anions from Ground Water Analyses Performed During Earlier Studies. Scales are in milligrams per liter.

study in 1977. Figure 24 presents a Piper diagram of the chemical analyses of the Jacumba Cold Springs and wells J3, J3A, and J4 from 1923 through 1980. From 1951 to 1980 there appears to have been little change in the chemistry of the ground water from either the cold springs or the wells drilled in the location of the springs. Brown's (1923) analysis shows a dominance of bicarbonate which causes it to plot apart from the other analyses. This difference in bicarbonate concentration, assuming that it is not the result of different methods of analysis, may reflect a much higher rate of ground water recharge during the 1920's. Babcock's (1958) analysis of the cold spring is almost identical to analyses of the Jacumba Hot Springs that have been done (Appendix K). Whether this is due to error in sampling and/or analytical technique is not clear, but the fact that his analysis of well J1 also appears anomolous may indicate that it was his technique of analysis. Thesken's (1977) analysis shows higher concentrations of sodium, potassium, and chloride. It is unlikely that his one sample would be this different, though it may reflect varying rates of ground water recharge and contamination by thermal springs.

The analyses of wells J1 and J2 do not indicate any significant change in the ground water chemistry between 1977 and 1980. The 1957 analysis by the town is incomplete. Babcock's (1958) analysis again appears anomolous in its anion content.

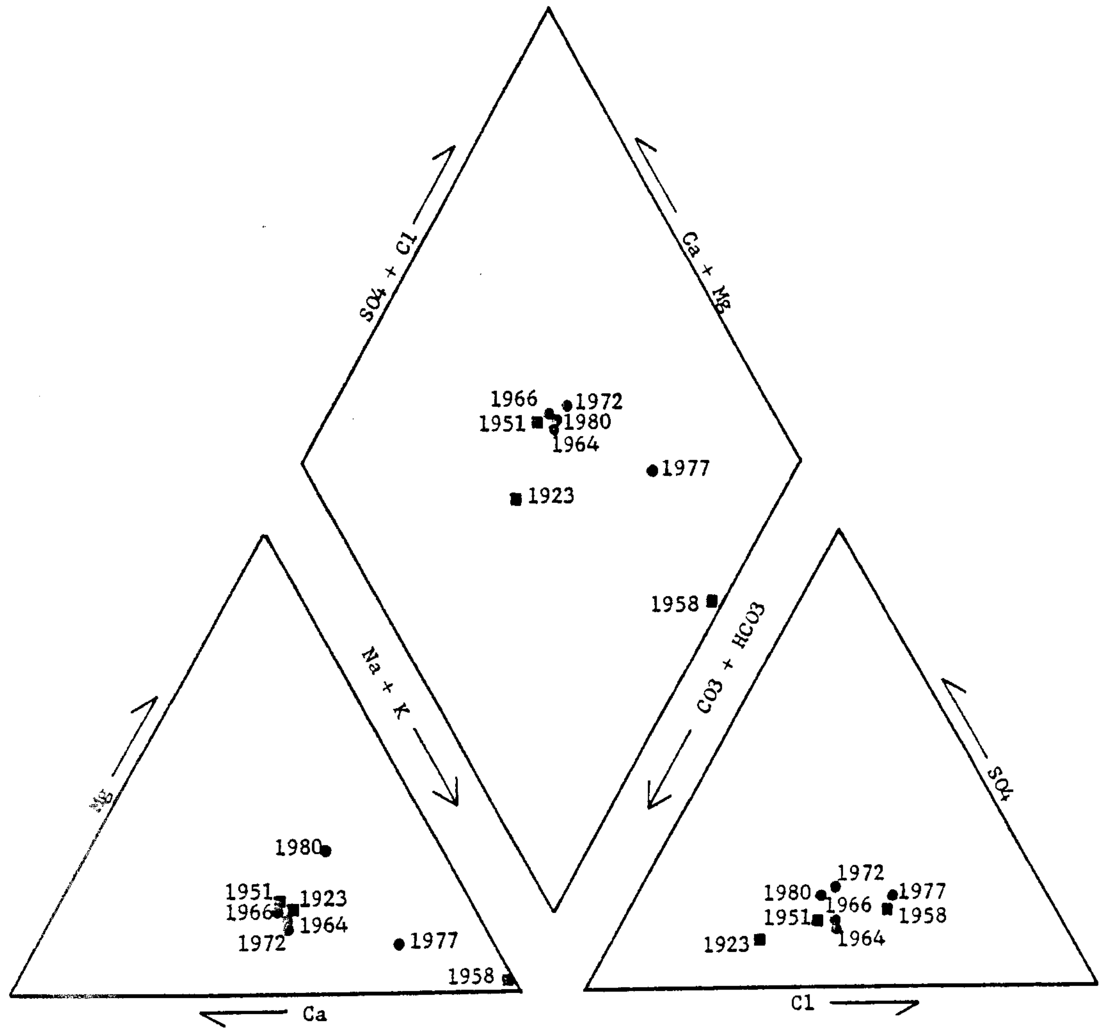

Figure 24. Piper Diagram of All Ground Water Analyses Performed on the Jacumba Cold Springs and Wells J3, J3A, and J4

■ Jacumba Cold Springs

● Wells J3, J3A, and J4

Ground Water Movement

Surface flow in the Jacumba Valley watershed, when there is any, flows from the surrounding hills and mountains into the valley. It then moves north to where it discharges from the valley into Carrizo Gorge. The movement of ground water in the Jacumba Valley watershed mimics the surface drainage. The hills and mountains surrounding the valley are the primary source of recharge for the valley's ground water system. When the ground water reaches the valley, it migrates north to the head of Carrizo Gorge where it discharges from the aquifers by springs, subsurface flow into the bedrock, and evapotranspiration.

Recharge Areas

About 90% of the calculated mean annual ground water recharge for Jacumba Valley occurs in the hills and mountains surrounding the valley. About 60% of the recharge occurs in the hills to the west of the valley where precipitation is highest (Appendix E). Most of this recharge eventually reaches the valley's ground water system in one of two ways: as shallow subsurface flow in residual soils and erosional stress-relief fractures, and as deep ground water flow in regional fractures. The surface drainage watershed is assumed to be the boundary for ground water recharge. It is distinctly possible that cross-boundary ground water movement could take place in regional fractures. Because there is no information related to this, it is assumed that cross-boundary ground water movement, if it does occur, occurs in both directions and the net change is insignificant. This author is aware that this may not be the actual case.

A large portion of Jacumba Valley's ground water recharge appears to reach the valley by migrating through the residual soils and near surface, erosional stress-relief fractures in the bedrock terrain. Shallow ground water movement in bedrock terrain typically follows the topography of the area and often coincides with the surface drainage patterns. This ground water can become concentrated in topographically low areas and follow the surface drainages into a valley. The Jacumba and Jacumé cold springs are evidence of shallow ground water in the bedrock terrain recharging Jacumba Valley's ground water system. Both springs flow year round, yet their discharge varies with the seasons. Both springs are fed by subsurface flow in the drainages in which they are located. The fact that these springs flow year round indicates that the drainages are supplied by ground water from the bedrock terrain to the west and not precipitation runoff. However, the seasonal variations in the flow rate of the springs suggests that this ground water system is limited in volume and that the period of time from infiltration to discharge is short. The water that infiltrates into the residual soils and shallow fractures in the bedrock to the west of Jacumba Valley will probably migrate toward topographically low areas and then follow surface drainages into the valley. Boundary Creek and the drainage west of Jacumé are prominant drainages; they, therefore, will have greater ground water flow reaching them and be able to support springs.

Deep ground water flow, in the regional fractures of the bedrock terrain, also moves toward Jacumba Valley and recharges the aquifers there. As with shallow ground water systems in bedrock, the movement of ground water in deep fractures reflects the topography of an area, but in a less pronounced manner. Ground water will move from higher elevations, such as mountains, toward lower elevations, such as valleys. The movement of this deep water will not reflect surface drainage patterns unless those patterns are controlled by the regional fractures. There is ground water in deep fractures in the bedrock surrounding Jacumba Valley, as indicated by the presence of thermal springs in the valley. The fact that the thermal springs show constant rates of discharge regardless of season indicates that the ground water system in the deep fractures is of substantial volume so as not to be affected by yearly variations in ground water recharge. The constant rate of discharge of the thermal springs also indicates that the period of time from infiltration to discharge is significantly longer than the shallow ground water system. (The thermal springs are artesian, indicating that the water in some of the deep fractures is under a considerable hydraulic head.) It is not known how much nonthermal ground water occurs in the deep, regional fractures in the Jacumba Valley area, but it is likely that a significant volume is present and that it migrates toward the valley. Little definitive information is known about ground water movement in the crystalline bedrock terrain of the study area. Much work needs to be done to clearly delineate the movement and quantity of ground water involved.

A small portion of Jacumba Valley's ground water recharge occurs as infiltration through stream channels and alluvial material in the valley. This form of recharge only occurs when precipitation is high enough to cause runoff from the surrounding hills and mountains to reach the valley. During the months of February and March, 1980, this form of recharge took place. Stream flow measurements along Boundary Creek in Jacumba Valley indicated that about 27% of the surface flow was lost due to infiltration and evaporation (Appendix D). The loss in other streams flowing through the valley was probably greater because they flowed across longer portions of the valley. This infiltration formed a significant portion of the 1979-1980 recharge, an estimated 10% or more. Later discussions will show that this type of recharge has only occurred four times in the last forty-eight years. Consequently, over long periods of time surface infiltration from runoff would not be a significant form of ground water recharge for Jacumba Valley.

Recharge to Jacumba Valley's Aquifers

The alluvial aquifer receives ground water recharge from the shallow bedrock ground water system and from surface infiltration due to surface stream flow. As indicated above, the contribution to recharge from surface runoff appears to be small over long periods of time, but can significantly affect the valley's ground water system while the infiltration occurs. During the spring of 1980 the surface infiltration caused a ground water mound to form in the alluvial aquifer. This mounding was evident in the water level measurements made on April 1, 1980 (Figures 25 and 26; Appendix H).

The majority of the ground water recharging the alluvial aquifer probably comes from the shallow ground water system in the bedrock terrain. While this source may recharge the aquifer wherever there is alluvium contacting bedrock, it is concentrated in the vicinity of major drainages entering Jacumba Valley from the west, specifically Boundary Creek and the drainage west of Jacume.

The limited thickness of the alluvial aquifer and the fact that it is underlain by volcanics and the Table Mountain aquifer throughout most of the valley suggests that this aquifer does not receive much recharge from ground water in the deep regional fractures in the bedrock terrain.

The Table Mountain aquifer receives ground water recharge from surface infiltration and probably from both the shallow and deep ground water systems in the bedrock terrain. Surface infiltration, from precipitation and surface runoff, is able to recharge the Table Mountain aquifer in the southern portion of Jacumba Valley where the aquifer is not overlain by the Jacumba Volcanics.

Ground water recharge from the shallow fracture system in the bedrock terrain into the Table Mountain aquifer is probably

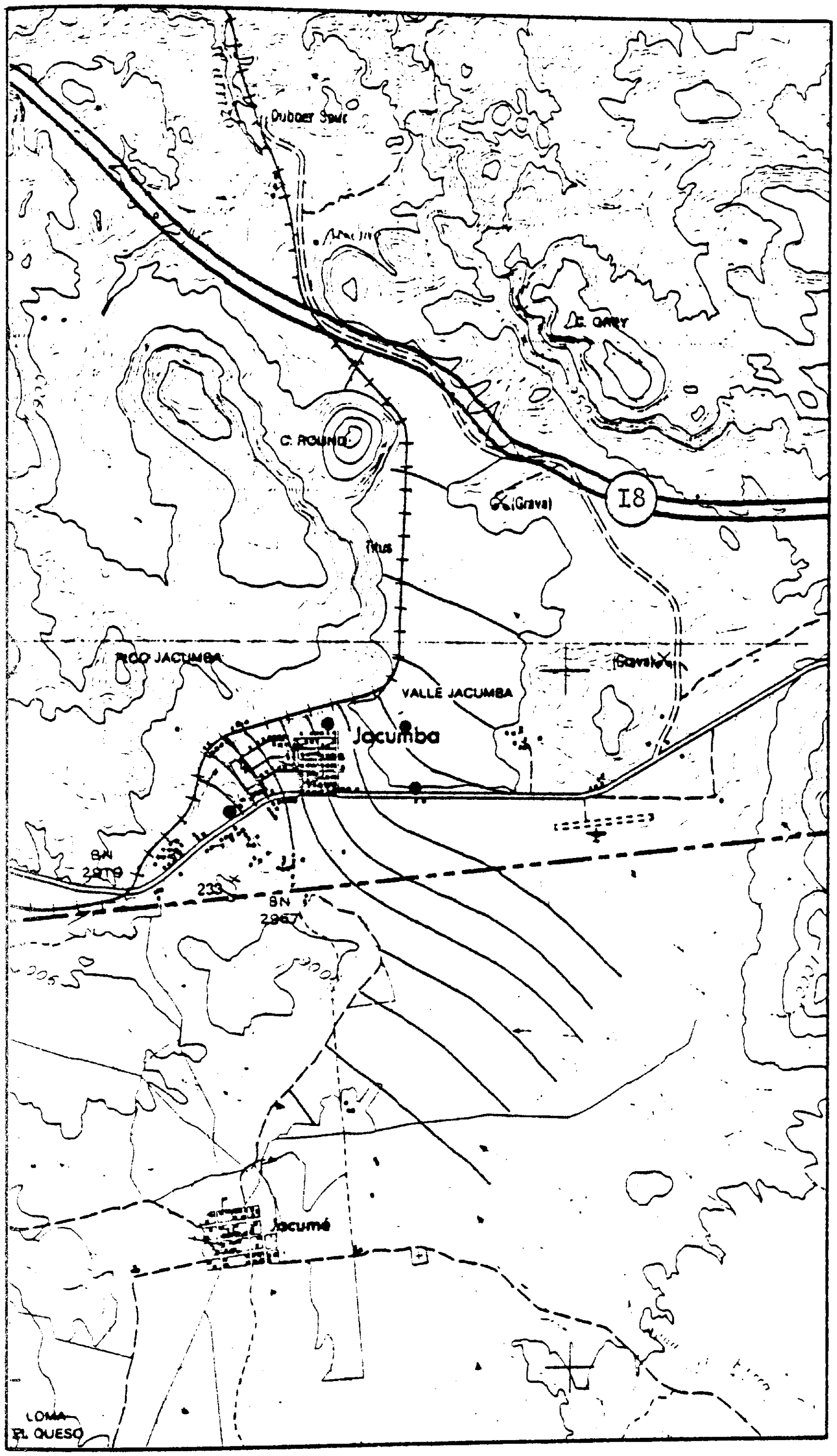

Figure 25. Hypothesized Alluvial Aquifer Water Table, November, 1979. (5-meter contour interval) (Dots indicate the location of wells Km, Kl, K3, and J3.) (Scale is 1:50,000.)

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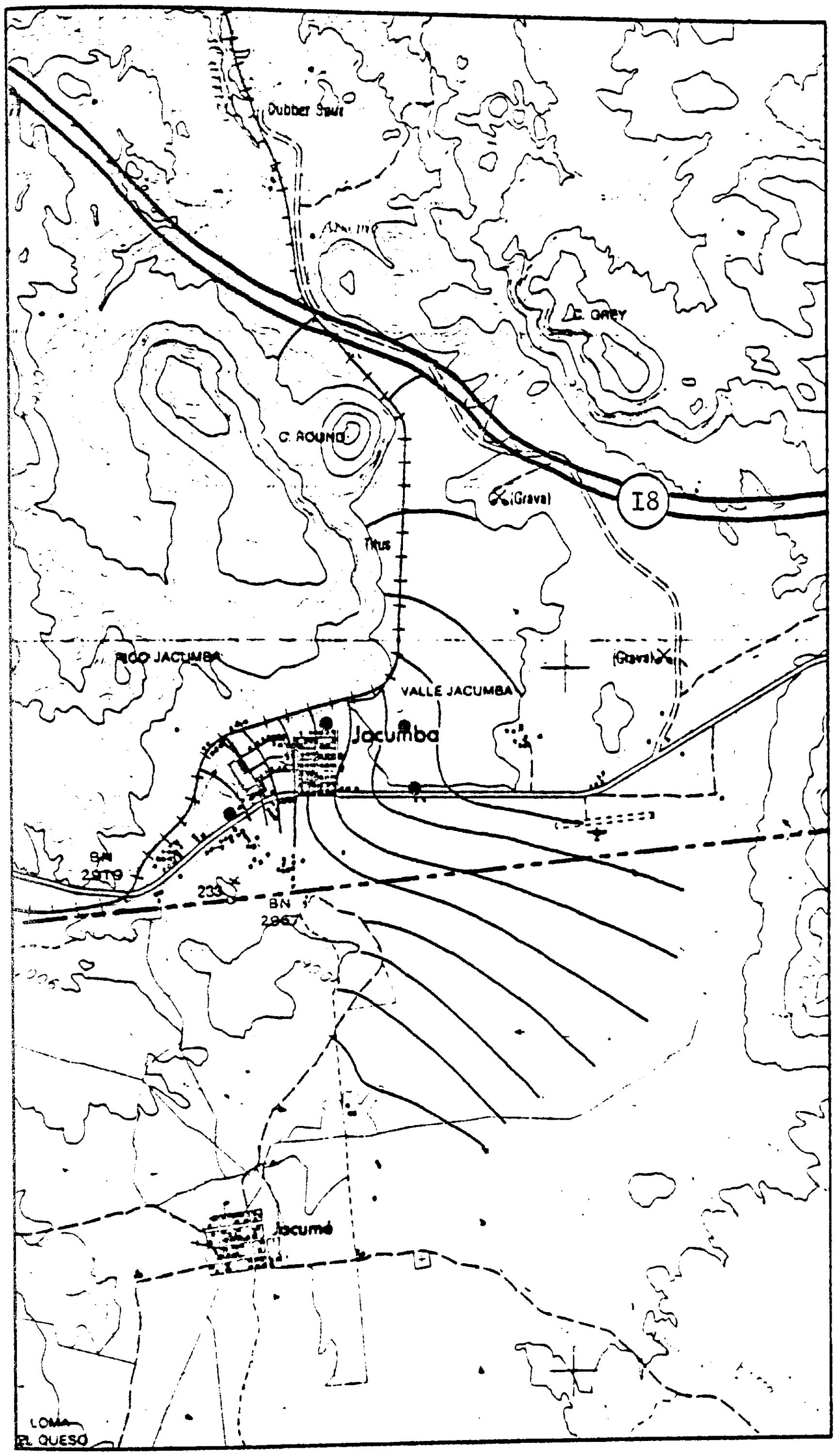


Figure 26. Hypothesized Alluvial Aquifer Water Table, April, 1980. (5-meter contour interval.) (Dots indicate the location of wells Km, K1, K3, and J3.) (Scale is 1:50,000.)

N

limited by the Jacumba Volcanics. Throughout much of Jacumba Valley the lower flows of the Jacumba Volcanics overlie the Table Mountain aquifer and appear to act as an aquitard. To the south of the international border, the alluvium and Table Mountain Formation are in hydrologic contact. In this portion of the valley ground water in the shallow bedrock fractures can recharge the Table Mountain aquifer.

The Table Mountain aquifer is probably recharged by ground water in the deep regional fractures in the bedrock terrain. This aquifer overlies bedrock throughout the valley and it is undoubtedly in hydrologic contact with some of the regional fractures. The northwest trending fault that passes through Jacumba ("a" in Figure 9, page 31) may restrict ground water movement in deep fractures. All of the thermal springs in the valley occur to the west of the fault. The ground water chemistry of wells which tap the Table Mountain aquifer, R1, R2, and T8, show no evidence of contamination by thermal waters, no high sodium or fluoride. This suggests that the fault in some way restricts the movement of the thermal ground water in the deep bedrock fractures. Whether the fault also restricts nonthermal ground water movement in regional fractures is not known, but possible.

The alluvial aquifer and the Table Mountain aquifer are in hydrologic contact south of the international border. This contact allows some ground water exchange between the aquifers to take place.

More work needs to be done to gain a clear and definitive understanding of where and how ground water in the bedrock terrain recharges the aquifers in Jacumba Valley.

Jacumba Valley's Aquifers

The ground water in the aquifers of Jacumba Valley flows north and discharges from the valley at the head of Carrizo Gorge. The water levels in the alluvial aquifer, as of November, 1979, indicated a hydraulic gradient descending toward the north of about 4.9 meters/kilometer (Figure 25, page 98). As of September, 1980, the gradient increased to 5.9-6.3 meters/kilometer. A hydraulic conductivity of 170 meters/day for the alluvial aquifer was calculated from the transmissivity of the aquifer, as determined by the pump test on well J1, and a saturated thickness of 17 meters. The hydraulic conductivity of the aquifer in the north end of the valley is probably less because the alluvium has a finer texture. The hydraulic conductivity of the Table Mountain aquifer was calculated to be 4×10^{-3} meters/day using the transmissivity determined by the pump test on well R2 and an estimated saturated aquifer thickness of 150 meters.

Discharge from Aquifers

Ground water is discharged from the aquifers of Jacumba Valley by evapotranspiration, subsurface flow into the bedrock, and surface flow from springs. The elevation of the water table in the alluvial aquifer roughly corresponds to the elevation of the valley floor north of Round Mountain. Phreatophyte growth in Jacumba Valley is concentrated in the area between Round Mountain and the old dam, and their growth undoubtedly reflects the near-surface water table. The phreatophytes in this area, mesquite and salt ceder, are capable of using about 200 centimeters of water per year (Robinson, 1958; Davis and DeWiest, 1966). The water used by these plants forms a significant portion of the ground water discharge from the alluvial aquifer.

A portion of the ground water discharge enters the fractured bedrock at the north end of the valley. For this study it is assumed that the only significant ground water discharge from the valley's aquifers into bedrock occurs at the north end of the valley. This assumption is considered valid because only the Carrizo Gorge area has a topographic gradient that would encourage ground water flow away from Jacumba Valley. The rate of ground water discharge into the bedrock depends on the hydrologic conductivity of and gradient into the bedrock at the north end of Jacumba Valley.

The third manner in which ground water is discharged from Jacumba Valley is through surface flow from the springs at the north end of the valley. These springs ("A," "B," and "C" in Figure 13, page 48) are not active at all times. The available information indicates that the activity of these springs is dependent on the elevation of the water table in the valley. Between June, 1979 and April, 1980, the only active spring at the north end of the valley was spring "C" located under the railroad trestle.

It flowed at a constant but low rate. The source of water for this spring is probably the Table Mountain aquifer. It is unlikely that the precipitation falling on the drainage upstream from the spring would be sufficient to maintain a constant flow throughout the summer and fall. In April, 1980, springs "A" and "B" became active. The water table in the alluvial aquifer had risen about 2 meters between November, 1979 and April, 1980. By September the water table had risen a total of 4.5 meters, springs "A" and "B" were still active and spring "C" had an increased flow.

The water level in the aquifers of Jacumba Valley is partially controlled by the discharge that occurs at the north end of the valley. In November, 1979, the discharge from the aquifers at the north end was primarily through evapotranspiration and subsurface flow into the fractured bedrock. Only the spring under the railroad trestle was active. That the net discharge from the alluvial aquifer was less than the net recharge, was evident because the water level in the alluvial aquifer was rising. It is likely that the same was true for the Table Mountain aquifer. As the water level in the valley rises, more water becomes available to plants allowing greater evapotranspiration. This rising water table eventually initiates surface discharge from the springs at the north end. The flow from these springs probably continues and increases as the valley's water table rises, until a threshold is reached where the total discharge equals the recharge. The discharge from the springs at the head of Carrizo Gorge probably fluctuates in the same manner as the rate of ground water recharge; however, the discharge fluctuations will lag somewhat behind the recharge fluctuations. Under normal recharge and discharge conditions, without large amounts of water being withdrawn by humans, periods of below normal precipitation will result in reduced ground water recharge to the valley, a declining water table, and decreasing discharge from the springs at the north end of the valley. Periods of above normal precipitation will result in increased ground water recharge, a rising water table in the valley, and increased discharge from the springs. Viewed over short periods of time the net ground water budget for Jacumba Valley would vary considerably. However, viewed over long periods of time, 100 years or more, the recharge to the valley would equal the discharge.

Ground Water Recharge

Recharge to a ground water system occurs when precipitation infiltrates below the active soil depth to the water table. Before this occurs, the precipitation is subject to loss either through surface runoff, evaporation, and retention in the active portion of the soil for later evapotranspiration. Figure 27 is a sketch of one year of Boulevard precipitation data showing the loss due to evaporation, soil moisture deficiency, and surface runoff. The remaining water infiltrates down to the water table. The precipitation, potential evapotranspiration, soil moisture deficiency, and surface runoff of an area are all important factors affecting

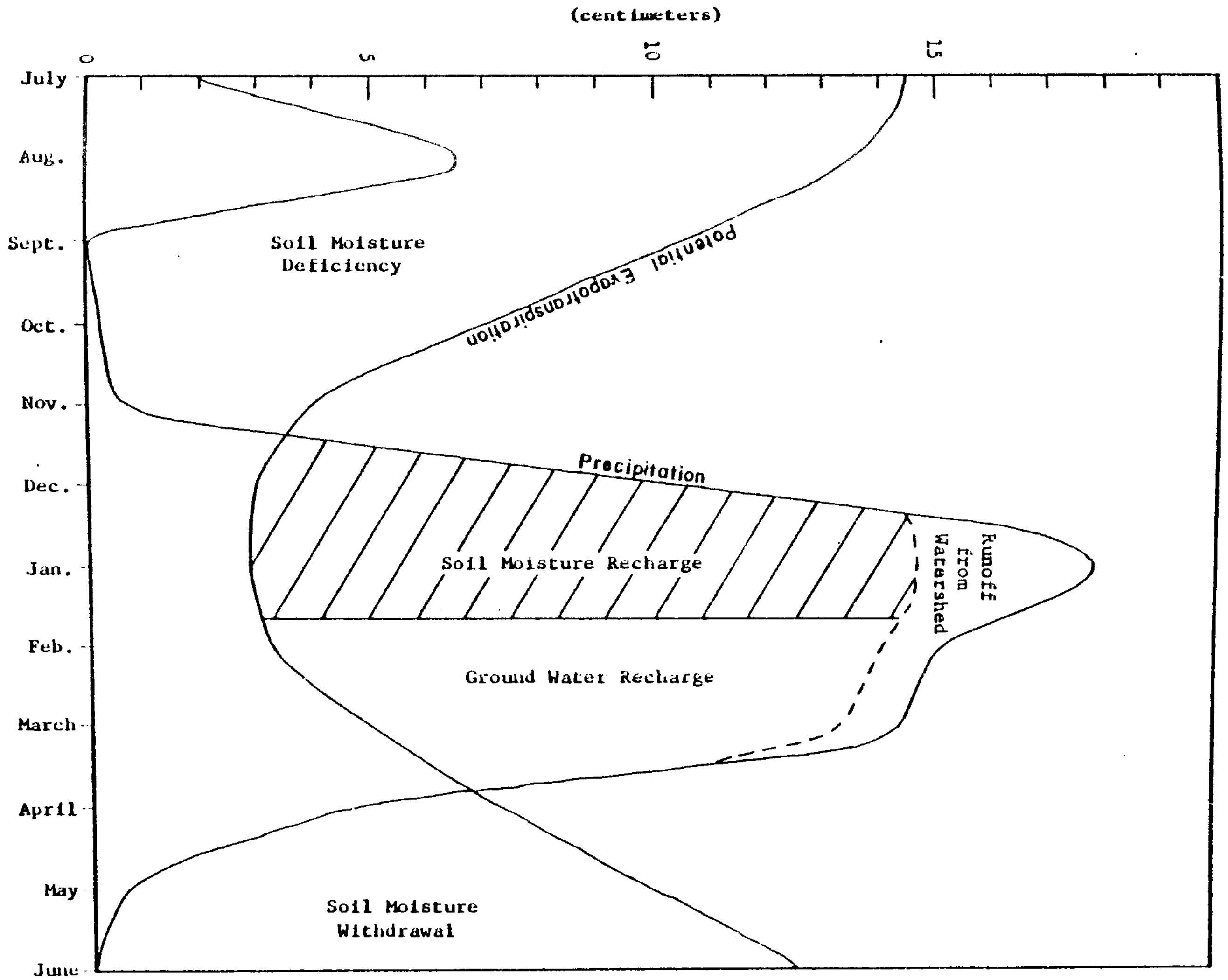


Figure 27. Sketch of the Relationship Between Precipitation, Potential Evapotranspiration, Surface Runoff, Soil Moisture, and Ground Water Recharge for the Boulevard Water Year 1977-1978

the amount of ground water recharge that occurs. All of these variables were considered in the ground water recharge calculations made for the Jacumba Valley watershed. From the monthly precipitation data, the potential evapotranspiration, the soil moisture deficiency, and the surface runoff were subtracted to determine the monthly ground water recharge. Table 4 is an example of the recharge calculations. The complete calculations are found in Appendix E. The example in Table 4 is of the same data diagrammed in Figure 27, the water year 1977-1978.

Table 4

Sample Ground Water Recharge Calculation
for the 1977-1978 Water Year

Month	Precipitation (cm)	Runoff (cm)	PET (cm)	Soil Moisture (cm)	Recharge (cm)
July	1.91	0	1.91	0	0
August	6.60	0	6.60	0	0
September	0	0	0	0	0
October	0.33	0	0.33	0	0
November	0.53	0	0.53	0	0
December	9.45	0	3.02	6.43	0
January	17.88	2.68	2.90	16.46	2.27
February	15.11	2.27	3.23	16.46	9.61
March	14.45	2.17	5.03	16.46	7.25
April	4.95	0	7.26	14.15	0
May	0.66	0	9.93	4.88	0
June	0	0	4.88	0	0
Total	71.88	7.12	40.74		19.13
		Infiltration in valley from runoff			2.13

Recharge Calculation Variables

The amount of precipitation that falls each month of the year and the amount of potential evapotranspiration for each month varies a great deal. Because of this variability and the fact that the months of highest precipitation coincide with the months of lowest potential evapotranspiration, ground water recharge occurs.

Potential evapotranspiration. The potential evapotranspiration for the Jacumba Valley watershed was calculated from the mean monthly pan evaporation of Lake Morena, California (Appendix A). Pan evaporation was related to natural evapotranspiration by a coefficient of 0.70. Few authors have studied the potential evapotranspiration in the area that includes Jacumba Valley. Hely and Peck (1964) concluded that in the mountainous areas west of the Salton Trough, a value of greater than 0.65 should be used with pan evaporation to compute the potential evapotranspiration. Crippen (1965), in his study of water loss from mountain basins in Southern California, stated that a consensus of studies indicated that evaporation from natural standing water bodies is 0.70 times pan evaporation. Close (1970) presented maps that show the potential evapotranspiration of the Jacumba area as between 71-76 centimeters, which is equivalent to using a 0.53-0.58 coefficient with the Lake Morena pan evaporation data. A coefficient of 0.70 was chosen on the basis of Hely and Peck (1964) and Crippen's (1965) work. The monthly potential evapotranspiration, in centimeters, used in the recharge calculations is:

July	August	September	October	November	December
14.50 cm	13.61 cm	10.62 cm	7.49 cm	3.99 cm	3.02 cm
January	February	March	April	May	June
2.90 cm	3.23 cm	5.03 cm	7.26 cm	9.93 cm	12.65 cm

The actual evapotranspiration for the study area is much less and is regulated by moisture availability.

Precipitation. Different portions of the Jacumba Valley watershed receive significantly different amounts of precipitation. The mountains to the west of Jacumba Valley receive much more than the valley. To account for this variability, when calculating ground water recharge, the precipitation data from both Jacumba and Boulevard was used. The watershed was divided into two sections along the 30.5 centimeter (12 inches) isohyetal line (Figure 2, page 12). The 30.5 centimeter line is roughly the average of the mean annual precipitation for Jacumba and Boulevard. The portion of the study area on the Jacumba side of the line was assumed to receive the precipitation recorded at Jacumba, and the area on the Boulevard side was assumed to receive the precipitation recorded at Boulevard.

Soil moisture deficiency. The active depth (rooting depth) and the specific retention of the soil play major roles in the recharge of ground water. The active portion of the soil acts as a reservoir for precipitation, storing a portion of it for later evaporation or use by plants. Once the soil's ability to retain water is satisfied, the remaining water in the soil migrates downward under the influence of gravity to the zone of ground water saturation. The specific retention of a soil and its active depth determine the volume of water that a soil is capable of retaining. The specific retention of the soils in the Jacumba Valley watershed were presented earlier and are in Appendix B.

The active depth of the soils developed on the crystalline bedrock in the watershed is assumed to be 61.0 centimeters (24 inches). This depth represents an average thickness of the soil. The mean thickness of the soils developed on the bedrock, as classified by the United States Soil Conservation Service and Forest Service (1973) is about 45.7 centimeters. Thickness of the soil encountered during the collection of the soil samples for testing was 30 centimeters to 65 centimeters. Based on this information, 61.0 centimeters was considered a reasonable and conservatively high active depth. This active depth was used only with type X soils. The active depth of the other soil types, W, Y, and Z, is limited by the rooting depth of plants. Limited examination of root depths in stream cuts and shallow holes, the generally sparse vegetation throughout much of the valley, and personal communication with Dave Huntley (1980) indicated that 91.4 centimeters (36 inches) was a valid, conservatively high, estimate of the active soil depth for type W, Y, and Z soils.

Ground water recharge was calculated for each soil type in the Jacumba and Boulevard portions of the watershed. Those values of recharge were then weighted according to the amount of area covered by each soil type. See Appendix E for details of recharge calculations.

Surface runoff. There is little information available on surface runoff in the Jacumba Valley watershed. Conversations with residents and observations made during this study suggest that runoff from the hills and mountains into Jacumba Valley does not occur frequently and runoff that reaches Carrizo Gorge, thereby discharging from the watershed, is very rare. Surface runoff is known to have occurred during summer cloudbursts, a hurricane in the fall of 1976, and winter months when precipitation is abnormally high. Surface runoff occurs when the rate of precipitation exceeds the permeability of the soil.

Summer cloudbursts can cause flash floods to enter Jacumba Valley from the surrounding mountains. This form of runoff is the result of extremely high rates of precipitation. According to residents, flash flooding is usually restricted to the edges of the valley. When runoff occurs, there will be some ground water recharge due to infiltration into stream channels and alluvium. It was not possible to quantify the runoff or potential ground water recharge for these events because of the lack of runoff data and the limited precipitation data. The short-lived and localized nature of summer cloudbursts and their associated runoff suggests that the volume of water available for ground water recharge is insignificant with respect to the annual ground water recharge budget. For the purpose of this study, it was assumed that no recharge occurs from the runoff of summer cloudbursts.

A hurricane during the fall of 1976 caused widespread flooding across Jacumba Valley and down through Carrizo Gorge. As with flash floods, there was probably some infiltration of the runoff into stream channels and valley alluvium. However, because of the lack of runoff data for this storm and the fact that storms of this severity are rare, it was assumed that this storm and others like it provide no ground water recharge.

Precipitation during winter months, November through April, is more abundant and is more likely to have surface runoff associated with it than summer months. During the months of February and March, 1980, precipitation on the Jacumba Valley watershed was extremely high and runoff was generated in the hills and mountains to the west and south of the valley. This runoff entered Jacumba Valley from Boundary Creek, the drainage west of Jacumé, and two drainages at the south end of the valley. The runoff flowed across a portion of the valley and discharged into Carrizo Gorge. Measurements of stream flow were made twice a month during the period of runoff (Appendix D). Because of the ease of access, the Boundary Creek flow was gaged as it entered the valley, flowed across a portion of it, and discharged into Carrizo Gorge. The stream measurements did not record the peak flows or clearly define the changes in rate of discharge, but they did provide a rough estimate of the total runoff.

According to residents of Jacumba, the first significant runoff began on February 14th. Runoff continued to flow into April. Precipitation on February 14th and just before was not particularly high when compared to precipitation during January (Appendix D). This indicates that this runoff was not the result of a high rate of precipitation during an individual event. Rather, it suggests that the relationship between precipitation and runoff is governed by a threshold. When a summer cloudburst occurs, the rate of precipitation can exceed the threshold permeability of the upper portion of the soil profile and runoff results. In a similar manner, the rate of precipitation over a longer period of time, weeks or months, may exceed the threshold permeability of the soil and underlying bedrock. Precipiation during the thirty-eight days prior to February 14th equalled 42 centimeters in Boulevard. This exceeds the mean annual precipitation for that station. Apparently, the 42 centimeters of precipitation in thirty-eight days exceeded the infiltration capacity of the soil and bedrock in the hills and mountains to the west and south of Jacumba Valley. The result was substantial runoff. Residents of Jacumba reported that a similar winter of high precipitation and runoff occurred in the late 1920's.

Data for the winter of 1925-1926 show high precipitation for the months of December through February. When the runoff occurred is not known, but over 40 centimeters of precipitation fell during these three months. Based on the limited information above, it was assumed that 40 centimeters of precipitation in three months or less will exceed the permeability threshold of the soil and result in a large volume of runoff. Based on this assumption, only four years, out of the forty-eight years of Boulevard precipitation record, show 40 centimeters or more precipitation in three months or less. This includes the winter of 1977-1978, which, according to residents, did not have any runoff. Jacumba precipitation records do not indicate any years with precipitation rates exceeding the 40 centimeter threshold.

The above discussion has dealt with large runoff events that resulted in flooding in Jacumba Valley and runoff that discharged into Carrizo Gorge. Smaller volumes of runoff may occur at other times during winter months. This runoff could enter the valley and recharge the aquifers, but not discharge into Carrizo Gorge. Information on such runoff in the Jacumba Valley watershed is not available. Therefore, it was assumed that such runoff, if it did occur, would not significantly affect the annual ground water recharge. The fact that ground water recharge due to runoff would result in less direct recharge from precipitation suggests that the watershed wide ground water budget would not be significantly altered. The 40-centimeter threshold observed during the winter of 1979-1980 suggests that winter runoff may actually be a rare occurrence.

Virtually all of the runoff of February through April, 1980 originated in the hills and mountains to the west and south of Jacumba Valley. Stream flow measurements provided an estimate of the total runoff, but were not detailed enough to determine what percentage of the precipitation ranoff during each precipitation event. Measurements of the flow in Boundary Creek as it entered Jacumba Valley indicated that about 20% of the February and March precipitation on the Boundary Creek watershed ranoff into the valley (Appendix D). This same runoff accounted for about 15% of the January-March precipitation. Past records for the four years when major runoff occurred do not indicate when runoff was initiated or what portion of the earlier precipitation contributed to the runoff. As a result of this uncertainty, it was decided to assume that all of the months of heavy precipitation resulted in runoff. Therefore, in the process of calculating ground water recharge, whenever the precipitation data indicated that there was over 40 centimeters of precipitation in three months or less, then 15% of that precipitation was assumed to runoff.

A portion of the runoff recharged the ground water system in Jacumba Valley by infiltrating through stream channels and alluvium. The average surface flow at the head of Carrizo Gorge was equivalent to about 74% of the flow measured in Boundary Creek as it entered Jacumba Valley. Because the majority of the runoff reaching Carrizo Gorge came from Boundary Creek, it was assumed that this measured loss of flow was representative of a single stream. The loss, through infiltration and evaporation, to the surface flow originating south of the international border was greater due to the much greater distance that runoff traversed in the valley. Based on the above information, it was conservatively assumed that 30% of the runoff entering Jacumba Valley would recharge the ground water system.

The sample ground water recharge calculation shown on page 108 indicates that during the months of heavy precipitation, January-March, 15% of the precipitation ranoff into Jacumba Valley. As that runoff crossed the valley to Carrizo Gorge, 30% of the flow infiltrated into the stream channel and alluvium and recharged the ground water system.

Calculated Ground Water Recharge

The calculated mean annual ground water recharge for the Jacumba Valley watershed is 3.39×10^6 cubic meters (2700 acre-feet) (Appendix E). This calculated recharge is a long-term mean and does not reflect the great variability in recharge that occurs from year to year. Figure 28 shows the calculated recharge and the yearly precipitation data for both Jacumba and Boulevard. For the Jacumba portion of the watershed, recharge occurred in only one out of seventeen years of record and only in areas with

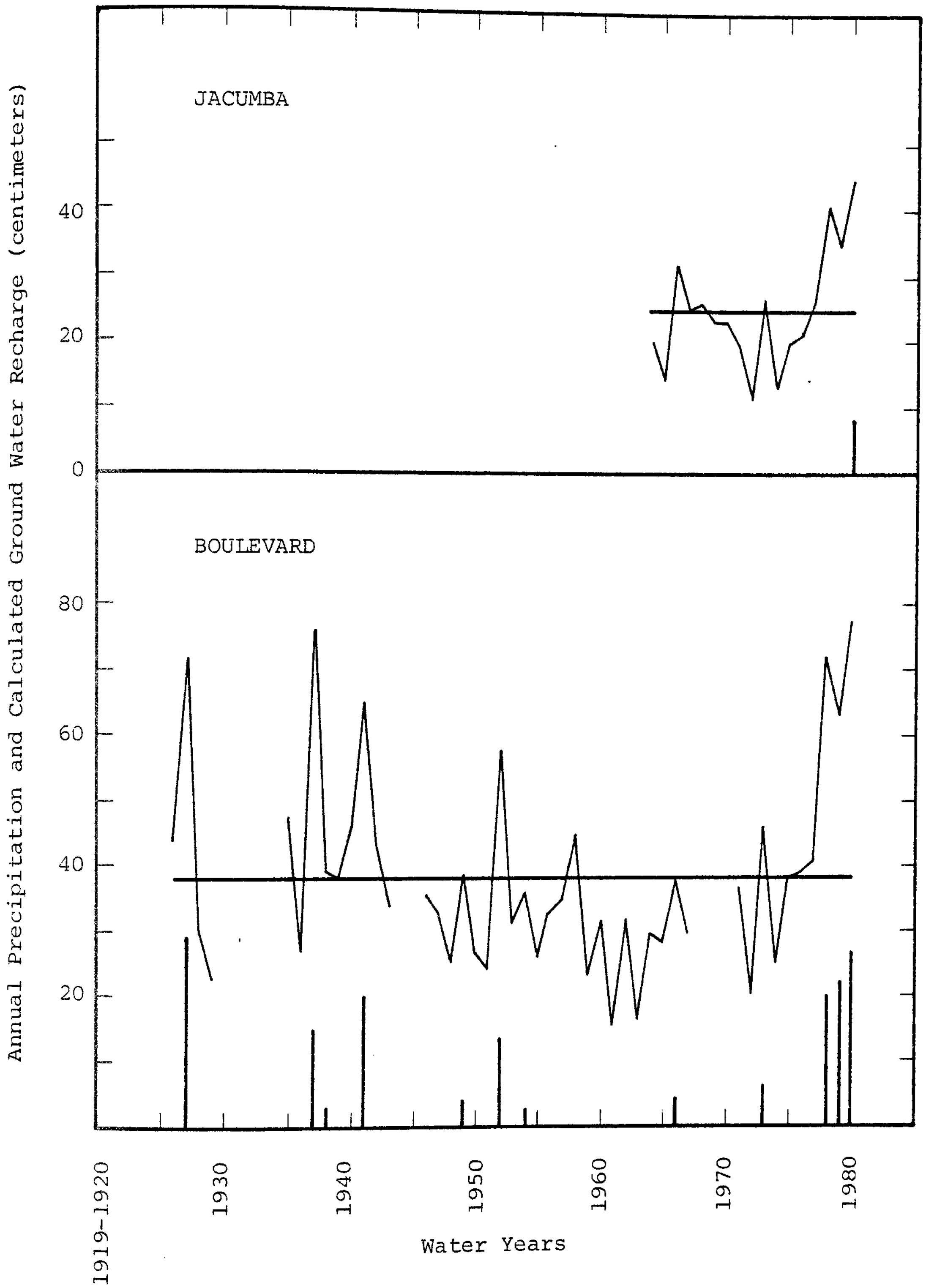


Figure 28. Plot of Annual Precipitation and the Calculated Ground Water Recharge for Jacumba and Boulevard, California. Thick vertical bars indicate the ground water recharge.

type W or type X soils. For the Boulevard area, recharge occurred in fourteen out of the forty-eight years of available records. About 90% of the total calculated recharge took place in areas of shallow type X soil developed on the crystalline basement.

The calculations show that recharge only occurs during the months of November through April because the high precipitation of those months coincides with low potential evapotranspiration. For the Boulevard data, there is a poor correlation between the yearly precipitation and the calculated recharge, the correlation coefficient is 0.76. However, the correlation between yearly recharge and the November through April precipitation is good, with a correlation coefficient of 0.96 (Appendix E). Figure 29 indicates that until the November through April precipitation reaches 30 to 33 centimeters (12-13 inches), no recharge occurs. All the precipitation is lost through evapotranspiration and satisfying the soil moisture deficiency. After the threshold is passed, the percentage of precipitation that recharges the ground water increases with increasing precipitation. Because no recharge occurs during summer months and no recharge occurs during the winter months until this threshold is passed, years with similar amounts of precipitation can have significantly different amounts of calculated recharge. For example, the water year 1965-1966 for Boulevard recorded 37.69 centimeters of precipitation and had 4.80 centimeters of calculated recharge for type X soils. The water year 1974-1975 recorded

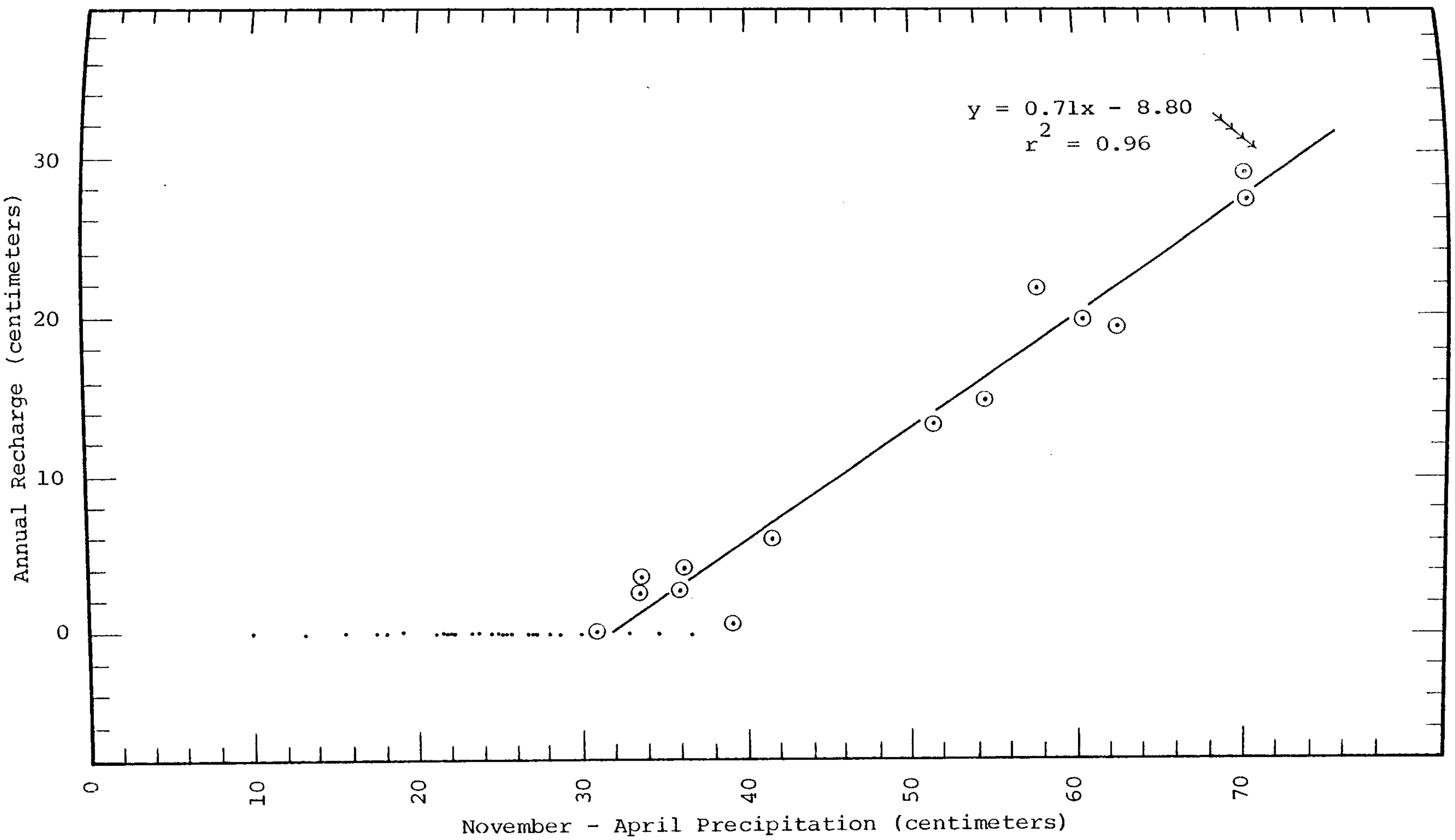


Figure 29. Graph Showing the Relationship Between the November Through April Precipitation Recorded at Boulevard and the Calculated Annual Recharge

37.62 centimeters of precipitation in Boulevard, but no recharge. The November through April precipitation for 1965-1966 was 36.27 centimeters and for 1974-1975 was 27.03 centimeters. This relationship between the November through April precipitation and calculated ground water recharge strongly suggests that the estimation of recharge in the semi-arid regions of southern California should be based on the November through April precipitation and not yearly precipitation records.

Possible Errors

The calculated ground water recharge can only be considered an estimate of the real ground water recharge. The numerous variables involved in the calculations and the generally scanty data mean that there could be considerable error.

Precipitation. Precipitation is the first variable involved in the recharge calculations. Generally, the available data from Boulevard and Jacumba are good and not likely subject to significant error. Although the forty-eight years of Boulevard precipitation records includes a large period of below normal precipitation, the mean annual precipitation is not very different from the mean calculated from the extrapolated data: 38.4 centimeters for the available data and 40.6 centimeters for the extrapolated data. The same is true for the Jacumba data. The aspect of the precipitation data, or lack of it, that is most likely to cause error is the fact that the precipitation for the entire Jacumba

Valley watershed is based on only two stations. The isohyetal lines drawn in Figure 2 (page 12) were modified from Hely and Peck (1964), but those authors had little data control from which to draw their lines in the Jacumba Valley area. This lack of control was not a serious problem for Hely and Peck because of the scale of their study. However, at the scale of this study, the amount of precipitation falling on the watershed significantly affects the calculated recharge. In modifying Hely and Peck's map, the lines were placed such that error would probably result in underestimating the precipitation for a particular location. However, if the 30.5-centimeter isohyetal line were shifted east or west by about 1 kilometer, the resulting change in the calculated recharge would be about 10%. Because the percentage of precipitation that recharges the ground water increases with increasing precipitation, variations in the precipitation could have a significant affect on the ground water recharge.

Runoff. The assumptions made regarding the occurrence of runoff and the affect that runoff has on ground water recharge were based on limited data. The estimates of recharge due to runoff were conservative. Because runoff only rarely discharges into Carrizo Gorge, the direct loss to the watershed is probably minimal. The most likely source of error related to runoff is the assumption that runoff does not occur during individual precipitation events unless over 40 centimeters of precipitation has fallen. There is not enough information available to quantify the possible error.

Potential evapotranspiration. As stated earlier, the closest evaporation station to Jacumba Valley is Lake Morena, California. This station's elevation and general climate are similar to Jacumba's, but Jacumba Valley is located on the east side of the mountains, is closer to the desert, and often has a strong wind blowing through the area. These factors could make a significant difference in the pan evaporation. The lack of data for this part of San Diego County makes it difficult to judge the possible error caused by the remote evaporation data.

The coefficient used to relate pan evaporation to natural evapotranspiration is based on a value Crippen (1965) used for the Southern California mountains. It is not specific to the Jacumba area and the local variations in evapotranspiration could be significant. It was not possible to make an estimate of the error in the ground water recharge calculations that may be caused by the potential evapotranspiration data.

Soils. As with the other variables involved in the calculated recharge, the soil moisture deficiency is based on limited data. As explained earlier, the soil classification used for this study was based on eleven soil samples. Although the values of the specific retention are similar to others obtained from tests in San Diego County (Huntley, personal communication, 1980), there is potential for error. A 10% increase in the specific retention of type X soil would result in a 10-15% decrease in the total calculated ground water recharge (Appendix E). The available water holding capacities of the United States Soil Conservation Service and Forest Service (1973) soils are much lower than the specific retention values determined by this author. Part of the reason for this difference may be that the United States Soil Conservation Service measured the water holding capacity down to the wilting point, while the tests for this study measured the specific retention compared to a dried sample. Recharge calculations based on the United States Soil Conservation Service's hydrologic groups, using their available water holding capacities and a 91-centimeter (36 inches) active soil depth, were made for the Jacumba Valley watershed (Appendix E). The mean annual calculated recharge was between 5.0×10^6 and 7.0×10^6 cubic meters (4000-5700 acre-feet). This is a significantly more liberal estimation of ground water recharge than that based on this report's soil types. Because it is possible for the soil moisture content to drop below the wilting point, the calculated recharge based on soil types W, X, Y, and Z is probably more accurate. The above values do give an indication of the possible error involved with the determination of the soil's hydrologic properties.

Error is also possible in determining the active soil depth. For example, if the active soil depth developed on the crystalline basement, type X, was 76 centimeters instead of

61 centimeters, the total calculated mean recharge would be reduced by about 30% (Appendix E). As with the other variables, the assumed active soil depths were considered to be conservatively high choices based on the available data.

The amount of area covered by the different soil types could also affect the recharge calculations. Type W and X soils are very similar in their soil moisture deficiencies, so the discrepancies in the amount of area covered by one or the other would not result in a significant error in the calculated recharge. However, differences in the area covered by soils W and X as compared to soils Y and Z would result in significant differences in the calculated recharge. Because the soil types were mapped primarily on the basis of lithology and geomorphology, with only limited field reconnaissance, there is undoubtedly error in the estimation of the area covered by each soil type. It was not possible to determine the potential error with the available information.

It is obvious from the above discussion that the combined potentional error could render the calculated ground water recharge meaningless. However, it is the belief of the author that the values used and the assumptions made during the calculations are the best possible considering the available information. Generally, the values chosen for the calculations were such that the calculated recharge would err by underestimating rather than overestimating the ground water recharge to the Jacumba Valley watershed.

Ground Water Budget

Recharge

The only known inflow into the Jacumba Valley ground water system is the recharge from precipitation that occurs in the watershed. It is assumed that virtually all of the ground water recharged in the surrounding hills and mountains eventually moves to the valley. The total inflow is about 3.39×10^6 cubic meters (2700 acre-feet) per year.

Ground Water Loss

There is little data available to determine the actual water loss from Jacumba Valley, but an estimate can be made. Current loss to the valley's ground water system is through evapotranspiration, surface and subsurface flow, and water use by residents of the watershed.

Human use. The private water company that supplies the town of Jacumba kept records for the year 1978 on the water used by the town's 120 hookups (Jacumba Associates, personal communication, 1980). These records show that 74,000 cubic meters (60 acre-feet) were used. This company supplies water to one third to one half of the residents of the watershed. The entire population of the watershed probably uses 140,000-150,000 cubic meters. This estimate may be high because the Mexican residents of the area tend to use less water than the Americans. Assuming that about 40% of this water is returned to the ground water system through septic systems and infiltration from irrigation, an estimate of 75,000-100,000 cubic meters (60-80 acre-feet) per year of ground water loss due to use by humans would be reasonable. During the 1950's and 1960's, water use by humans was greater due to extensive irrigation and the construction of Interstate 8.

Evapotranspiration. The water loss through evaporation and transpiration associated with the springs located in and around Jacumba Valley, excepting those springs at the north end of the valley, is not significant. The majority of ground water loss from Jacumba Valley occurs at the north end of the valley. There the evapotranspiration from the growth of phreatophytes is fed by the northward flow of the ground water in the valley's aquifers. The phreatophytes at the north end of the valley can potentially use 480,000-780,000 cubic meters/year (390-630 acre-feet/year). This is based on the 240,000-390,000 square meters that were estimated to be covered by dense phreatophyte growth, and an assumed annual use of 2.0 meters. The estimated water use by the phreatophytes is a rough average of the use by salt ceder, a very high water user, and mesquite as presented by Robinson (1958) and Davis and DeWiest (1966). The water use by the phreatophytes will vary depending on the elevation of the water table in the valley and the weather.

Subsurface discharge. The subsurface flow into the bedrock at the north end of Jacumba Valley is controlled by the hydraulic conductivity of and the hydraulic gradient in the bedrock there. Because the hydraulic conductivity of the bedrock is not known, the subsurface flow into the bedrock was estimated based on the potential flow through the valley's aquifers north of Interstate 8.

In the area north of Interstate 8, the alluvial aquifer is about 450 meters wide and has an estimated saturated thickness of 5 meters. The hydraulic conductivity of the aquifer, as determined by the pump test on well J1, is 170 meters/day. Using the alluvial aquifer hydraulic gradient measured in November, 1979, 4.9 meters/kilometer, the estimated subsurface flow through the aquifer north of the interstate is about 700,000 cubic meters/year (570 acre-feet/year) (Appendix G). The maximum possible flow, based on the hydraulic gradient of 7.5 meters/kilometer, for the highest water levels on record in 1955, is about 1,048,000 cubic meters/year (850 acre-feet/year) (Appendix G).

The cross-sectional area of the Table Mountain aquifer in the vicinity of Interstate 8 is estimated to be 216,000 square meters. The hydraulic conductivity of the aquifer, as determined by the pump test on well R2, is 4.13×10^{-3} meters/day. The hydraulic gradient in April, 1980 between well R1 and the bottom of the aquifer north of Interstate 8 was about 45 meters/kilometer. This gradient was used under the assumption that water flowed into the bedrock throughout the entire thickness of the aquifer. The estimated ground water flow through the Table Mountain aquifer is roughly 15,000 cubic meters/year (12 acre-feet/year)(Appendix G).

These values of subsurface flow from the aquifers into the bedrock are maximum possible values. The hydraulic conductivity of the alluvial aquifer at the north end of the valley is probably lower than the 170 meters/day determined in the vicinity of well J1 because the alluvium appears to be finer. Also, the hydraulic conductivity of the bedrock is probably significantly less than that of either aquifer. Therefore, the actual subsurface discharge into the bedrock will probably be less than the 715,000-1,063,000 cubic meters/year (580-860 acre-feet/year) combined flow estimated above. This low rate of subsurface flow into the bedrock will be a factor in causing the water table in the valley to rise. The ground water flow in the aquifers that is not able to discharge into the bedrock will eventually be discharged from the springs at the north end of Jacumba Valley.

Springs. The discharge from the Jacumba Valley ground water system through springs at the north end varies depending on the water level in the valley. During much of the period of study, only spring "C" discharged, at a rate of about 4,000 cubic meters/year (3 acre-feet/year). By May, 1980, the combined discharge of the three springs had risen to roughly 90,000 cubic meters/year (73 acre-feet/year). In September, the estimated discharge of the three springs was about 30,000 cubic meters/year (24 acre-feet/year). This flow was primarily from spring "C."

Ground water budget. When the springs at the north end of Jacumba Valley are not flowing, the maximum net discharge from the valley's ground water system through evapotranspiration and subsurface flow into the bedrock is 1,195,000-1,843,000 cubic meters/year (970-1500 acre-feet/year). With this discharge the valley's ground water budget shows a net increase of 1,547,000-2,195,000 cubic meters/year (1250-1780 acre-feet/year). When current human use is included, the annual ground water discharge is 1,270,000-1,943,000 cubic meters (1030-1580 acre-feet), with a resulting net ground water budget increase of 1,447,000-2,210,000 cubic meters/year (1170-1720 acre-feet/year).

A ground water budget for the twenty-four year period between 1955 and the fall of 1979 was estimated using water level records and the ground water recharge calculations (Appendix G). For that period, the alluvial aquifer lost between 3,9000,000-6,000,000 cubic meters (3160-4860 acre-feet) of stored water due to a decline in the water table of about 9 meters. The calculated ground water recharge during that period was roughly 2,680,000 cubic meters (21,700 acre-feet)(Appendix G). This value of recharge assumed that all of the ground water recharge that occurred in the watershed during the water year 1977-1978 had reached Jacumba Valley and that the 1978-1979 recharge had not reached the valley. The actual conditions probably entailed part of the 1977-1978 recharge still in watershed still moving toward the valley, and a portion of the 1978-1979 recharge having already reached the valley. Because this ground water budget is only an estimate, this assumption is considered valid. Therefore, the ground water budget for this twenty-four year period had a net discharge of 30,700,000-32,800,000 cubic meters (24,900-26,600 acre-feet). Averaged over the twenty-four years, the annual loss was 1,300,000-1,400,000 cubic meters (1040-1110 acre-feet). This value falls within the range of 1,270,000-1,943,000 cubic meters/year (1030-1580 acre-feet/year) loss estimated above. The estimated ground water budget for 1955-1979 did not consider the discharge to the Table Mountain aquifer because of the lack of information.

Over long periods of time, when the ground water in the valley is not disturbed by human activities, the water budget of Jacumba Valley will be balanced. The ground water not lost through evapotranspiration and subsurface flow into the bedrock, is lost through discharge from the springs at the north end of the valley. During shorter periods of time, the ground water budget of the valley could show a net loss or a net increase, depending on the amount of ground water recharge entering the valley at the time.

During the period of this study the ground water budget of Jacumba Valley was showing a net increase, as evidenced by the rising water table in the valley. The water budget will probably continue to show a net increase until the recharge rate decreases significantly and/or the springs at the north end of the valley flow at a markedly increased rate. If the residents of

Jacumba Valley were to artificially maintain the water table in the valley at a level that would not allow the springs to flow, the valley ground water system would not naturally balance its budget by discharging ground water from the springs. Thus, the 1,547,000-2,195,000 cubic meters/year (1254-1780 acre-feet/year) of ground water recharge not lost by evapotranspiration and sub-surface flow into the bedrock would be available for human use. This would not cause mining of the ground water stored in the aquifers.

The above values of water loss are estimated and more accurate determination of the ground water budget should proceed any detailed water use planning for the Jacumba Valley watershed.

The thermal springs in Jacumba Valley may circulate ground water derived from the Jacumba Valley watershed. Even though this water is not lost to the valley's ground water system, its changed chemistry makes it of poor quality for public use. This thermal water could be considered a loss to the useable ground water supply, though at the present time contamination problems are minor. The thermal springs are currently flowing at a combined rate of about 250,000 cubic meters/year (200 acre-feet/year).

The fact that Jacumba Valley straddles the international boundary between the United States and Mexico does not alter the ground water budget of the valley, but it could affect the amount of water available for use by each side. About half of the valley's calculated mean annual ground water recharge, 1,600,000 cubic meters

(1300 acre-feet), occurs in the United States and in the Boundary Creek drainage which enters the valley on the United States side of the border. About 1,360,000 cubic meters/year (1100 acre-feet/year) actually infiltrates into the ground on the United States side of the watershed. Over three fourths of the saturated portions of the two aquifers are located on the United States side of the valley. At the present time, the residents of the United States have developed the ground water resources, whereas the Mexicans get most of their water from the springs to the west of Jacumé. If either country attempted to maximize their use of ground water by using all of the ground water annually recharged or by mining the water stored in the aquifers, it would seriously affect the water supply available to the other country. If extensive development of either side of the valley is planned, it would save much trouble if the problems of water rights were first discussed.

Chapter 4

THE THERMAL SPRINGS OF JACUMBA VALLEY

Location and Description

The thermal springs of Jacumba Valley have been known and used for many years. The number of springs has varied over time, but they have generally been located in two areas (Figure 30). On the United States side of the valley, the springs have been located in the area that is now the western side of the town of Jacumba. The main spring was located in the immediate vicinity of well JHS. Waring (1915) reported a flow rate of about 60 liters/minute and a temperature of 36°C for the main spring. The thermal waters from this main spring are currently being brought to the surface by a 61-meter well that was drilled and cased through alluvium and ended in bedrock (County of San Diego, Department of Public Health, personal communication, 1980). When the well was drilled in 1955, it was flowing at a rate of 280 liters/minute and the water reportedly reached 3.5 meters into the air (San Diego Union, 1955). The water temperature was 40.5°C. Thesken (1977) reported a flow rate as 470 liters/minute and a temperature of 38°C. In the past, other thermal springs were located on the west side of Jacumba, but they are no longer active (Figure 30). The springs issued from alluvium, but are near outcrops of crystalline bedrock.

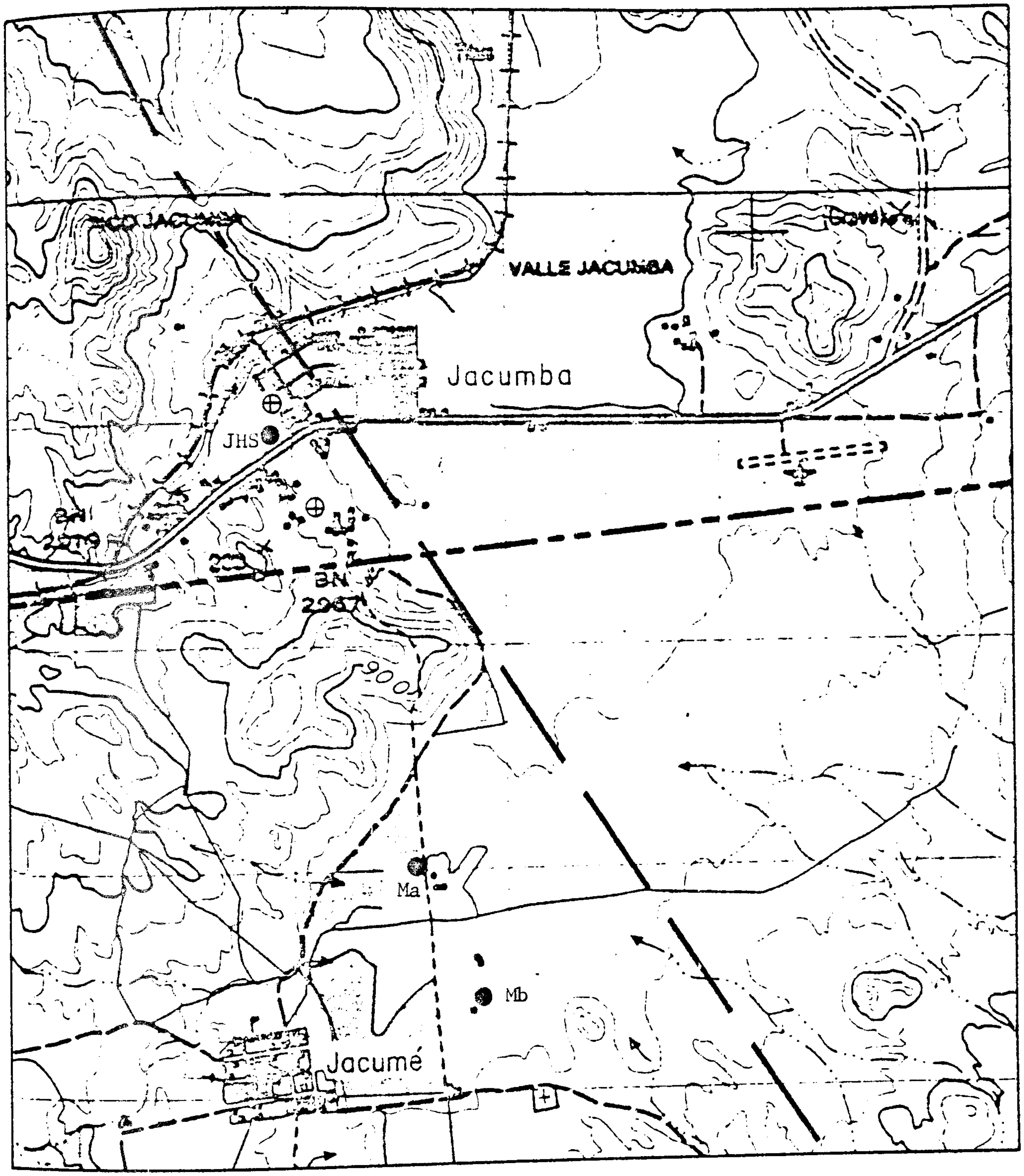


Figure 30. Location of Thermal Springs and Well JHS in Jacumba Valley. Thick dashed line is the inferred position of the northwest trending fault "a" in Figure 9 (page 31). (Scale 1:28,000.)

● Active thermal spring or well

⊕ Inactive thermal spring

▬▬ Fault

N

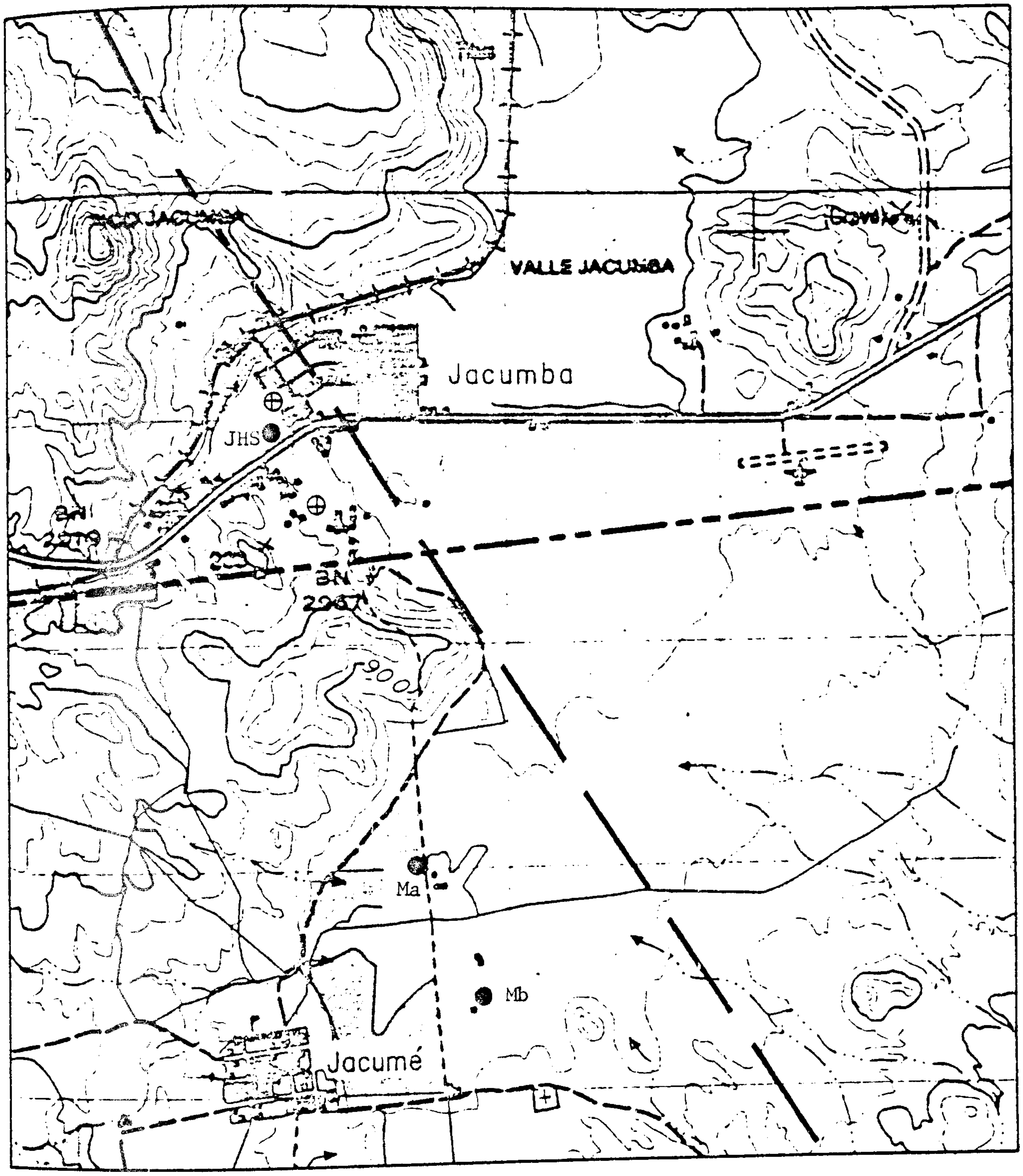


Figure 30. Location of Thermal Springs and Well JHS in Jacumba Valley. Thick dashed line is the inferred position of the northwest trending fault "a" in Figure 9 (page 31). (Scale 1:28,000.)

● Active thermal spring or well

⊕ Inactive thermal spring

━━ Fault

N

The Mexican thermal springs are located to the northeast of the town of Jacumé (Figure 30). These springs are undeveloped and, at the present time, exist only as standing pools of water or minor seeps flowing at less than 3 liters/minute. The water is cool. According to historical reports and residents of the valley, these springs at one time flowed at sufficient rates to be warm and were good for bathing. As with the United States springs, the Mexican springs occur in alluvial material close to crystalline bedrock outcrops.

Chemistry

The chemistry of the thermal waters on the United States side of the valley has been tested a number of times. The water of the main Jacumba Hot Spring was tested in 1915 by Waring, in 1960 by the town of Jacumba (County of San Diego, Department of Public Health, personal communication, 1980), and in 1977 by Thesken. For this study, the author analyzed thermal waters from well JHS and springs Ma and Mb in Mexico (Appendix K). All of the samples of the United States thermal waters are similar, with high silica content and a dominance of sodium (Figures 31 and 32). Figures 31 and 32 also have a ground water sample, well J3A, plotted for reference. There is no evidence of significant change in the chemistry over the past sixty-five years. The Mexican thermal springs have generally similar chemistry, except that their position on the Piper diagram indicates some contamination

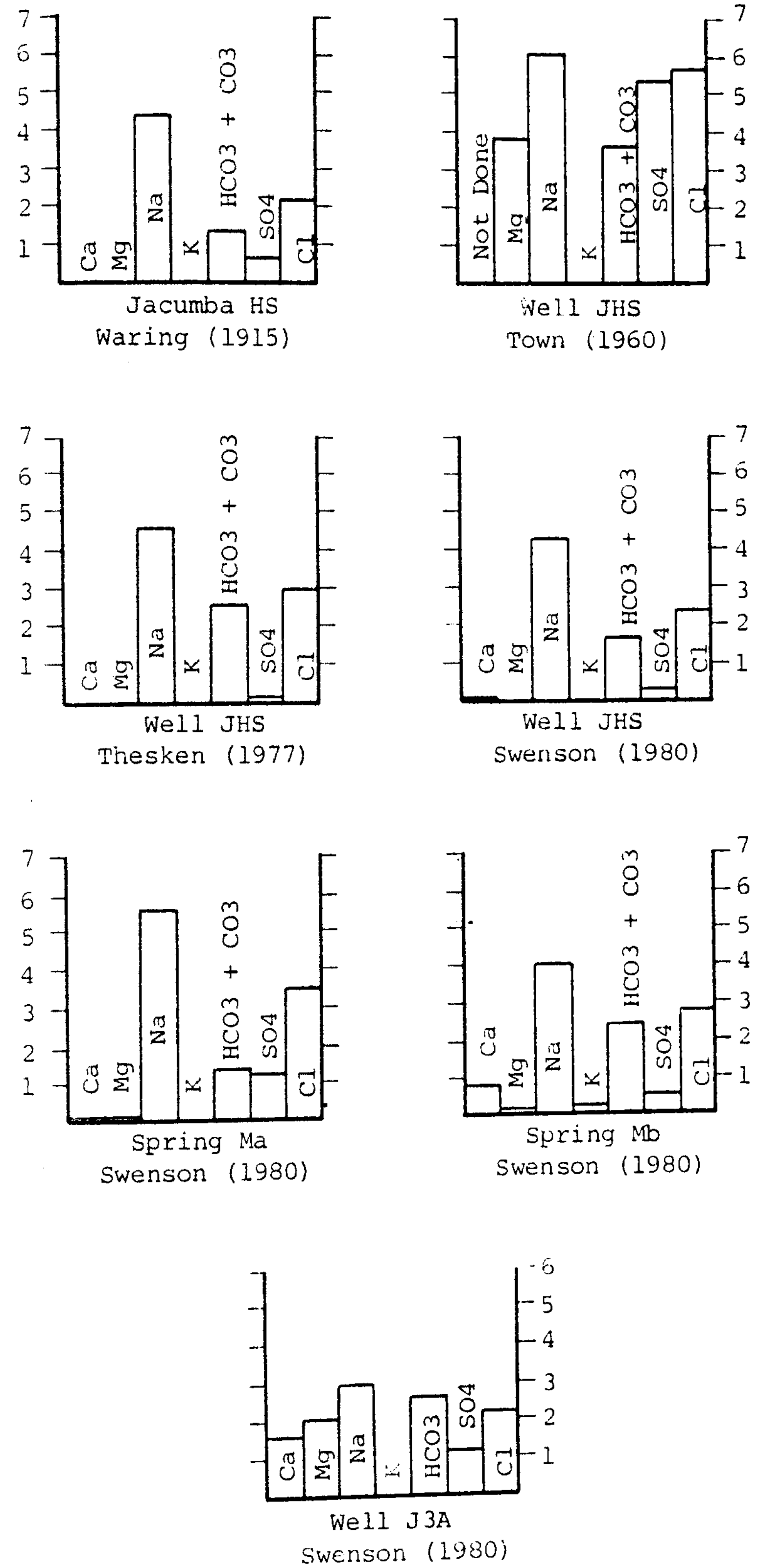


Figure 31. Histogram of Major Cations and Anions for All Analyses Performed on Thermal Waters in Jacumba Valley. Scales are in milligrams per liter.

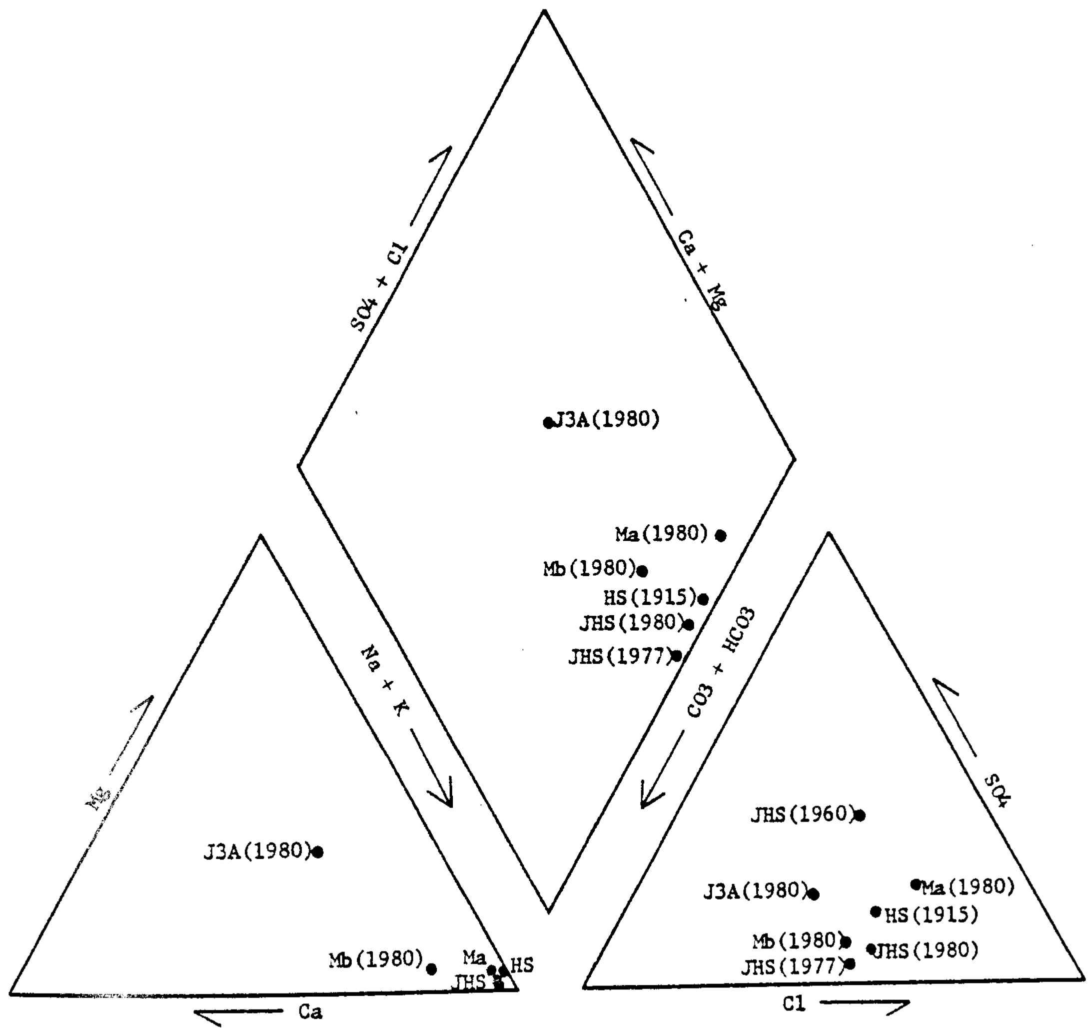


Figure 32. Piper Diagram of All Analyses of the Thermal Waters in Jacumba Valley. Sample J3A is included for reference.

due to mixing with the cold ground waters (Figures 31 and 32).

Temperature at Depth

Richard Thesken (1977), in his chemical study of the Jacumba Hot Spring and the nonthermal ground water in the valley, concluded that there was no mixing of the thermal waters with the ground water. This is not surprising because the well he sampled is cased to prevent mixing. He estimated the temperature at depth as 91°C, and concluded that water circulating to a depth of about 1,000 meters under a normal geothermal gradient would account for this temperature.

Hydrology of the Thermal Springs

The thermal springs of Jacumba Valley all occur to the west of the northwest trending fault which passes through Jacumba (Figure 30, page 133). Although they are not located along the trace of the fault, their position, along with the fact that the water in the Table Mountain aquifer does not show any thermal contamination, suggests that the fault restricts the movement of the thermal water by acting as an aquitard. That the springs occur in two specific areas, and not all along the fault, suggests that the intersection of another regional structure with the fault may control the position of the springs. Aerial photographs of the plutonic terrain to the west of Jacumba Valley show numerous, well-developed, east-west fractures (see Plate I, page 25).

These fractures may be the regional structures which intersect the fault and control the position of the thermal springs. It is possible that some of the fractures have better hydraulic conductivity than others, thereby further restricting the location of the springs.

The principal area of ground water recharge for Jacumba Valley is to the west of the valley; consequently, this would be the prime source of ground water for the thermal springs. This author proposes that the ground water recharges the thermal system along some of the regional fractures to the west of Jacumba Valley. The ground water circulates to depth along these fractures, is heated, and then moves upward when the fractures intersect the fault (Figure 33). These springs are artesian because the ground water recharge source is in the hills to the west of the valley.

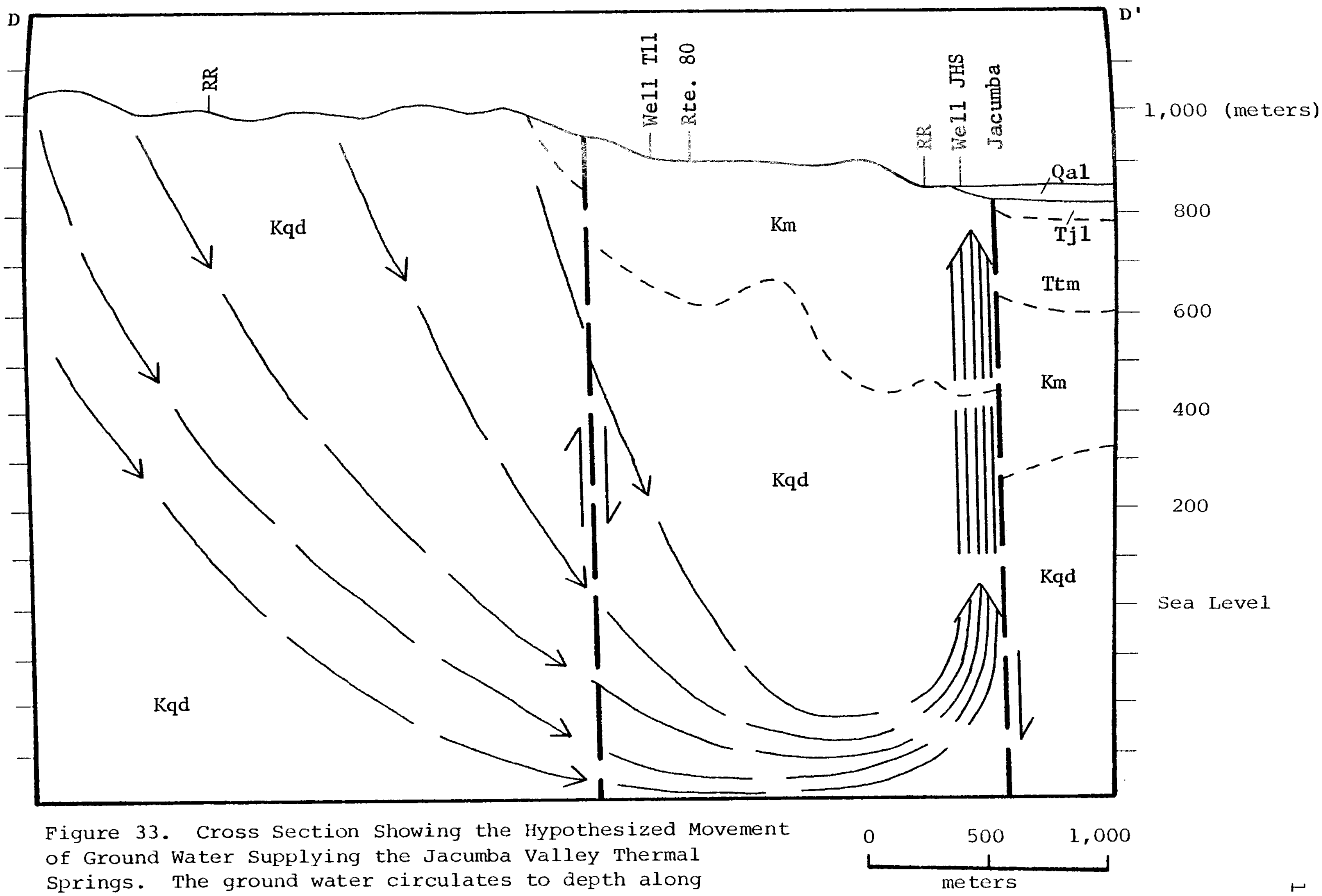


Figure 33. Cross Section Showing the Hypothesized Movement of Ground Water Supplying the Jacumba Valley Thermal Springs. The ground water circulates to depth along regional fractures, then rises to the surface in the vicinity of fault "a" in Figure 9 (page 31).

Chapter 5

FUTURE STUDIES AND CONCLUSIONS

Future Studies

Future hydrologic studies in the Jacumba Valley watershed should focus on obtaining quantitative information. This study was severely limited by the lack of data in all areas. Extensive pump tests in both aquifers in the valley, more geophysical surveys of the valley, and extended monitoring of the water levels in wells would provide a much more accurate understanding of the Jacumba Valley aquifers. By more accurately determining the variables involved in the ground water recharge calculations (potential evapotranspiration, soil moisture deficiency, surface runoff, and area-wide precipitation), the input portion of the ground water budget can be further refined. There is a real need to determine the loss to the ground water system of Jacumba Valley. At the current time, the values used for loss in the ground water budget are crude estimates. Because this loss, especially at the north end of the valley, plays a major role in determining the ground water budget, it is vital to understand it better. Future studies designed to provide a more accurate model of the ground water system of Jacumba Valley would allow sustained use and protection of the resource for a long time.

A limited program of monitoring the water levels in wells by the residents of the valley would not only provide a valuable record for future studies, but would enable residents to monitor their water supply and understand some of the fluctuations that occur. This would probably help them to better manage their water supply.

Considerably more study of the thermal springs in Jacumba Valley is needed to determine their nature and potential for development.

Conclusions

Three different aquifers provide water to the residents of the Jacumba Valley watershed. The crystalline basement terrain surrounding the valley provides water for domestic supplies. This water comes primarily from fractures, commonly shallow, erosion stress-relief fractures. The well yields from this terrain can be quite variable. This aquifer has adequate hydraulic conductivity and storage capacity for use by individual households, but it is unlikely that it would be capable of sustaining extensive development.

The alluvial aquifer in Jacumba Valley presently supplies the majority of the water used by the residents of the valley. The ease of drilling wells, the relatively shallow water table, and the high transmissivity of the aquifer, 1.98 $meter^2$/minute, have encouraged the development of this aquifer. This aquifer has only a limited amount of available water in storage, between 3,940,000-7,890,000 cubic meters (3200-6400 acre-feet). This limited storage capacity was a factor in threats to the water supply of Jacumba during the 1960's.

The largest aquifer in Jacumba Valley, and the least used one, is the Table Mountain aquifer. It has an estimated 104,000,000-207,000,000 cubic meters (84,000-168,000 acre-feet) of recoverable water stored in it. Development of this aquifer is more difficult. Throughout most of the United States side of the valley, where the Table Mountain aquifer is the thickest (200 meters), this aquifer is overlain by up to 80 meters of alluvium and volcanics. The transmissivity of this aquifer is low, 4.3×10^{-4} $meter^2/minute$, thus requiring numerous wells for extensive development.

About 90% of the ground water recharge for Jacumba Valley occurs in the hills and mountains surrounding the valley. This recharge reaches the valley in two manners. A major portion of the water enters a shallow ground water system in the mountains. This system of residual soils and stress-relief fractures causes the ground water to follow the shape of the surface topography as it moves toward the valley. Much of this ground water enters Jacumba Valley as subsurface flow in drainages such as Boundary Creek. The Jacumba and Jacumé cold springs are fed by this ground water recharge. The second manner in which ground water recharge reaches the valley is through deep regional fractures. This system of deep fractures also feeds the thermal springs in the valley.

Once the water has entered the valley's aquifers, it moves north toward the head of Carrizo Gorge. At the north end of Jacumba Valley, the ground water is discharged by evapotranspiration by phreatophytes, subsurface flow into the bedrock, and surface flow from springs.

The calculated mean annual ground water recharge for the Jacumba Valley watershed is 3,390,000 cubic meters (2700 acre-feet). It is assumed that the majority of this recharge eventually reaches the valley. The recharge calculations took into consideration the following variables: monthly precipitation in the valley and watershed, the potential evapotranspiration, the soil moisture deficiency, and the surface runoff. Recharge does not occur every year or in regular amounts. Recharge only occurs during the winter months of November through April. There is good correlation between the November through April precipitation and the yearly calculated recharge. Until the November through April precipitation reaches about 30 centimeters, there is no recharge. After that threshold is passed, the percentage of precipitation that recharges the ground increases with increasing precipitation.

When viewed over a long period of time, the ground water budget of Jacumba Valley is balanced. The total recharge equals the total loss through evapotranspiration, subsurface flow into the bedrock, and surface discharge from springs. For shorter periods of time, up to thirty years, there can be considerable variation in the budget. During periods of below normal ground water recharge, the budget will suffer a deficit, and during periods of above normal recharge, the budget will show an increase in available water. The estimated annual loss through evapotranspiration and subsurface flow into the bedrock at the head of Carrizo Gorge is 1,195,000-1,843,000 cubic meters (970-1500 acre-feet). This loss assumes that the springs at the north end of the valley are inactive. This estimated loss would result in an annual net increase of 1,547,000-2,195,000 cubic meters (1250-1780 acre-feet) providing the springs remain inactive. With no interference by humans, this increase is eventually lost through discharge from the springs at the north end of the valley. If the water table in the valley were artificially maintained at a low enough level to minimize the flow from the springs, the 1,547,000-2,195,000 cubic meters would be available for human use without overtaxing the ground water system. Extensive development of the ground water resources by either the United States or Mexico could impair the water supply of the other country.

Much of the quantitative information presented in this report was arrived at with limited supporting data. While the model of the ground water hydrology of Jacumba Valley is considered valid, more detailed quantitative study of the area should be done if the development of the ground water resources is to be maximized.

REFERENCES CITED

REFERENCES CITED

American Public Health Association, 1976, Standard methods for the examination of water and waste water, (4th ed.): Washington, D.C., American Public Health Association, 651 p.

Babcock, B. A., 1958, Ground water occurrences and quality, San Diego County: Unpublished Master's Thesis, University of Southern California, 123 p.

Bailey, C. A., n.d., Notes on Jacumba: On file in the San Diego Historical Society Library and Manuscript Collection, 5 p.

Brooks, B., and Roberts, E., 1954, Geology of the Jacumba area, San Diego and Imperial Counties, in Jahns, R. H., ed., Geology of southern California: Calif. Div. Mines and Geology Bull. 170, map sheet 23.

Brown, J. S., 1923, The Salton Sea region, California: U.S. Geol. Survey Water-Supply Paper 497, 292 p.

California Department of Water Resources, 1974, Evaporation from water surfaces in California: Calif. Dept. Water Resources Bull., v. 73-1, p. 170.

Carslaw, H. S., and Jaeger, J. C., 1951, Conduction of heat in solids, (2d ed.): Oxford, Oxford at the Claredon Press, pp. 64-70.

Chebotarev, I. I., 1955, Metamorphism of natural waters in the crust of weathering: Geochim. et Cosmochim. Acta, v. 8, pp. 22-48, 137-170, 198-212.

Chow, Ven Te, ed., 1964, Handbook of applied hydrology; a compendium of water resources technology: New York, McGraw-Hill Book Co., 876 p.

Close, H., ed., 1970, Climates of San Diego County, agricultural relationships: University of California Agricultural Extension Service in Cooperation with Environmental Sciences Services Administration and U.S. Weather Bureau, 128 p.

Comision de Estudios del Territorio Nacional, 1977, La Rumerosa 111D63 and Neji 111D73 geologic maps: Mexico, Secretaria de Programacion y Presupuesto.

County of San Diego, 1977, Generalized vegetation map: Department of Transportation (mapping section).

Crippen, J. R., 1965, Natural water loss and recoverable water in mountain basins of southern California: U.S. Geological Survey Prof. Paper 417-E, 24 p.

Davis, S. N., and DeWiest, R. J. M., 1966, Hydrogeology: New York, John Wiley & Sons, Inc., 463 p.

Detzer, J. E., 1973, Jacumba: mountain empire town with bibles and bullets on the border: San Diego, by the Author, 19 pp.

Dibblee, T. W., 1954, Geology of the Imperial Valley region, California, in Jahns, R. H., ed., Geology of southern California: California Div. Mines and Geology Bull., v. 170, pp. 21-28.

Dominico, P. A., 1972, Concepts and models in groundwater hydrology: New York, McGraw-Hill Book Co., 405 p.

Ellis, A. J., and Lee, H., 1919, Geology and ground waters of the western part of San Diego County, California: U.S. Geol. Survey Water-Supply Paper 446, 321 p.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall Inc., 437 p.

Ganus, W. J., 1973, Problems related to the evaluation of ground-water resources of the crystalline rock area, San Diego County, in Ross, A., and Dowland R., eds., Studies on the geology and geologic hazards of the greater San Diego area, California: San Diego Association of Geologists Guidebook, pp. 111-118.

Hach Chemical Company, 1973, Hach methods manual, (9th ed.): Ames, Iowa, by the Author, 119 p.

Hawkins, J. W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, southern California and Baja California: Geol. Society of America Bull., v. 81, pp. 3323-3338.

Hely, A. G., and Peck, E. L., 1964, Precipitation, runoff and water loss in the lower Colorado River-Salton Sea area: U.S. Geol. Survey Prof. Paper 486-B, 16 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Hileman, J. A., Allen, C. R., and Nordquist, J. M., 1973, Seismicity of the southern California region: 1 January 1932 to 31 December 1972: Pasadena, Calif. Institute of Technology, Seismological Laboratory, 453 p.

Jahns, R. H., 1954, Geology of Peninsular Range Province, southern California and Baja California: Calif. Div. Mines and Geology Bull., v. 170, chap. 2, pp. 29-52.

Kelly, J. L., n.d., Life on a San Diego County ranch: Notes on file in the San Diego Historical Society, Library and Manuscript Collection, 21 p.

Larsen, E. S., Jr., Everhart, D. L., and Merrian, R., 1951, Crystalline rocks of southwestern California: Calif. Div. Mines Bull., v. 159, 136 p.

Meinzer, O. E., 1927, Plants as indicators of ground water: U.S. Geol. Survey Water-Supply Paper 577, 95 p.

Merrian, R., 1951, Groundwater in bedrock in western San Diego County, California: Calif. Div. Mines Bull., v. 159, pp. 117-235.

Miller, W. J., 1935, Geomorphology of the southern Peninsular Range of California: Geol. Society of America Bull., v. 46, pp. 1535-1561.

Minch, J. A., 1970, Early Tertiary paleogeography of a portion of the northern Peninsular Range, in Pacific slope geology of northern Baja California and adjacent Alta California: Am. Assoc. of Petroleum Geologists (Pacific Section), Fall Field Trip Guidebook, pp. 83-87.

________, 1972, The late Mesozoic-early Tertiary framework of continental sedimentation, northern Peninsular Ranges, Baja California, Mexico: Unpublished Doctoral Dissertation, University of California, Riverside, 223 p.

Minch, J. A., and Abbott, P. L., 1973, Post-batholithic geology of the Jacumba area, southeastern San Diego County, California: Transactions of the San Diego Society of Natural History, v. 17, no. 11, pp. 129-135.

Peterson, G. L., and Abbott, P. L., 1973, Weathering of the pre-Eocene terrane along coastal southwestern California and northwestern Baja California, in Ross, A., and Dowland, R., eds., Studies on the geology and geologic hazards of the greater San Diego area, California: San Diego Association of Geologists Guidebook, pp. 19-22.

Peterson, G. L., Gastil, R. G., and Allison, E. C., 1970, Geology of the Peninsular Ranges: Calif. Div. Mines and Geology, Mineral Info Service, v. 23, pp. 124-127.

Robinson, T. W., 1958, Phreatophytes: U.S. Geol. Survey Water-Supply Paper 1423, 84 p.

San Diego Union, October 24, 1868.

________, July 12, 1925.

________, March 25, 1934.

________, March 10, 1954.

________, January 7, 1955.

________, December 15, 1956.

________, January 6, 1957.

________, December 10, 1957.

________, July 1, 1959.

________, July 23, 1959.

________, November 17, 1963.

________, July 5, 1964.

________, July 13, 1975.

Stewart, J. W., 1962, Relation of permeability and jointing in crystalline metamorphic rocks near Jonesboro, Georgia: U.S. Geol. Survey Prof. Paper 450-D, pp. 168-170.

Thesken, R., 1977, A geochemical study of a hot spring and well waters in Jacumba, California: Unpublished Senior Report, San Diego State University, 53 p.

Todd, D, K., 1959, Ground-water hydrology: New York, John Wiley and Sons, Inc., 336 p.

United States Environmental Sciences Services Administration, monthly issues beginning in 1965, Climatological data: California: U.S. Environmental Sciences Services Administration.

United States Soil Conservation Service and Forest Service, 1973, Soil survey, San Diego, California: U.S. Dept. of Agriculture in cooperation with the University of California Agricultural Experimental Station, 387 p.

United States Weather Bureau, monthly issues from 1931 through 1965, Climatological data: California: U.S. Department of Commerce.

Walpole, R. E., and Myers, R. H., 1972, Probability and statistics for engineers and scientists: New York, Macmillan Publishing Co., Inc., 512 p.

Waring, G. A., 1915, Springs of California: U.S. Geol. Survey Water-Supply Paper 338, 410 p.

Webber, P., 1979, Vegetation and environmental data from San Diego County, unprocessed data--130 stands: Unpublished data, used with permission.

Weber, F. H., 1963, Geology and mineral resources of San Diego County, California: Calif. Div. Mines and Geology, County Report 3, 309 p.

Zohdy, A. A. R., 1973, A computer program for the automatic interpretation of Schlumberger sounding curves over horizontally stratified media: Springfield, VA, Rep. PB-232703/AS Nat. Technical Information Service.

Zohdy, A. A. R., Eaton, G. P., and Mabey, D. R., 1974, Application of surface geophysics to ground-water investigations, techniques of water-resources investigations of the United States Geological Survey: Washington, D.C., U.S. Government Printing Office, 116 p.

APPENDICES

APPENDIX A

METEROLOGIC DATA

Jacumba Monthly Precipitation Records (County of San Diego, 1980, personal communication)

Water Year	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Total
1962-1963									1.18	0.60	0	0	
1963-1964	0	0	1.02	2.46	0.33	0.20	1.06	0.70	1.68	0.15	0.35	0	7.95
1964-1965	0	0	0	0.36	0.88	0.55	0.21	1.21	0.05	2.38	0	0	5.64
1965-1966	0.35	0.31	0.08	0	3.82	4.03	2.00	1.38	0.74	0	0	0	12.71
1966-1967	0.46	0.25	0	1.45	0.42	3.68	0.87	0	0.43	2.13	0.04	0	9.73
1967-1968	0.25	0.33	1.50	0	2.38	3.83	0.07	0.28	0.81	0.75	T	0	10.20
1968-1969	1.71	0.12	0	0.11	0.29	0.91	2.43	2.18	0.77	0.11	0.40	0	9.03
1969-1970	1.77	0.02	0.29	0	1.38	0.19	0.27	1.81	2.93	0.48	0	0.03	9.17
1970-1971	0.08	1.43	0.04	0.32	0.82	2.14	0.71	0.75	0.26	0.69	0.07	0	7.31
1971-1972	0.10	1.32	0.14	0.56	0.02	1.68	0	0.03	0	0.09	0.05	0.47	4.46
1972-1973	0.01	0	0.01	1.78	1.40	1.38	1.03	2.35	2.56	0.10	0	0	10.62
1973-1974	0	0.74	0	0	0.81	0.04	3.00	0.06	0.41	0.13	0.06	0	5.25
1974-1975	1.46	0	0.67	0.92	0.17	0.73	0.29	0.61	2.22	0.98	0	0	8.05
1975-1976	0.41	0.02	0.17	0.06	1.88	0.30	0.05	3.15	1.32	0.93	0.18	0	8.47
1976-1977	1.26	0	4.56	0.12	0.66	0.43	1.31	0.32	1.38	0.04	0.63	0	10.71
1977-1978	0.09	2.13	0	1.06	0.08	2.79	3.91	2.19	2.70	0.87	0.19	0	16.01
1978-1979	0	0.11	0.35	0.83	2.56	2.76	3.13	1.47	2.36	0	0.38	0	13.95
1979-1980	0.05	0.40	0.19	0.26	0.06	0.23	6.56	5.26	2.63	1.12	0.91	0	17.67
MEAN	0.47	0.42	0.53	0.61	1.06	1.52	1.58	1.40	1.36	0.64	0.18	0.03	9.82

Boulevard Monthly Precipitation Records (United States Environmental Sciences Services Administration, 1965-1980; United States Weather Bureau, 1931-1964; NOAA, 1980, personal communication)

Water Year	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Total
1924-1925						1.90	0.30	0.49	1.92	2.29	0.05	0.04	IR
1925-1926	1.90	0.90	0	3.85	1.43	0.70	0.83	2.53	0.40	4.63	0.14	0	17.31
1926-1927	0	0.15	0	0	0.38	10.70	0.76	11.58	3.22	1.15	0.53	0	28.47
1927-1928	0.63	0	0	2.33	0.88	3.81	0.54	2.77	0.60	0	0.18	0	11.74
1928-1929	0	0	0	0.35	0.51	1.50	2.19	2.10	1.28	0.97	0	0	8.90
1929-1930	0.96	1.51	3.38	NR	NR	NR	7.98	0.86	2.69	0.40	2.60	0	IR
1930-1931	0	2.16	0	0	1.79	0	1.95	4.12	0	0.90	0.40	0	11.32
1931-1932	0	0.53	0	0.49	1.81	2.75	NR	NR	NR	NR	NR	NR	IR
1932-1933	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
1933-1934	NR	NR	NR	NR	0.61	1.63	0.31	1.58	0.12	0	0	0.04	IR
1934-1935	0.40	2.45	0.04	0.43	0.36	1.91	3.36	4.21	3.07	2.47	0	0	18.70
1935-1936	0.11	0.69	0	0.04	0.20	0.95	0.48	5.27	2.13	0.76	0	0	10.63
1936-1937	1.65	4.96	0	1.60	0.79	6.86	3.83	5.51	3.91	0.56	0.12	0.11	29.90
1937-1938	0.15	0.95	0	0	0	1.21	1.32	4.96	5.85	0.85	0.16	0	15.45
1938-1939	2.57	0.25	0	0	0	4.81	3.10	2.26	1.65	0.38	0	0	15.02
1939-1940	0	1.00	5.94	0.41	1.06	0.67	1.98	3.91	0.82	2.25	0	0	18.04
1940-1941	0	0.46	0.21	1.41	0.72	7.90	2.09	3.32	4.90	4.79	0	0	25.80
1941-1942	0.10	1.83	0.15	2.61	0.48	5.44	0	3.05	2.02	1.26	0	0	16.94
1942-1943	0	0	0	0.33	0	1.07	5.60	1.74	2.47	2.04	0	0	13.25
1943-1944	NR	NR	NR	NR	NR	NR	1.54	7.10	1.16	0.92	NR	NR	IR

Boulevard Monthly Precipitation Records (Continued)

Water Year	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Total
1944-1945	NR	NR	NR	NR	4.55	0.74	1.03	1.03	4.35	0.06	NR	0	IR
1945-1946	0	3.28	1.54	0.16	0	3.88	1.11	0.79	2.37	1.08	0.01	NR	IR
1946-1947	1.52	0.90	1.62	0.80	3.80	1.75	0.62	0.44	0.44	1.19	0.03	0	13.11
1947-1948	0	0.53	0.12	0.24	0.26	2.85	0.18	1.93	2.61	0.45	0.09	0.50	9.76
1948-1949	0	0	0.23	0.99	0	2.77	6.69	2.25	1.48	0.09	0.71	0	15.21
1949-1950	0	0.13	0	0.83	0.92	2.96	2.34	1.21	1.33	0.43	0.34	0	10.49
1950-1951	0.71	0	0	0	0.72	0.38	3.22	0.91	0.91	2.37	0.30	0	9.52
1951-1952	0.35	1.89	0	0.56	1.01	5.12	4.82	0.45	7.21	1.59	0	0	23.00
1952-1953	0	0.44	0.23	0	3.84	2.92	1.14	0.57	1.54	0.97	0.40	0.03	12.08
1953-1954	0.07	0.79	0.10	0	0.61	0.16	4.50	1.72	6.05	0.16	0	0.10	14.26
1954-1955	1.03	0.01	0.30	0	0.57	0.68	3.78	1.01	0.64	0.47	1.70	0.03	10.22
1955-1956	0.58	3.72	0	0	1.13	1.44	1.77	1.50	0.02	2.35	0.56	0	13.07
1956-1957	0.61	0	0	0.14	0	0.35	6.68	0.56	1.43	0.99	2.64	0.35	13.75
1957-1958	0	0.16	0	2.81	0.68	0.74	0.50	3.11	5.20	4.17	0.28	0.08	17.57
1958-1959	0.05	1.41	0.74	0.03	1.23	0.05	1.15	4.37	0	0.05	0.11	0	9.19
1959-1960	0.01	2.29	0.47	1.00	0	1.98	2.84	2.42	0.30	0.92	0.29	0	12.52
1960-1961	0.36	0	1.66	0	1.21	0.25	0.95	0	1.41	0	0	0	5.84
1961-1962	0	2.08	0	0.12	0.03	2.14	3.34	2.93	1.36	0	0.63	0.03	12.66
1962-1963	0	0	0.26	0.07	0	0.61	0.51	2.02	1.56	1.38	0	0	6.41
1963-1964	0	0.23	2.15	0.64	1.70	0.32	1.81	0.96	2.70	0.81	0.64	0	11.96

Boulevard Monthly Precipitation Records (Continued)

Water Year	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Total
1964-1965	0.74	0.12	0	0.40	1.60	1.34	0.31	1.73	0.34	4.34	0	0	10.92
1965-1966	0.17	0.15	0.18	0	5.74	4.37	1.92	1.51	0.74	0	0.06	0	14.84
1966-1967	0.10	0.10	0	1.35	0.75	4.76	1.15	0	0.67	2.51	0.36	0.13	11.88
1967-1968	0.86	0.31	1.96	0	2.31	3.90	NR	NR	NR	NR	NR	NR	IR
1968-1969	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
1969-1970	NR	NR	NR	0	2.05	0.39	0.71	1.07	4.36	1.52	0	0.03	IR
1970-1971	0.30	1.71	0.03	0.32	2.00	3.96	1.43	1.51	0.63	1.76	0.92	0	14.57
1971-1972	0	0.67	0.22	1.36	0.12	4.45	0	0.25	0	0.33	0.30	0.25	7.95
1972-1973	0	0.02	0.11	1.66	2.57	1.92	2.34	3.60	5.74	0.22	0.10	0	18.28
1973-1974	0	0.75	0	0.07	1.88	0.07	5.13	0.17	1.11	0.38	0.16	0	9.72
1974-1975	1.02	0	0.31	2.53	0.57	1.47	0.22	1.76	4.63	1.99	0.16	0.15	14.81
1975-1976	0.53	0.19	0.69	0.12	3.01	0.79	0.02	5.39	2.32	2.09	0.13	0	15.28
1976-1977	2.48	0	3.73	1.22	1.04	0.89	2.59	0.61	2.14	0.27	1.41	0	16.38
1977-1978	0.75	2.60	0	0.13	0.21	3.72	7.04	5.95	5.69	1.95	0.26	0	28.30
1978-1979	0.06	0.05	0.58	0.99	3.81	4.92	5.69	2.39	5.70	0.10	0.42	0	24.71
1979-1980	0	0.50	0.03	1.09	0.17	0.85	10.92	8.93	4.42	2.22	1.42	0	30.55
MEAN	0.42	0.87	0.55	0.67	1.20	2.38	2.43	2.55	2.35	1.27	0.37	0.04	15.10

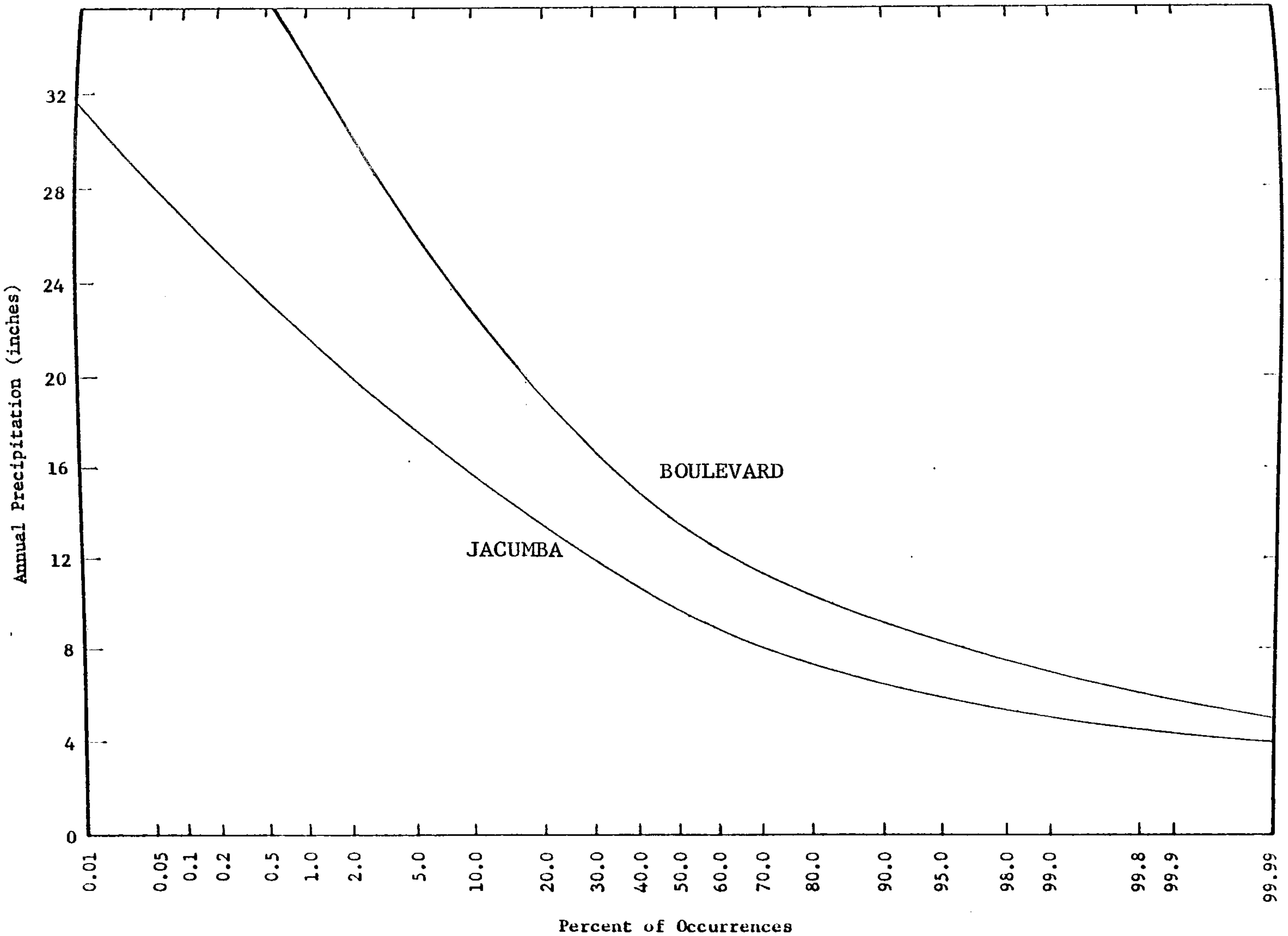


Figure 34. Probability of Occurrence of Yearly Precipitation for Jacumba and Boulevard

Extrapolated Boulevard Yearly Precipitation Records

Water Year	Yearly Precipitation	Correlation Station
1887-1888	9.3	Lake Cuyamaca
1888-1889	21.8	Lake Cuyamaca
1889-1890	25.3	Lake Cuyamaca
1890-1891	26.2	Lake Cuyamaca
1891-1892	16.5	Lake Cuyamaca
1892-1893	16.5	Lake Cuyamaca
1893-1894	6.7	Lake Cuyamaca
1894-1895	22.6	Lake Cuyamaca
1895-1896	10.0	Lake Cuyamaca
1896-1897	16.9	Lake Morena
1897-1898	12.8	Lake Morena
1898-1899	11.0	Lake Morena
1899-1900	15.7	Lake Morena
1900-1901	17.8	Lake Cuyamaca
1901-1902	15.1	Lake Cuyamaca
1902-1903	17.7	Lake Cuyamaca
1903-1904	10.0	Lake Cuyamaca
1904-1905	23.8	Lake Cuyamaca
1905-1906	23.2	Lake Cuyamaca
1906-1907	20.3	Lake Morena
1907-1908	14.1	Lake Morena
1908-1909	19.7	Lake Morena
1909-1910	16.0	Lake Morena
1910-1911	14.9	Lake Morena
1911-1912	16.4	Lake Morena
1912-1913	12.3	Lake Morena
1913-1914	15.7	Lake Morena
1914-1915	22.2	Lake Morena

Water Year	Yearly Precipitation	Correlation Station
1915-1916	28.2	Lake Morena
1916-1917	13.2	Lake Morena
1917-1918	14.3	Lake Morena
1918-1919	14.7	Lake Morena
1919-1920	20.7	Lake Morena
1920-1921	12.5	Lake Morena
1921-1922	27.6	Lake Morena
1922-1923	16.1	Lake Morena
1923-1924	13.2	Lake Morena
1924-1925	14.4	Lake Morena
1929-1930	17.3	Lake Morena
1931-1932	21.3	Lake Morena
1932-1933	14.2	Lake Morena
1933-1934	8.9	Lake Morena
1943-1944	19.4	Lake Morena
1944-1945	15.8	Lake Morena
1967-1968	19.6	Lake Morena
1968-1969	15.7	Lake Morena
1969-1970	9.1	Lake Morena

Extrapolated Boulevard Precipitation Data

The extrapolated Boulevard precipitation data was calculated by comparing the available yearly data with yearly data from Lake Morena and Lake Cuyamaca. The line which best fits the data plotted in Figures 35 and 36 was determined by linear regression using the method of least squares.

The 95% confidence interval for the mean response $\mu y/x_o$ was determined using the following equation (Walpole and Myers, 1972):

$$\hat{y}_o - t_{\frac{\alpha}{2}} S \sqrt{\frac{1}{n} + \frac{(x_o - \bar{x})^2}{S_{xx}}} < \mu y/x_o < \hat{y}_o - t_{\frac{\alpha}{2}} S \sqrt{\frac{1}{n} + \frac{(x_o - \bar{x})^2}{S_{xx}}}$$

$t_{\frac{\alpha}{2}}$ is a value of the $t_{\frac{\alpha}{2}}$ distribution with n-2 degrees of freedom

$$S = \sqrt{\frac{S_{yy} - \rho S_{xy}}{n-2}}$$

n = number of points

$\bar{x}$ = mean of x values

$\bar{y}$ = mean of y values

$$S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})$$

$$S_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2$$

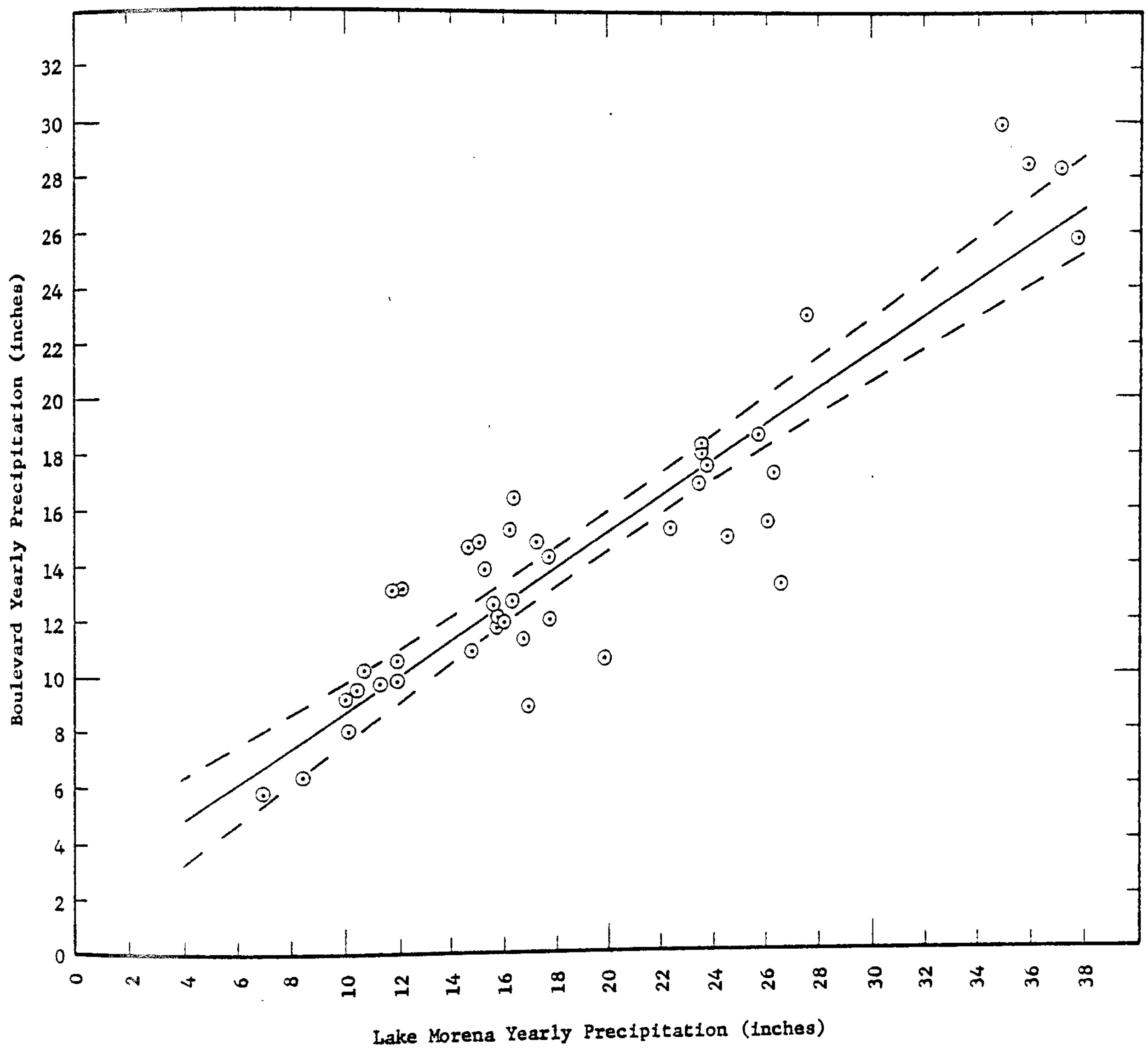


Figure 35. Data Plot of Boulevard and Lake Morena Yearly Precipitation and 95% Confidence Interval for the Mean Response $\mu y/x_o$

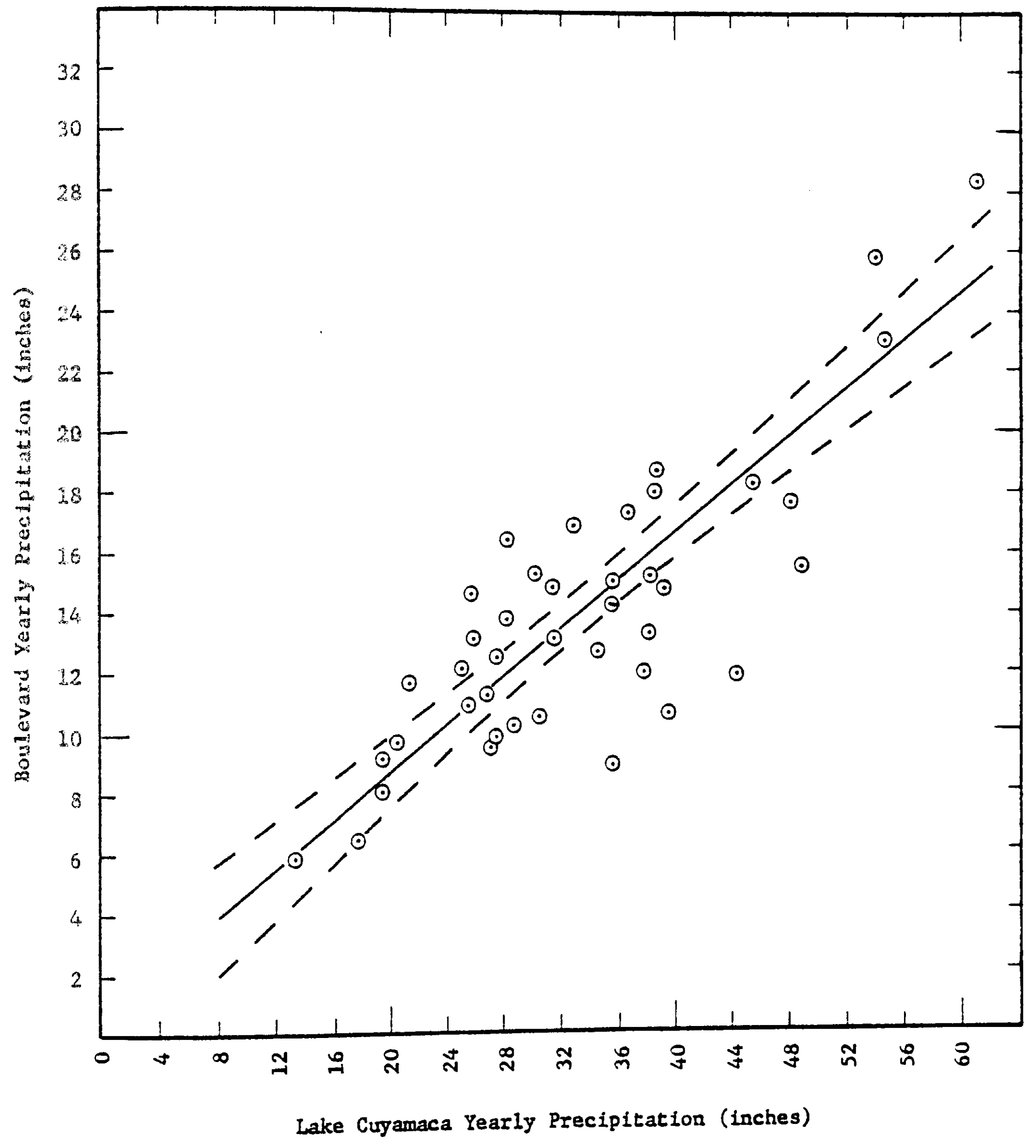


Figure 36. Data Plot of Boulevard and Lake Cuyamaca Yearly Precipitation and 95% Confidence Interval for the Mean Response $\mu y/x_o$

MEAN PAN EVAPORATION DATA FOR LAKE MORENA, CALIFORNIA

Mean monthly and yearly evaporation from a class L pan located at Morena Dam (1946-1974) (Calif. Dept. of Water Resources, 1974)

July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly (inches)
8.15	7.65	5.97	4.22	2.24	1.70	1.63	1.81	2.83	4.09	5.59	7.12	53.01

APPENDIX B

SOILS

SOILS

The soil classification used in this report was based on eleven soil samples that were collected from the Jacumba Valley watershed and tested in the laboratory. The collection location of each sample is shown on the geologic map. Each soil sample was collected in a pipe 1.5 inches in diameter that was driven into the ground by a hand sledge. After removal from the ground, the ends of the pipes were plugged to prevent loss of soil. In the laboratory, each sample was submerged in water for about one week. The saturated sample was then weighed on a scale. The samples were then drained and weighed followed by drying in an oven and the weighing of the dried sample.

Sample 1 (Type Z)

The soil is clay rich alluvium from the northern end of Jacumba Valley.
The sampling pipe was driven 27 inches into the ground.
The soil sample was 10 inches long. There was 17 inches of compaction.

Saturated weight (2/28/80)	22 ounces
Drained weight (3/1/80)	22 ounces
Drained weight (3/5/80)	22 ounces
Dried weight (3/18/80)	16 ounces

Volume of water = 10.3 cubic inches
Volume of sample = 17.7 cubic inches

Porosity = 59% (the porosity was probably greater before compaction during sampling)
Specific retention = 0.59 $inches^3$ of $water/inch^3$ of soil (this value may have been affected by the compaction during sampling)

Sample 2 (Type W)

This sample is sandy alluvium from an alluvial fan on the eastern edge of the valley.
The sampling pipe was driven 25.5 inches into the ground.
The sampling was 20 inches long. There was 5.5 inches of compaction.

Saturated weight (2/28/80)	48 ounces
Drained weight (3/1/80	46 ounces
Drained weight (3/5/80)	46 ounces
Dried weight (3/18/80)	42 ounces

Volume of water (saturated) = 10.3 cubic inches
Volume of water (drained) = 6.9 cubic inches
Volume of sample = 35.3 cubic inches

Porosity = 37% (corrected for compaction, porosity before correction was 29%)
Specific retention = 0.16 $inches^3$ of $water/inch^3$ of soil (corrected for compaction, specific retention before correction was 0.20 $inches^3$ of $water/inch^3$ of soil)

Sample 3 (Type X)

This soil was developed on metamorphic terrain.
The sampling pipe was driven 10.5 inches into the ground.
The soil sample was 8.75 inches long. There was 1.75 inches of compaction.

Saturated weight (2/28/80)	21 ounces
Drained weight (3/1/80)	21 ounces
Drained weight (3/5/80)	21 ounces
Dried weight (3/18/80)	18 ounces

Volume of water (saturated) = 5.7 cubic inches
Volume of water (drained) = 5.7 cubic inches
Volume of sample = 15.46 cubic inches

Porosity = 40% (corrected for compaction, porosity before correction was 33%)
Specific retention = 0.28 $inches^3$ of $water/inch^3$ of soil (corrected for compaction, specific retention before correction was 0.33 $inches^3$ of water/ $inch^3$ of soil)

Sample 4 (Type Y)

This sample is of clay rich soil that developed on the Jacumba Volcanics.
The sampling pipe was driven 11.5 inches into the ground.
The soil sample was 5.5 inches long. There was 6 inches of compaction.

Saturated weight (2/28/80)	13 ounces
Drained weight (3/1/80)	13 ounces
Drained weight (3/5/80)	13 ounces
Dried weight (3/18/80)	11 ounces

Volume of water (saturated) = 3.5 cubic inches
Volume of water (drained) = 3.5 cubic inches
Volume of sample = 9.7 cubic inches

Porosity = 74% (corrected for compaction, porosity before correction was 35%)
Specific retention = 0.35 $inches^3$ of water/$inch^3$ of soil (because clay was a major constituent in this sample the value for specific retention was not corrected for compaction)

Sample 5 (Type Y)

This soil sample consisted of fine sandy alluvium collected from the center of Jacumba Valley.
The sampling pipe was driven 10.5 inches into the ground.
The soil sample was 9.5 inches long. There was 1 inch of compaction.

Saturated weight (2/28/80)	22 ounces
Drained weight (3/1/80)	22 ounces
Drained weight (3/5/80)	22 ounces
Dried weight (3/18/80)	18 ounces

Volume of water (saturated) = 6.9 cubic inches
Volume of water (drained) = 6.9 cubic inches
Volume of sample = 16.8 cubic inches

Porosity = 45% (corrected for compaction, porosity before correction was 41%)
Specific retention = 0.37 $inches^3$ of water/$inch^3$ of soil (corrected for compaction, specific retention before correction was 0.41 $inches^3$ of water/$inch^3$ of soil)

Sample 6 (Type X)

This soil was developed on metamorphic terrain.
The sampling pipe was driven 10.5 inches into the ground.
The soil sample was 9.5 inches long. There was 1 inch of compaction.

Saturated weight (2/28/80)	24 ounces
Drained weight (3/1/80)	23 ounces
Drained weight (3/5/80)	23 ounces
Dried weight (3/18/80)	20 ounces

Volume of water (saturated) = 6.9 cubic inches
Volume of water (drained) = 5.2 cubic inches
Volume of sample = 16.8 cubic inches

Porosity = 45% (corrected for compaction, porosity before correction was 41%)
Specific retention = 0.28 inches^3 of water/inch^3 of soil (corrected for compaction, specific retention before correction was 0.31 inches^3 of water/inch^3 of soil)

Sample 7 (Type W)

This soil sample is of sandy alluvium from an alluvial fan on the eastern edge of Jacumba Valley.
The sampling pipe was driven 20.5 inches into the ground.
The soil sample was 15.0 inches long. There was 5.5 inches of compaction.

Saturated weight (3/26/80)	1023 grams
Drained weight (3/28/80)	974 grams
Drained weight (3/31/80)	969 grams
Dried weight	845 grams

Volume of water (saturated) = 10.9 cubic inches
Volume of water (drained) = 7.6 cubic inches
Volume of sample = 26.5 cubic inches

Porosity = 56% (corrected for compaction, porosity before correction was 41%)
Specific retention = 0.21 inches^3 of water/inch^3 of soil (corrected for compaction, specific retention before correction was 0.29 inches^3 of water/inch^3 of soil)

Sample 8 (Type X)

This soil was developed on plutonic terrain.
The sampling pipe was driven 10.75 inches into the ground.
The soil sample was 8.5 inches long. There was 2.25 inches of compaction.

Saturated weight (3/26/80)	569 grams
Drained weight (3/28/80)	558 grams
Drained weight (3/31/80)	558 grams
Dried weight	479 grams

Volume of water (saturated) = 5.5 cubic inches
Volume of water (drained) = 4.8 cubic inches
Volume of sample = 15.0 cubic inches

Porosity = 46% (corrected for compaction, porosity before correction was 37%)
Specific retention = 0.25 inches^3 of water/inch^3 of soil (corrected for compaction, specific retention before correction was 0.32 inches^3 of water/inch^3 of soil)

Sample 9 (Type Y)

This sample is of clay rich soil that developed on the Jacumba Volcanics.
The sampling pipe was driven 10.75 inches into the ground.
The soil sample was 5.25 inches long. There was 5.5 inches of compaction.

Saturated weight (3/26/80)	272 grams
Drained weight (3/28/80)	267 grams
Drained weight (3/31/80)	267 grams
Dried weight	205 grams

Volume of water (saturated) = 4.1 cubic inches
Volume of water (drained) = 3.8 cubic inches
Volume of sample = 9.3 cubic inches

Porosity = 90% (corrected for compaction, porosity before correction was 44%)
Specific retention = 0.41 inches^3 of water/inch^3 of soil (because clay was a major constituent in this sample, the value for specific retention was not corrected for compaction)

Sample 10 (Type X)

This soil was developed on metamorphic terrain.
The sampling pipe was driven 10.75 inches into the ground.
The soil sample was 9.25 inches long. There was 1.5 inches of compaction.

Saturated weight (3/26/80)	593 grams
Drained weight (3/28/80)	577 grams
Drained weight (3/31/80)	577 grams
Dried weight	486 grams

Volume of water (saturated) = 6.5 cubic inches
Volume of water (drained) = 5.5 cubic inches
Volume of sample = 16.3 cubic inches

Porosity = 46% (corrected for compaction, porosity before correction was 40%)
Specific retention = 0.29 inches^3 of water/inch^3 of soil (corrected for compaction, specific retention before correction was 0.34 inches^3 of water/inch^3 of soil)

Sample 11 (Type X)

This soil was developed on metamorphic terrain.
The sampling pipe was driven 10.5 inches into the ground.
The soil sample was 9.5 inches long. There was 1.0 inches of compaction.

Saturated weight (3/26/80)	612 grams
Drained weight (3/28/80)	586 grams
Drained weight (3/31/80)	586 grams
Dried weight	516 grams

Volume of water (saturated) = 5.9 cubic inches
Volume of water (drained) = 4.3 cubic inches
Volume of sample = 16.8 cubic inches

Porosity = 39% (corrected for compaction, porosity before correction was 35%)
Specific retention = 0.23 inches^3 of water/inch^3 of soil (corrected for compaction, specific retention before correction was 0.25 inches^3 of water/inch^3 of soil)

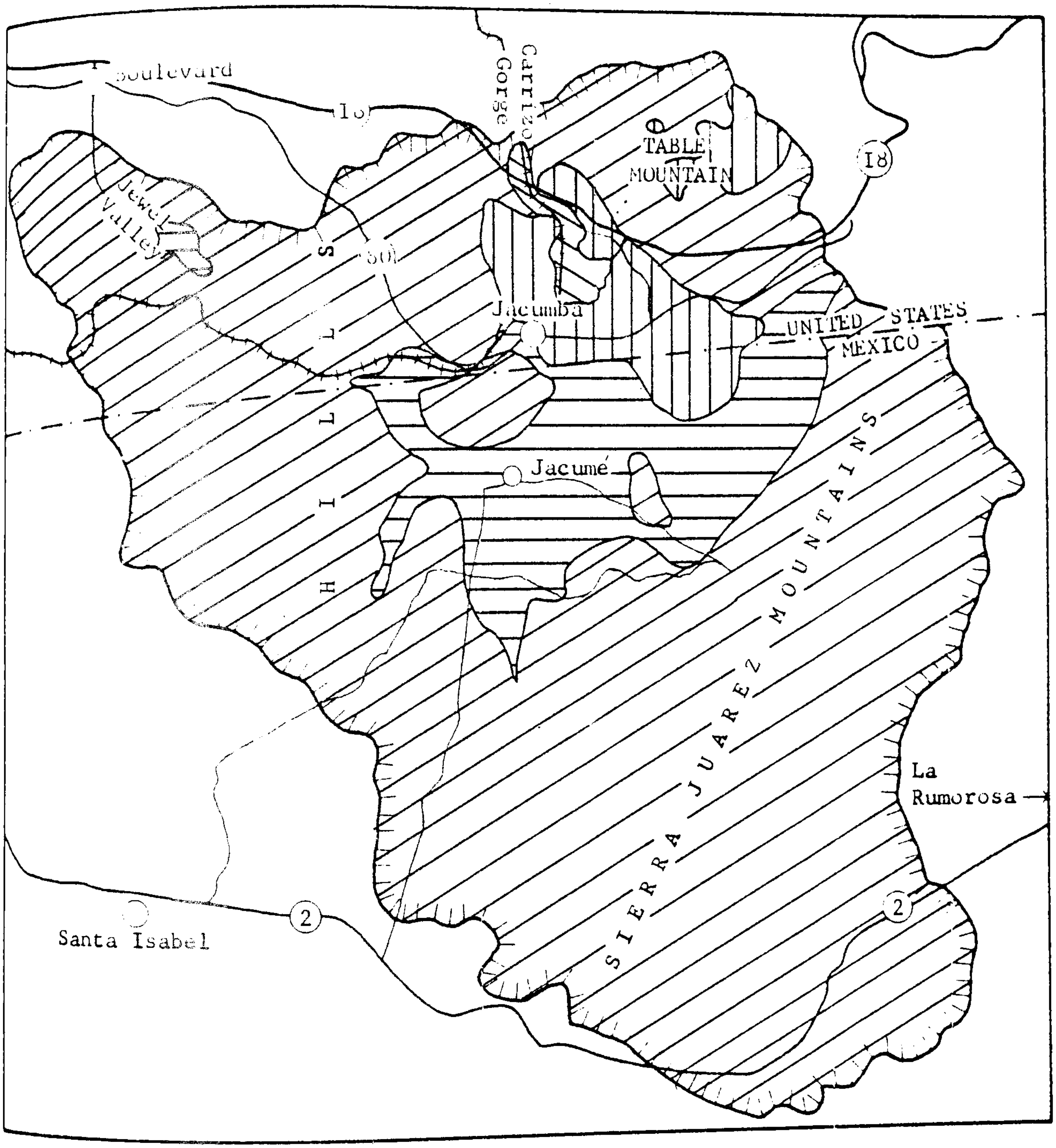


Figure 37. Soils of the Jacumba Valley Watershed (Scale about 1:143,000)

Soil Type	Sample #	Porosity	Specific Retention	Description
W	2	37%	0.16 in.^{3}/in.^{3} soil	Sandy alluvium
	7	56%	0.21 in.^{3}/in.^{3} soil	Sandy alluvium
	Mean	46%	0.19 in.^{3}/in.^{3} soil	

This soil type is composed of medium to coarse-grained sand and gravelly sand found on alluvial fans, in stream channels, and as alluvian fill in small mountain valleys. Eolian deposits are also included. The assumed active depth for this soil type is 36 inches. In the portion of the Jacumba Valley watershed that receives Boulevard precipitation this soil type covers about 9.9 x 10^6 square feet. It covers about 3.898 x 10^8 square feet in that portion of the watershed receiving Jacumba precipitation.

Soil Type	Sample #	Porosity	Specific Retention	Description
X	3	40%	0.28 in.^{3}/in.^{3} soil	Metamorphic residuum
	6	45%	0.28 in.^{3}/in.^{3} soil	Metamorphic residuum
	8	46%	0.25 in.^{3}/in.^{3} soil	Plutonic residuum
	10	46%	0.29 in.^{3}/in.^{3} soil	Metamorphic residuum
	11	39%	0.23 in.^{3}/in.^{3} soil	Metamorphic residuum
	Mean	43%	0.27 in.^{3}/in.^{3} soil	

This soil type is composed of residuum formed on the metamorphic and plutonic bedrock which crops out in the hills and mountains surrounding Jacumba Valley. The active depth of this soil type is 24 inches because it only forms a thin cover on the bedrock. In the portion of the Jacumba Valley watershed that receives Boulevard precipitation, this soil type covers about 6.441×10^8 square feet. It covers about 2.0415×10^9 square feet in that portion of the watershed receiving Jacumba precipitation.

Soil Type	Sample #	Porosity	Specific Retention	Description
Y	4	74%	0.35 in.^{3}/in.^{3} soil	Volcanic residuum
	5	45%	0.37 in.^{3}/in.^{3} soil	Fine sand alluvium
	9	90%	0.41 in.^{3}/in.^{3} soil	Volcanic residuum
	Mean	70%	0.38 in.^{3}/in.^{3} soil	

This soil type is composed of clay rich residuum developed on the Jacumba Volcanics and the fine sandy alluvium in Jacumba Valley, The assumed active depth for this soil type is 36 inches. In the portion of the Jacumba Valley watershed that receives Jacumba precipitation, this soil type covers about 1.916×10^8 square feet. There is no soil of this type in that portion of the watershed receiving Boulevard precipitation.

Soil Type	Sample #	Porosity	Specific Retention	Description
Z	1	>59%	0.59 $in.^3/in.^3$ soil	Clay rich alluvium

This soil type is composed of clay rich alluvium found in the northern end of Jacumba Valley. The assumed active layer for this soil type is 36 inches. In the portion of the Jacumba Valley watershed that receives Jacumba precipitation, this soil type covers about 2.31×10^7 square feet. There is no soil of this type in that portion of the watershed receiving Boulevard precipitation.

The United States Soil Conservation Service and Forest Service (1973) mapped and classified the soils on the United States side of the Jacumba Valley watershed. Listed below are the soil types classified by the Soil Conservation Service.

Soils of the Jacumba Valley Watershed as Classified by the United States Soil Conservation Service and Forest Service (December, 1973)

Soil Type	Permeability	AWHC*	Runoff	Hydrologic Group	Soil Depth
Acid igneous rock land	none	0 (inches)	rapid	D	shallow (inches)
Calpine coarse sandy loam (slope 5-9%)	mod. rapid	4.5 - 6.5	slow	B	up to 60
Calpine coarse sandy loam (slope 9-15%)	mod. rapid	4.5 - 6.5	slow - med.	B	up to 60
Carrizo very gravelly sand	very rapid	1.5 - 3.0	very slow	A	up to 60
Indio silt loam (slope 0-2%)	moderate	7.5 - 9.5	slow	C	up to 60
Indio silt loam (slope 2-5%)	moderate	7.5 - 9.5	slow	C	up to 60
Indio silt loam, saline (slope 0-2%)	moderate	7.5 - 9.5	very slow	C	up to 60
La Posta loamy coarse sand	rapid	2.0 - 3.0	medium	A	16 - 30
La Posta rocky loamy coarse sand	rapid	1.0 - 2.0	medium	A	
La Posta - Sheephead complex	mod. rapid	1.0 - 2.5	med.-rapid	A,C	10 - 32
Loamy alluvial land	moderate	6.0 - 9.0		B	greater than 60
Mecca coarse sandy loam	moderate	5.0 - 6.0	slow	B	greater than 60
Metamorphic rock land	none	none	very rapid	D	shallow
Mottsville loamy coarse sand (slope 2-9%)	very rapid	4.0 - 5.0	slow-med.	A	up to 60
Mottsville loamy coarse sand (slope 9-15%)	very rapid	4.0 - 5.0	medium	A	up to 60
Ramona sandy loam (slope 5-9%)	mod. slow	8.5 - 10.5	slow-med.	C	up to 74
Ramona sandy loam (slope 9-15%)	mod. slow	8.5 - 10.5	medium	C	up to 74

* Available water holding capacity

Soils of the Jacumba Valley Watershed as Classified by the United States Soil Conservation Service and Forest Service (December, 1973) (Continued)

Soil Type	Permeability	AWHC*	Runoff	Hydrologic Group	Soil Depth
Reiff fine sandy loam	mod. rapid	7.5 - 9.5	very slow	B	up to 60
Rositas loamy coarse sand	rapid	3.0 - 4.0	slow-med.	A	up to 60
Rough broken land	none	none	very rapid	D	little
Sloping gullied land	none	none	very rapid	B	debris
Stony land	none	none	very rapid	A	talus
Tollhouse rocky coarse sandy loam (slope 5-30%)	rapid	1.0 - 2.0	med.-rapid	C	5 - 20
Tollhouse rocky coarse sandy loam (slope 30-65%)	rapid	1.0 - 2.0	very rapid	C	5 - 20

*Available water holding capacity

UNITED STATES SOIL CONSERVATION SERVICE HYDROLOGIC SOIL GROUPS

Hydrologic Group	Description
A	Soils have high infiltration rate when thoroughly wetted, permeability is rapid to very rapid. Chiefly deep soils, well drained to excessively drained sand and/or gravel. The rate of water transmission is high, very slow to medium runoff potential. 0-30% slopes. Available water holding capacity is 1.0-5.0 inches.
B	Soils have moderate infiltration rate when thoroughly wetted, permeability is moderate to moderately rapid. Chiefly moderately deep to deep soils, moderately well drained to well drained moderately coarse grained texture. The rate of water transmission is moderate, very slow to medium runoff potential. 0-9% slopes. Available water holding capacity is 4.5-9.5 inches.
C	Soils have slow infiltration rate when thoroughly wetted, permeability is moderately slow to moderately rapid. Chiefly soils that have a layer impeding downward movement of water, moderately fine to fine texture. The rate of water transmission is slow, slow to rapid runoff potential. 0-65% slopes. Available water holding capacity is 1.0-10.5 inches.
D	Soils have very slow infiltration rate when thoroughly wetted, little permeability. Chiefly clays with high shrink-swell potential, soils that have high permenent water table, soils that have claypan or clay layer at or near the surface, or soils that are shallow over nearly impervious material, generally rock areas with little soil. The rate of water transmission is very slow, runoff potential is rapid to very rapid. No available water holding capacity.

APPENDIX C

VEGETATION

The vegetation in the Jacumba Valley watershed has been grouped into three different plant communities. Oberbauer (personal communication, 1980) provided the following list of plants that are typical of two of these communities:

Creosote Bush Scrub -	Creosote bush (Larrea tridentata)
	Burroweed (Ambrosia dumosa)
	Ocotillo (Fouqueria splendens)
	Brittlebush (Encelia farinosa)
	Jumping cholla (Opuntia bigelovii)
	Barrel cactus (Ferocactus acanthodes)
	Desert lavender (Hyptis emoryi)
	Cheesebush (Hymenoclea salsola)
Desert Transition -	Turpentine broom (Thamnosma montana)
	Desert apricot (Prunus fremontii)
	Condaliopsis (Condaliopsis parryi)
	Nolina (Nolina bigelovii)
	California junipers (Juniperus cal-ifornicus)
	Scrub oak (Quercus turbinella)

Patric Webber (1979) studied two sites within the Jacumba Valley watershed (see geologic map in pocket). Vegetation data from these sites are presented below.

Site 70 - Species	Percent Cover
Adenostoma fasciculatum	45%
Adenostoma sparsifolium	1%
Ceanothus greggii	15%
Eriogonum fasciculatum	2%
Opuntia prolifera	1%
Rhus ovata	5%
Salvia mellifera	1%
Sambucus mexicana	1%
Yucca schidigeri	2%
Tree cover	0%
Shrub cover	73%
Herb cover	25%
Cryptogam cover	3%
Litter	25%
Rock cover	5%
Bare soil cover	40%

Site 71 - Species	Percent Cover
Adenostoma fasciculatum	30%
Asctostaphylas glanca	8%
Eriogonum fasciculatum	1%
Gutierrezia california	1%
Haplopappus linearifolius	3%
Juniperus california	5%
Lotus scoparius	1%
Opuntia littoralis	2%
Quercus dumosa	6%
Rhus ovata	5%
Yucca schidigeri	3%
Tree cover	0%
Shrub cover	66%
Herb cover	2%
Cryptogam cover	1%
Litter	15%
Rock cover	45%
Bare soil cover	30%

APPENDIX D

RUNOFF

RUNOFF

No significant surface flow occurred in Jacumba Valley between June, 1979 and February, 1980. Between February, 1980 and June, 1980, the surface flow in the valley was measured. Stream flow measurements were made at five localities in the valley (see Runoff Data, page ; Figures 38 and 39). The surface flow in Boundary Creek was gaged beneath the Old State Highway 80 bridge west of Jacumba and along the artificial channel on the northern edge of Jacumba. Surface flow from the Mexican side of Jacumba Valley was measured in a ditch on the eastern side of Jacumba near a trailer park. Surface flow in the drainage west of Jacumé was gaged twice to the west of that town. The surface flow leaving Jacumba Valley and entering Carrizo Gorge was measured at the old dam at the north end of the valley.

Measurements made at the old dam were made in the same manner as for flow over a broad-crested weir. All other measurements were made by determining the average cross sectional area of the channel and then timing a floating object as it traversed a 50-foot section. Because of the wide and shallow nature of most of the channels, these measurements are only estimates.

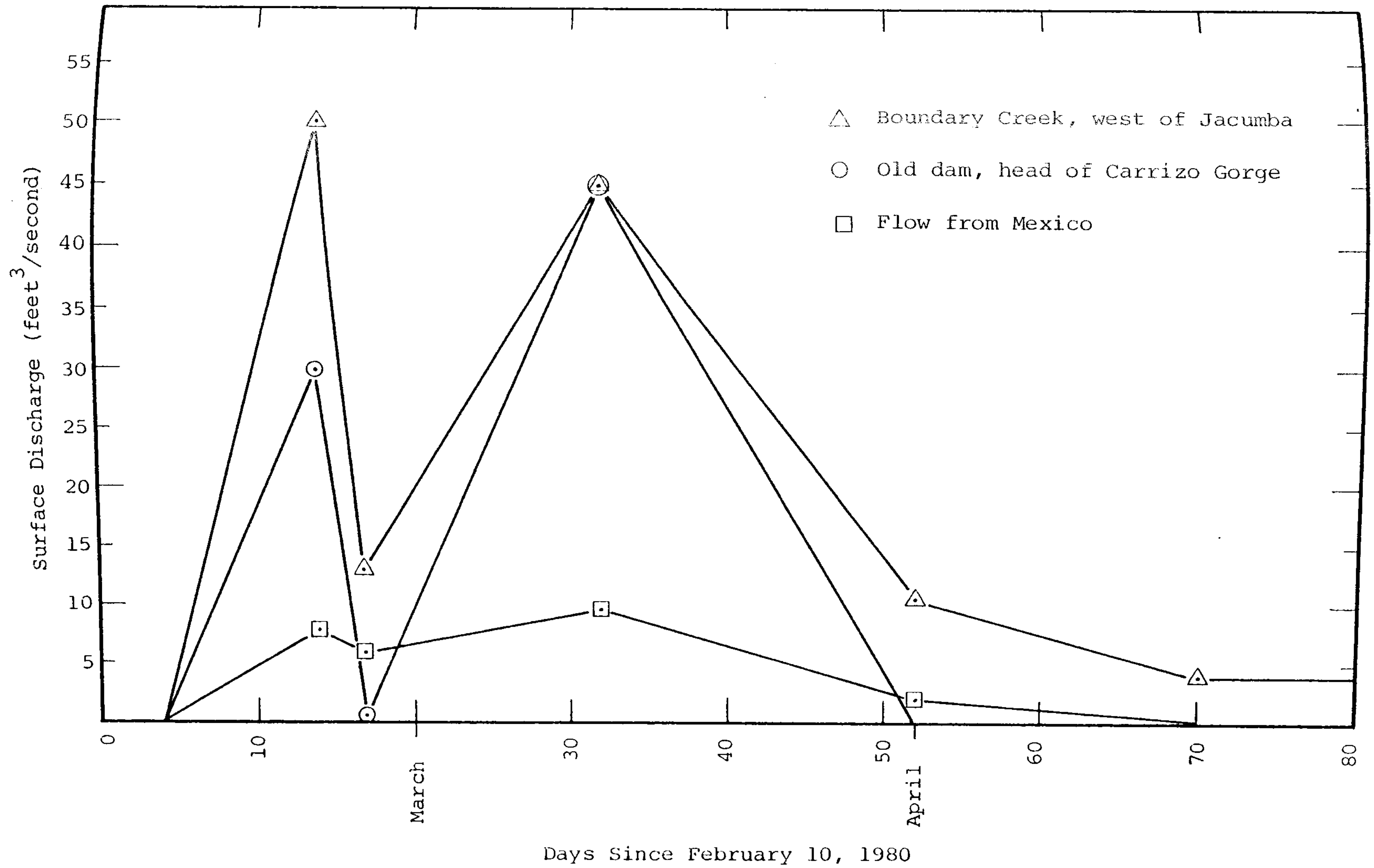
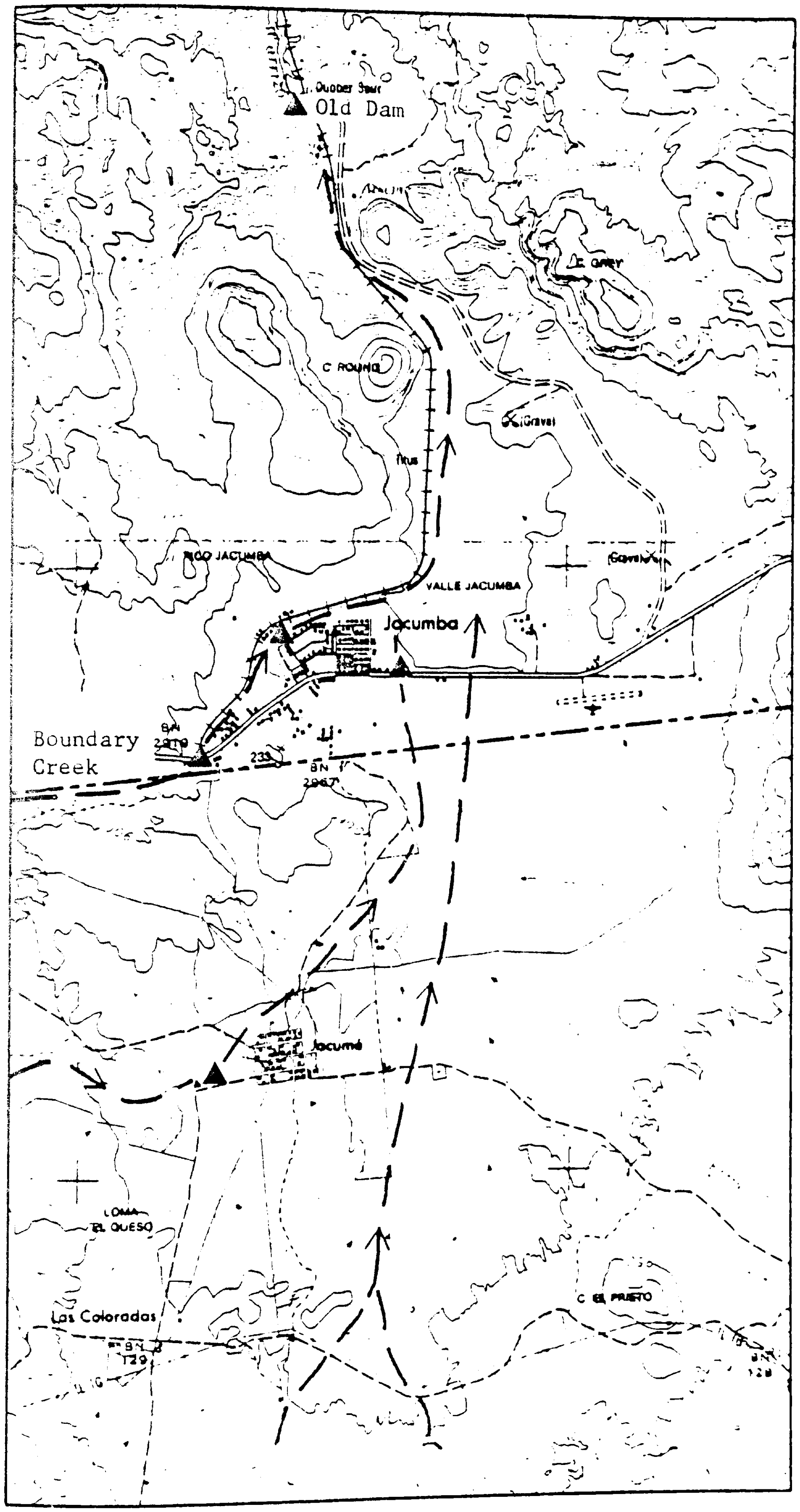


Figure 38. Selected Stream Flow Measurements Made During February, March, and April, 1980



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▲ Gauging station

Figure 39. Surface Flow Patterns in Jacumba Valley During the Months of February, March, and April, 1980 (Scale 1:50,000)

RUNOFF DATA, FEBRUARY THROUGH MAY, 1980

Date	Location	Discharge
2/12/80	No surface flow entering Jacumba Valley	
2/24/80	Boundary Creek, west of Jacumba	50 $feet^3$/second
	Boundary Creek, north of Jacumba	37 $feet^3$/second
	Flow from Mexico, east of Jacumba	8 $feet^3$/second
	Old dam, head of Carrizo Gorge	30 $feet^3$/second
2/27/80	Boundary Creek, west of Jacumba	13 $feet^3$/second
	Boundary Creek, north of Jacumba	9 $feet^3$/second
	Flow from Mexico, east of Jacumba	6 $feet^3$/second
	Old dam, head of Carrizo Gorge	0.8 $feet^3$/second
3/12/80	Boundary Creek, west of Jacumba	40 $feet^3$/second
	Boundary Creek, north of Jacumba	49 $feet^3$/second
	Flow from Mexico, east of Jacumba	9.6 $feet^3$/second
	Old dam, head of Carrizo Gorge	45 $feet^3$/second
4/1/80	Boundary Creek, west of Jacumba	10.5 $feet^3$/second
	Flow from Mexico, east of Jacumba	2 $feet^3$/second
	Drainage west of Jacumé	5 $feet^3$/second
	Old dam, head of Carrizo Gorge	0.06 $feet^3$/second
4/13/80	Drainage west of Jacumé	4.5 $feet^3$/second
4/20/80	Boundary Creek, west of Jacumba	3.8 $feet^3$/second
	Flow from Mexico, east of Jacumba	No Flow
	Old dam, head of Carrizo Gorge	No Flow
5/9/80	Boundary Creek, west of Jacumba No other gauging station had surface flow.	3.7 $feet^3$/second
5/29/80	Boundary Creek, west of Jacumba No other gauging station had surface flow.	4 $feet^3$/second

RUNOFF ANALYSIS

The total estimated discharge of Boundary Creek, as measured west of Jacumba, between February 14th and April 1st, was 1.15×10^8 cubic feet. The surface flow entering the United States side of Jacumba Valley from Mexico was roughly 2.5×10^7 cubic feet and the total estimated discharge over the old dam at the head of Carrizo Gorge was 8.4×10^7 cubic feet.

The Boundary Creek watershed covers about 5.06×10^8 square feet. The majority of this watershed receives the precipitation recorded at Boulevard. The February and March discharge of Boundary Creek, as measured west of Jacumba, accounted for about 20%, 2.7 inches, of the February and March precipitation on the Boundary Creek watershed. The 2.7 inches of precipitation that ranoff is equivalent to about 12% of the January through March precipitation. The February through May runoff accounts for about 3.3 inches or 14% of the January through March precipitation. Precipitation during the months of April and May was not included because the potential evapotranspiration exceeded the precipitation. These values are only estimates of the actual runoff. The stream flow measurements were not made often enough to accurately gauge the runoff. Upstream from the gauging station on the west side of Jacumba, Boundary Creek flows through a small alluviated valley. This alluvium probably absorbed a portion of the runoff and reduced the volume of flow measured. Because of the lack of information, it was assumed that Boundary Creek runoff was representative of the other areas of runoff in the Jacumba Valley watershed.

The discharge into Carrizo Gorge accounted for about 74% of the February and March runoff measured in Boundary Creek. Except during periods of peak runoff, the runoff reaching the old dam was predominantly from Boundary Creek. In order to conservatively estimate the amount of infiltration, it was assumed that only the Boundary Creek runoff was reaching Carrizo Gorge. Using this assumption, roughly 26% of the Boundary Creek runoff was lost through infiltration and evaporation as it traversed a portion of Jacumba Valley. This is equivalent to about 0.7 inches of precipitation on the Boundary Creek watershed. The loss, due to infiltration and evaporation, from the runoff originating south of the international border was much greater due to the greater distance the flow had to traverse in the valley. The few runoff measurements made near Jacumé support this.

Based on the above information, it was conservatively assumed that 70% of all runoff that entered Jacumba Valley, during the months of February through May, 1980, evaporated as it flowed across the valley or was discharged from the watershed into Carrizo Gorge. The remaining 30% of the runoff was assumed to have infiltrated into the stream channels and valley alluvium and recharged the valley's ground water system.

The stream flow measurements and the determination of the total runoff are subject to significant error. The assumptions made over estimated the loss to the Jacumba Valley watershed. This would result in an underestimation of the ground water recharge.

DAILY PRECIPITATION RECORDS FOR BOULEVARD, CALIFORNIA, JANUARY-APRIL, 1980*

January:

7	-	0.30 (inches)
8	-	0.20
9	-	1.35
10	-	1.18
11	-	1.48
12	-	0.33
13	-	0.05
14	-	0.08
15	-	0.03
18	-	0.72
27	-	0.03
28	-	0.32
29	-	2.11
30	-	2.70
31	-	0.04

February:

13	-	0.55
14	-	1.01
15	-	0.81
16	-	0.17
17	-	0.90
18	-	2.10
19	-	1.37
20	-	1.22
21	-	0.80
22	-	T

March:

2	-	T
3	-	1.03
4	-	0.10
6	-	0.93
7	-	0.13
10	-	0.50
11	-	0.81
18	-	0.19
19	-	0.16
22	-	0.35
26	-	0.22

April:

1	-	0.34
2	-	0.20
21	-	0.01
22	-	0.30
23	-	0.74
24	-	0.04
28	-	0.03
29	-	0.51
30	-	0.05

*Taken from United States Environmental Service Administration monthly issues.

APPENDIX E

GROUND WATER RECHARGE CALCULATIONS

Ground Water Recharge Calculations: Jacumba Precipitation Data, Type W Soil

Soil Type W

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1963-1964	7.95 (inches)	0 (inches)	7.95 (inches)	0 (inches)
1964-1965	5.64	0	5.64	0
1965-1966	12.71	0	12.71	0
1966-1967	9.73	0	9.73	0
1967-1968	10.20	0	10.20	0
1968-1969	9.03	0	9.03	0
1969-1970	9.17	0	9.17	0
1970-1971	7.31	0	7.31	0
1971-1972	4.46	0	4.46	0
1972-1973	10.62	0	10.62	0
1973-1974	5.25	0	5.25	0
1974-1975	8.05	0	8.05	0
1975-1976	8.47	0	8.47	0
1976-1977	10.71	0	10.71	0
1977-1978	16.01	0	16.01	0
1978-1979	13.95	0	13.95	0
1979-1980	17.67	0	14.45	3.22
17 year mean				0.19

Ground Water Recharge Calculations: Jacumba Precipitation Data, Type X Soil

Soil Type X

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1963-1964	7.95 (inches)	0 (inches)	7.95 (inches)	0 (inches)
1964-1965	5.64	0	5.64	0
1965-1966	12.71	0	12.71	0
1966-1967	9.73	0	9.73	0
1967-1968	10.20	0	10.20	0
1968-1969	9.03	0	9.03	0
1969-1970	9.17	0	9.17	0
1970-1971	7.31	0	7.31	0
1971-1972	4.46	0	4.46	0
1972-1973	10.62	0	10.62	0
1973-1974	5.25	0	5.25	0
1974-1975	8.05	0	8.05	0
1975-1976	8.47	0	8.47	0
1976-1977	10.71	0	10.71	0
1977-1978	16.01	0	16.01	0
1978-1979	13.95	0	13.95	0
1979-1980	17.67	0	14.09	3.58
17 year mean				0.21

Ground Water Recharge Calculations: Boulevard Precipitation Data, Type W Soil

Soil Type W

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1925-1926	17.31 (inches)	0 (inches)	17.31 (inches)	0 (inches)
1926-1927	28.47	3.94	14.62	9.91
1927-1928	11.74	0	11.74	0
1928-1929	8.90	0	8.90	0
1929-1930	incomplete record			
1930-1931	11.32	0	11.32	0
1931-1932	incomplete record			
1932-1933	no record			
1933-1934	incomplete record			
1934-1935	18.70	0	18.57	0.13
1935-1936	10.63	0	10.63	0
1936-1937	29.90	3.02	22.21	4.67
1937-1938	15.45	0	13.58	0.92
1938-1939	15.02	0	15.02	0
1939-1940	18.04	0	18.04	0
1940-1941	25.80	0	18.08	7.72
1941-1942	16.94	0	16.94	0
1942-1943	13.25 (no record for May and June)			0
1943-1944	incomplete record			
1944-1945	11.49 (no record for July - September)			
1945-1946	14.22	0	14.22	0
1946-1947	13.11	0	13.11	0
1947-1948	9.76	0	9.76	0
1948-1949	15.21	0	13.94	1.27
1949-1950	10.49	0	10.49	0

Ground Water Recharge Calculations: Boulevard Precipitation Data, 193
Type W Soil (Continued)

Soil Type W

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1950-1951	9.52 (inches)	0 (inches)	9.52 (inches)	0 (inches)
1951-1952	23.00	0	17.82	5.18
1952-1953	12.08	0	12.08	0
1953-1954	14.26	0	13.22	1.04
1954-1955	10.22	0	10.22	0
1955-1956	13.07	0	13.07	0
1956-1957	13.75	0	13.75	0
1957-1958	17.57	0	17.57	0
1958-1959	9.19	0	9.19	0
1959-1960	12.52	0	12.52	0
1960-1961	5.84	0	5.84	0
1961-1962	12.66	0	12.66	0
1962-1963	6.41	0	6.41	0
1963-1964	11.96	0	11.96	0
1964-1965	10.92	0	10.92	0
1965-1966	14.84	0	13.31	1.53
1966-1967	11.88	0	11.88	0
1967-1968	incomplete record			
1968-1969	no record			
1969-1970	10.13 (no record for July - September)			0
1970-1971	14.57	0	14.57	0
1971-1972	7.95	0	7.95	0
1972-1973	18.28	0	16.10	2.18
1973-1974	9.72	0	9.72	0
1974-1975	14.81	0	14.81	0
1975-1976	15.28 (inches)	0 (inches)	15.28 (inches)	0 (inches)
1976-1977	16.38	0	16.38	0
1977-1978	23.30	2.80	18.32	7.18
1978-1979	24.71	0	16.19	8.52
1979-1980	30.55	3.64	17.51	9.40
48 year mean				1.24
Recharge due to infiltration from runoff				4.02

Ground Water Recharge Calculations: Boulevard Precipitation Data, Type X Soil

Soil Type X

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1925-1926	17.31 (inches)	0 (inches)	17.31 (inches)	0 (inches)
1926-1927	28.47	3.94	14.26	10.27
1927-1928	11.74	0	11.74	0
1928-1929	8.90	0	8.90	0
1929-1930	incomplete record			
1930-1931	11.32	0	11.32	0
1931-1932	incomplete record			
1932-1933	no record			
1933-1934	incomplete record			
1934-1935	18.70	0	18.21	0.49
1935-1936	10.63	0	10.63	0
1936-1937	29.90	3.02	21.85	5.03
1937-1938	15.45	0	13.22	1.28
1938-1939	15.02	0	14.93	0.09
1939-1940	18.04	0	18.04	0
1940-1941	25.80	0	17.72	8.08
1941-1942	16.94	0	16.94	0
1942-1943	13.25 (no record fro May and June)			0
1943-1944	incomplete record			
1944-1945	11.49 (no record for July - September)			0
1945-1946	14.22	0	14.22	0
1946-1947	13.11	0	13.11	0
1947-1948	9.76	0	9.76	0
1948-1949	15.21	0	13.58	1.63
1949-1950	10.49	0	10.49	0

Ground Water Recharge Calculations: Boulevard Precipitation Data, Type X Soil (Continued)

Soil Type X

Water Year	Precipitation	Runoff	Evapotranspiration	Calculated Recharge
1950-1951	9.52 (inches)	0 (inches)	9.52 (inches)	0 (inches)
1951-1952	23.00	0	17.46	5.54
1952-1953	12.08	0	12.08	0
1953-1954	14.26	0	12.86	1.40
1954-1955	10.22	0	10.22	0
1955-1956	13.07	0	13.07	0
1956-1957	13.75	0	13.75	0
1957-1958	17.57	0	17.57	0
1958-1959	9.19	0	9.19	0
1959-1960	12.52	0	12.52	0
1960-1961	5.84	0	5.84	0
1961-1962	12.66	0	12.66	0
1962-1963	6.41	0	6.41	0
1963-1964	11.96	0	11.96	0
1964-1965	10.92	0	10.92	0
1965-1966	14.84	0	12.95	1.89
1966-1967	11.88	0	11.88	0
1967-1968	incomplete record			
1968-1969	no record			
1969-1970	10.13 (no record for July - September)			0
1970-1971	14.57	0	14.57	0
1971-1972	7.95	0	7.95	0
1972-1973	18.28	0	15.74	2.54
1973-1974	9.72	0	9.72	0
1974-1975	14.81	0	14.81	0
1975-1976	15.28 (inches)	0 (inches)	15.28 (inches)	0 (inches)
1976-1977	16.38	0	16.38	0
1977-1978	28.30	2.80	17.96	7.54
1978-1979	24.71	0	15.83	8.88
1979-1980	30.55	3.64	17.15	9.76
48 year mean				1.34
Recharge due to infiltration from runoff				4.02

GROUND WATER RECHARGE CALCULATIONS

The mean annual ground water recharge for the Jacumba Valley watershed was calculated in the following manner:

Boulevard Precipitation Data:

Soil type W covers 9.91 x 10^6 square feet. This soil type averaged 1.24 inches of recharge per year.
The mean annual recharge for the type W soil is 1.02 x 10^6 cubic feet.

Soil type X covers 6.4415 x 10^8 square feet. This soil type averaged 1.34 inches of recharge per year.
The mean annual recharge for the type X soil is 7.193 x 10^7 cubic feet.

Jacumba Precipitation Data:

Soil type W covers 3.8979 x 10^8 square feet. This soil type averaged 0.19 inches of recharge per year.
The mean annual recharge for the type W soil is 6.17 x 10^6 cubic feet.

Soil type X covers 2.04145 x 10^9 square feet. This soil type averaged 0.21 inches of recharge per year.
The mean annual recharge for the type X soil is 3.573 x 10^7 cubic feet.

The total mean annual ground water recharge due to infiltration from precipitation is 1.1485 x 10^8 cubic feet.

Ground water recharge due to infiltration from runoff in Jacumba Valley equalled 4.02 inches for the 48 years of precipitation records in Boulevard. This runoff was generated on both type W and type X soils in the Boulevard portion of the watershed. The total ground water recharge for the entire 48 years was 2.1911 x 10^8 cubic feet. The mean annual recharge is 4.56 x 10^6 cubic feet.

The total mean annual ground water recharge for the Jacumba Valley watershed is 1.1942×10^8 cubic feet (3.3815×10^6 cubic meters (2740 acre-feet).

ERROR ANALYSIS FOR GROUND WATER RECHARGE CALCULATIONS

Error

A 10% error in determining the specific retention of a soil type would result in a 10-15% error in the calculated recharge for that soil type.

Type X Soil

specific retention = 0.27 $inch^3$ of water/$inch^3$ of soil
10% error = 0.03
If the true specific retention were = 0.30 $inch^3$ of water/$inch^3$ of soil, the the following change in the calculated recharge would result:

Boulevard Precipitation Data:

Year Recharge Occurred	Recharge (inches)	Recharge with Error (inches)
1926-1927	10.27	9.54
1934-1935	0.49	0
1936-1937	5.03	4.31
1937-1938	1.28	0.63
1938-1939	0.09	0
1940-1941	8.08	7.43
1948-1949	1.63	0.98
1951-1952	5.54	4.89
1953-1954	1.40	0.75
1965-1966	1.89	1.24
1972-1973	2.54	1.89
1977-1978	7.54	6.82
1978-1979	8.88	8.23
1979-1980	9.76	9.04
Total	64.42	55.75
Mean (48 years)	1.33	1.16
Error		13%

Jacumba Precipitation Data:

1979-1980	3.58	2.98
Mean (17 years)	0.21	0.17

The error calculated above for type X soil would result in a 13% decrease in the mean annual calculated recharge for the entire watershed. A 10% error in the specific retention for type W soil would result in only a 1% error in the total calculated recharge. This is because type X soil covers a much greater area than type W soil.

RECHARGE CALCULATIONS BASED ON THE UNITED STATES SOIL CONSERVATION SERVICE HYDROLOGIC SOIL GROUPS

Soil Groups	Available Water Holding Capacity (inches)	Active Soil Depth (inches)
A	0.05-0.07	36
B	0.09-0.13	36
C	0.10-0.14	36
D	0	0

Using the above values, yearly recharge calculations were made in the same manner as the original recharge calculations. These calculations are summarized in Error Analysis for Ground Water Recharge Calculations, page . The mean annual ground water recharge for the Jacumba Valley watershed, based on the above hydrologic soil groups, was calculated in the following manner:

Boulevard Precipitation Data:

Group A soil covers 2.0259×10^8 square feet. This soil group averaged 3.18-3.85 inches of recharge per year.
The mean annual recharge for the group A soil is $5.369\text{-}6.500 \times 10^7$ cubic feet.

Group B soil covers 9.03×10^6 square feet. This soil group averaged 1.97-2.60 inches of recharge per year.
The mean annual recharge for the group B soil is $1.48\text{-}1.96 \times 10^6$ cubic feet.

Group C soil covers 3.7971×10^8 square feet. This soil group averaged 1.76-2.38 inches of recharge per year.
The mean annual recharge for the group C soil is $5.57\text{-}7.53 \times 10^7$ cubic feet.

Jacumba Precipitation Data:

Group A soil covers 3.0716 x 10^8 square feet. This soil group averaged 1.07-1.42 inches of recharge per year.

The mean annual recharge for the group A soil is 2.739-3.635 x 10^7 cubic feet.

Group B soil covers 1.4044 x 10^8 square feet. This soil group averaged 0.53-0.85 inches of recharge per year.

The mean annual recharge for the group B soil is 6.20-9.95 x 10^6 cubic feet.

Group C soil covers 8.2731 x 10^8 square feet. This soil averaged 0.40-0.76 inches of recharge per year.

The mean annual recharge for the group C soil is 2.758-5.240 x 10^7 cubic feet.

The total mean annual ground water recharge due to infiltration from precipitation is 1.7204-2.4096 x 10^8 cubic feet.

Ground water recharge due to infiltration from runoff in Jacumba Valley equalled 4.02 inches for the 48 years of precipitation records in Boulevard. The total ground water recharge for the entire 48 years was 1.9810 x 10^8 cubic feet. The mean annual recharge is 4.13 x 10^6 cubic feet.

The total mean annual ground water recharge for the Jacumba Valley watershed is 1.7617-2.4509 x 10^8 cubic feet (4.9886-6.9402 x 10^6 cubic meters)(4043-5624 acre-feet).

Groundwater Recharge Calculations Based on the United States Soil Conservation Service and Forest Service (December, 1973) Soil Groups

Boulevard Precipitation Data

Water Year	Soil Group A	Soil Group B	Soil Group C
1926-1927	14.22 - 15.06 (inches)	12.18 - 13.50 (inches)	11.61 - 13.14 (inches)
1927-1928	1.00 - 1.84	0 - 0.28	0
1928-1929	0 - 0.51	0	0
1930-1931	1.36 - 2.20	0 - 0.42	0 - 0.06
1934-1935	4.45 - 5.29	2.41 - 3.73	1.84 - 3.37
1935-1936	1.63 - 2.47	0 - 0.91	0 - 0.55
1936-1937	8.99 - 9.83	6.95 - 8.27	6.38 - 7.91
1937-1938	5.24 - 6.08	3.20 - 4.52	2.63 - 4.16
1938-1939	4.05 - 4.89	2.01 - 2.95	1.44 - 2.97
1939-1940	0.96 - 1.88	0 - 0.24	0
1940-1941	12.79 - 12.88	10.00 - 11.32	9.43 - 10.96
1941-1942	2.41 - 3.25	0.37 - 1.69	0 - 1.33
1942-1943	2.90 - 3.74	0.86 - 2.18	0.29 - 1.82
1944-1945	2.03 - 2.87	0.08 - 1.40	0 - 0.95
1945-1946	0.17 - 1.01	0	0
1946-1947	0.27 - 1.11	0	0
1947-1948	0 - 0.31	0	0
1948-1949	5.59 - 6.43	3.45 - 4.87	2.98 - 4.50
1949-1950	0.45 - 1.29	0	0
1950-1951	0 - 0.40	0	0
1951-1952	9.50 - 10.34	7.46 - 8.78	6.89 - 8.42
1952-1953	1.48 - 2.32	0 - 0.76	0 - 0.40
1953-1954	5.36 - 6.20	3.32 - 4.64	2.75 - 4.28
1954-1955	0.12 - 0.96	0	0
1956-1957	3.02 - 3.86	0.98 - 2.30	0.41 - 1.94
1957-1958	3.85 - 4.79	1.81 - 3.13	1.24 - 2.77

Groundwater Recharge Calculations Based on the United States Soil Conservation Service and Forest Service (December, 1973) Soil Groups (Continued)

Water Year	Soil Group A	Soil Group B	Soil Group C
1958-1959	0.59 - 1.43 (inches)	0 (inches)	0 (inches)
1959-1960	1.12 - 1.96	0 - 0.40	0 - 0.04
1961-1962	2.29 - 3.13	0	0
1965-1966	5.85 - 6.69	3.81 - 5.13	3.24 - 4.77
1966-1967	1.06 - 1.90	0 - 0.34	0
1969-1970	0 - 0.70	0	0
1970-1971	1.21 - 2.05	0 - 0.49	0 - 0.13
1971-1972	0.74 - 1.58	0 - 0.02	0
1972-1973	6.50 - 7.34	4.46 - 5.78	3.89 - 4.42
1973-1974	1.47 - 2.31	0 - 0.75	0 - 0.39
1974-1975	0.62 - 1.46	0	0
1975-1976	1.94 - 2.78	0 - 1.22	0 - 0.86
1977-1978	10.94 - 11.78	8.90 - 10.22	8.33 - 9.86
1978-1979	12.84 - 13.68	10.80 - 12.12	10.23 - 11.76
1979-1980	13.72 - 14.56	11.68 - 13.00	11.11 - 12.64
48 year mean	3.18 - 3.85	1.97 - 2.60	1.76 - 2.38

Jacumba Precipitation Data

Water Year	Soil Group A	Soil Group B	Soil Group C
1965-1966	3.54 - 4.38 (inches)	1.50 - 2.82 (inches)	0.93 - 2.46 (inches)
1966-1967	0 - 0.81	0	0
1967-1968	0.93 - 1.77	0 - 0.21	0
1969-1969	0 - 0.52	0	0
1972-1973	0 - 0.06	0	0
1973-1974	0 - 0.18	0	0
1975-1976	0 - 0.20	0	0
1977-1978	3.49 - 4.33	1.45 - 2.77	0.88 - 2.41
1979-1980	7.54 - 8.38	5.50 - 6.82	4.93 - 6.46
17 year mean	1.07 - 1.42	0.53 - 0.85	0.40 - 0.76

APPENDIX F

AQUIFER PROPERTIES

AQUIFER PROPERTIES

Calculations of the Saturated Volume of the Table Mountain Aquifer

Calculations of saturated volume were based on the cross-sections A-A' and B-B' and the water level measured in well R1. The aquifer was divided into two sections along the northwesterly trending fault that passes between Round Mountain and the long flat hill to the west.

East Section

This section is 5200 feet wide. It was divided into three portions.

Northern portion: 4600 feet long. Saturated thickness ranges from 0 in the north to 600 in the south.
Volume = (5200 ft)(4600 ft)(600 ft)1/2 =
7.176×10^9 cubic feet

Middle portion: 9400 feet long. The saturated thickness ranges from 600 feet in the north to 550 feet in the south.
Volume = (5200 ft)(9400 ft)(575 ft) =
2.8106×10^{10} cubic feet

South portion: 4200 feet long. Saturated thickness ranges from 550 feet in the north to 200 feet in the south.
Volume = (5200 ft)(4200 ft)(50 ft) +
(5200 ft)(4200 ft)(550 ft)1/2 =
7.098×10^9 cubic feet

West Section

This section is 4100 feet wide. It was divided into three portions.

Northern portion: 6000 feet long. The saturated thickness ranges from 0 in the north to 600 feet in the south.
Volume = (4100 ft)(6000 ft)(600 ft)1/2 =
7.380×10^9 cubic feet

Middle portion: 4000 feet long. The saturated thickness is 600 feet.
Volume = (4100 ft)(4000 ft)(600 ft) = 9.840×10^9 cubic feet

Southern portion: 8300 feet long. The saturated thickness ranges from 600 feet in the north to 200 feet in the south.
Volume = (4100 ft)(8300 ft)(200 ft) +
(4100 ft)(8300 ft)(400 ft)1/2 =
1.3612×10^{10} cubic feet

Total Saturated Volume = 7.3212×10^{10} cubic feet (2.0731×10^{9} cubic meters)

Recoverable Water, based on a 5% specific yield, 3.661×10^{9} cubic feet
(1.037×10^{8} cubic meters)
(84,000 acre-feet)

based on a 10% specific yield, 7.321×10^{9} cubic feet
(2.073×10^{8} cubic meters)
(168,000 acre-feet)

Calculations of the Saturated Volume of the Quarternary Alluvium Aquifer

The calculations were based on two different water levels in the alluvial aquifer: (1) the water table as measured in November, 1979, and (2) the maximum water level on record, about 30 feet below the surface in well J1 in 1955. The alluviated portion of Jacumba Valley where ground water occurs in significant quantities was divided into five sections for the calculations (Figure 40).

Section A

Width = 1250 feet
Length = 7000 feet
Saturated thickness (1) north to south 0-30 feet, east to west 0-30-0 average thickness is 15 feet
(2) north to south 0-50 feet, east to west 0-50-0 average thickness is 25 feet

Volume: (1) (1250 ft)(7000 ft)(15 ft) = 1.31×10^8 cubic feet
(2) (1250 ft)(7000 ft)(25 ft) = 2.19×10^8 cubic feet

Section B

Width = 2000 feet
Length = 2000 feet
Saturated thickness (1) 30 feet
(2) 50 feet

Volume: (1) (2000 ft)(2000 ft)(30 ft) = 1×10^5 cubic feet
(2) (2000 ft)(2000 ft)(50 ft) = 2×10^5 cubic feet

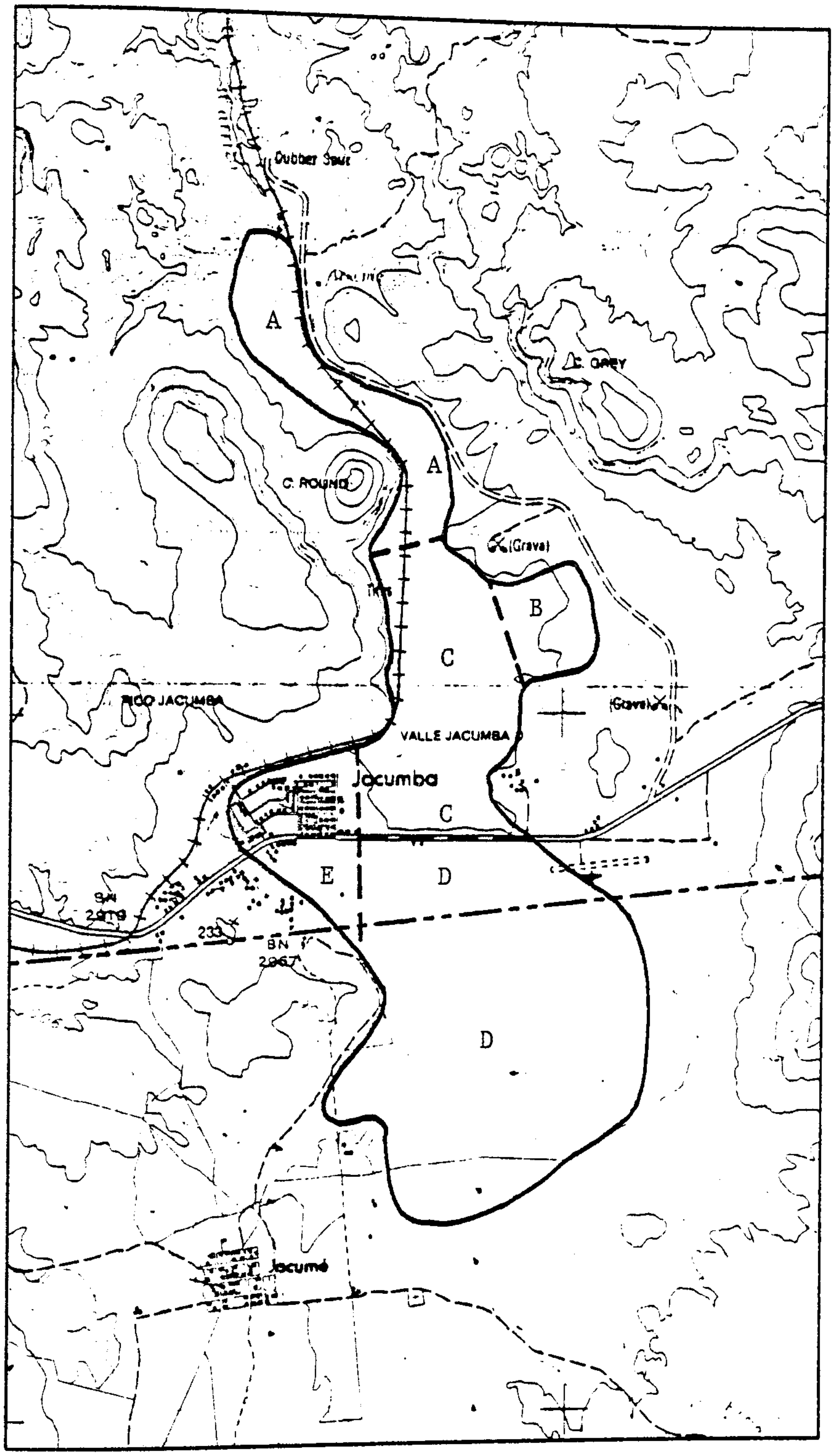

Figure 40. Sections of the Quaternary Alluvial Aquifer Used for the Calculation of the Saturated Volume (Scale 1:50,000)

N

Section C

Width = 2330 feet
Length = 6000 feet
Saturated thickness (1) north to south 30-60 feet, east to west 30-0 in northern half and 0-60 in southern half average is 45 feet
(2) north to south 50-90 feet, east to west 50-0 in northern half and 0-90 in southern half average is 70 feet

Volume: (1) (2330 ft)(6000 ft)(45 ft) = 6.29×10^8 cubic feet
(2) (2330 ft)(6000 ft)(70 ft) = 9.79×10^8 cubic feet

Section D

Width = 7100 feet
Length = 8300 feet
Saturated thickness (1) north to south 60-0 feet, east to west 0-60-0 average is 30 feet
(2) north to south 90-0 feet, east to west 0-90-0 average is 45 feet

Volume: (1) (7100 ft)(8300 ft)(30 ft)1/2 = 1.768×10^9 cubic feet
(2) (7100 ft)(8300 ft)(45 ft)1/2 = 2.652×10^9 cubic feet

Section E

Width = 3300 feet
Length = 5200 feet
Saturated thickness (1) north to south 0-60-0 feet, east to west 0-60 feet average is 30 feet
(2) north to south 0-90-0 feet, east to west 90-0 average is 45 feet

Volume: (1) (3300 ft)(5200 ft)(30 ft)1/2 = 2.57×10^8 cubic feet
(2) (3300 ft)(5200 ft)(45 ft)1/2 = 3.86×10^8 cubic feet

Total Saturated Volume: (1) 2.785×10^9 cubic feet (7.89×10^7 cubic meters)

(2) 4.236×10^9 cubic feet (1.200×10^8 cubic meters)

Recoverable Water:

Based on a 5% specific yield:

(1) 1.39×10^8 cubic feet
(3.94×10^6 cubic meters)
(3195 acre-feet)

(2) 2.12×10^8 cubic feet
(6.00×10^6 cubic meters)
(4860 acre-feet)

Based on a 10% specific yield:

(1) 2.79×10^8 cubic feet
(7.89×10^6 cubic meters)
(6390 acre-feet)

(2) 4.24×10^8 cubic feet
(1.20×10^7 cubic meters)
(9720 acre-feet)

Attempted Calculation of Specific Yield

The specific yield of the Table Mountain aquifer and the alluvial aquifer was calculated by using data on fluctuations in the aquifers water tables caused by localized, intense ground water recharge events. The propagation of the recharge pulse through the aquifers was assumed to be similar to the propagation of heat through a semi-infinite solid. Carslaw and Jaeger (1951) present equations relating the velocity of propagation of the heat pulse and the change in amplitude of the pulse to the diffusivity of the medium. The basic equation for a heat pulse propagating through a semi-infinite solid is: $V = Ae^{-kx}\text{Cos}(\omega t - kx - \varepsilon)$. V is the velocity of propagation of the pulse, A is the amplitude of the pulse, k is the diffusivity of the medium, x is the distance the pulse has moved through the medium, $\omega = \frac{2\Pi}{\text{Period}}$. From this basic equation, Carslaw and Jaeger (1951) derived the equation $V = (2k\omega)^{1/2}$, which relates the velocity of propagation of the heat pulse to the diffusivity of the medium. The equation

$$A_d = A_s e^{-x\sqrt{\frac{\omega}{2k}}}$$

was derived relating the change in amplitude in the pulse to the diffusivity of the medium. A_s is the amplitude of the pulse at the surface and A_d is the amplitude of the pulse at some depth within the medium.

Table Mountain Aquifer

Surface flow on the Mexican side of Jacumba Valley recharged the Table Mountain aquifer, probably in the area between Jacumé and the international border. The recharge began on February 14th and was first recorded in well R1 eighty-five days later on May 9th. The period of the recharge pulse, as determined at well Km, was fifty days. The distance between the place of recharge and well R1 is 2100-3000 meters. From this the velocity was determined to be 25-36 meter/day and the diffusivity of the aquifer was 2485-5147 meter^2/day.

The transmissivity of the Table Mountain aquifer, as determined by the pump test on well R2, is 0.62 meter^2/day. The calculated specific yield for this aquifer is 1.2×10^{-4} to 2.5×10^{-4}. Because of the unreasonably low values, it is apparent that these values represent the storage coefficient and not the specific yield. The fact that the storage coefficient was calculated and not the specific yield may be due to the partial confinement of the Table Mountain aquifer.

Quaternary Alluvium Aquifer

Recharge to the alluvial aquifer occurred in the vicinity of well Km. The recharge began on February 14th.

The period of the recharge pulse was fifty days, as determined by the surface runoff data and the water level measurements in well Km. The attempt to calculate the diffusivity and specific yield of the aquifer used data from well Km, Kl, and K3. The calculations were based on the velocity of propagation of the recharge pulse and the change in amplitude of the pulse. The transmissivity of the alluvial aquifer is 2850 meter^2/day, as determined by the pump test on well J1.

Boundary Creek to well K1

Distance = 270 meters
The recharge pulse was first measured in the well 27 days after the beginning of recharge near well Km
Velocity = 10 meters/day
Diffusivity = 403 $meter^2$/day

Amplitude at the surface = 6.71 meters
Amplitude at depth = 2.74 meters
Diffusivity = 5,710 $meter^2$/day
Specific Yield = 50%

Boundary Creek to well K3

Distance = 670 meters
The recharge pulse was first measured in the well 85 days after the beginning of recharge near well Km
Velocity = 7.9 meters/day
Diffusivity = 250 $meter^2$/day

Amplitude at the surface = 6.71 meters
Amplitude at depth = 0.96 meters
Diffusivity = 7460 $meter^2$/day
Specific Yield = 38%

Well K1 to well K3

Distance = 480 meters
The recharge pulse was first measured at the two wells 58 days apart
Velocity = 8.3 meters/day
Diffusivity = 270 $meter^2$/day

Amplitude at well K1 = 2.74 meters
Amplitude at well K3 = 0.96 meters
Diffusivity = 13,390 $meter^2$/day
Specific Yield = 21%

Mean Values

Mean diffusivity based on the velocity of propagation calculations = 308 $meter^2/day$

Mean specific yield = 926%

Mean diffusivity based on the change in amplitude calculations = 8,853 $meter^2/day$

Mean specific yield = 32%

The value of specific yield determined by the velocity of propagation calculations is unreasonably high. The value of specific yield determined by the change in amplitude calculations also appears rather high and shows considerable variation in the calculations. As a result, none of the calculated values are considered valid estimates of the aquifer's specific yield. The inability to calculate the specific yield may be due to the long periods between the water level measurements in the wells. This made the determination of the velocity of propagation and the change in amplitude inaccurate. It is also possible that while the recharge pulse was propagating through the entire aquifer, the value of transmissivity was determined for only the coarsest portion of the aquifer.

APPENDIX G

GROUND WATER BUDGET

GROUND WATER BUDGET

Subsurface Discharge Calculations

The subsurface discharge of ground water from the Table Mountain and Quaternary Alluvium aquifers, into the bedrock at the north end of Jacumba Valley, was estimated by calculating the volume of water that could flow through the aquifers in the area north of Interstate 8. Darcy's law and data obtained from pump tests and water level measurements were used to make the calculations. The results of the calculations are estimates and are assumed to represent the maximum possible subsurface discharge. The actual subsurface discharge from the aquifers into the bedrock is undoubtedly less due to the lower hydraulic conductivity of the bedrock.

Table Mountain Aquifer

$Q = KA\Delta h/L$
$T = 0.62$ meter^2/day
$b = 150$ meters
$K = T/b = 4.13 \times 10^{-3}$ meters/day
A (north of Interstate 8) = (1440 meters)(150 meters) = 216,000 square meters
L (to well R1) = 3800 meters
Δh (from the water level in well R1 to the lower contact of the formation just north of Interstate 8) = 170 meters

$Q = 40$ meter^3/day = 14,600 meter^3/year (12 acre-feet/year)

Quaternary Alluvium Aquifer

$Q = Ka\Delta h/L$

$T = 2850\ \text{meter}^2/\text{day}$

$b = 16.8$ meters

$K = T/b = 170$ meters/day

A (north of Interstate 8) = (450 meters)(5 meters) = 2250 square meters

L (to well K3) = 3650 meters

Δh (Nov. 1979) = 18.3 meters (in well K3)

Δh (1955) = 27.4 meters (in well K3)

Q (Nov. 1979) = 1918 meter^3/day = 699,975 meter^3/year (567 acre-feet/year)

Q (1955) = 2871 meter^3/day = 1,048,050 meter^3/year (849 acre-feet/year)

Ground Water Budget 1955-1979

The ground water budget for Jacumba Valley, during the period 1955-1979, was calculated using the available data on ground water recharge and changes in water levels in the alluvial aquifer.

Calculated Ground Water Recharge 1955-1978

Ground water recharge only occurred in the Boulevard portion of the Jacumba Valley watershed. It was assumed that all of the recharge during the 1977-1978 water year had reached the valley's ground water system and that none of the 1978-1979 recharge had reached the valley. The actual case is that a portion of each year's recharge had already reached Jacumba Valley, while the remainder was still moving through the bedrock aquifer to the west of the valley. Estimates of recharge were made for the water years 1967-1968 and 1968-1969, 3.5 inches and 1.0 inches respectively.

Type W Soil

16.32 inches of total recharge between 1955-1978.
The area covered by type W soil in the Boulevard portion of the watershed is = 9.91×10^6 square feet.
Total recharge = 1.35×10^7 cubic feet (3.82×10^5 cubic meters)

Type X Soil

17.40 inches of total recharge between 1955-1978.
The area covered by type X soil in the Boulevard portion of the watershed is = 6.44147×10^8 square feet.
Total recharge = 9.340×10^8 cubic feet (2.645×10^7 cubic meters)

Total ground water recharge 1955-1978 = 2.683×10^7 cubic meters (21,740 acre-feet)

Loss from Storage in the Alluvial Aquifer 1955-1979

During the period 1955-1979 the water level in well K3 declined from 2760 feet to 2728 feet. The loss of available storage due to this decline is:

3.90×10^6 cubic meters (3160 acre-feet) based on a 5% specific yield

6.00×10^6 cubic meters (4860 acre-feet) based on a 10% specific yield

Total Ground Water Budget 1955-1979

The total ground water budget for Jacumba Valley shows a net loss of between 3.07×10^7 cubic meters (24,900 acre-feet) and 3.28×10^7 cubic meters (26,600 acre-feet) depending on the specific yield of the aquifer.

The average yearly loss is: 1.3×10^6 cubic meters (1040 acre-feet)

to

1.4×10^6 cubic meters (1110 acre-feet)

The ground water budget is an estimate. In its calculation, it was assumed that there was no loss of stored water in the Table Mountain aquifer. There was very likely some loss of storage in that aquifer; however, there is no water level data to indicate a loss.

APPENDIX H

WATER LEVEL RECORDS

WATER LEVEL RECORDS

Date	Well	Depth to Water	Well Elevation	Recorded by
7/55	K3	38.5 (feet)	2798.5 (feet)	driller (Ketchum, 1980)
	08 J	43.3	2790.0	Calif. D.W.R. (1980)*
9/55	08 K	46.3	2790.0	" " " "
	08 Q	55.4	2790.0	" " " "
10/55	J1	43	2800	driller (C.S.D.P.H., 1980)#
5/56	08 Q	56.3	2790.0	Calif. D.W.R., (1980)*
	09 H	100.1	2860.0	" " " "
9/56	08 J	54.2	2790.0	" " " "
	08 Q	62.2	2790.0	" " " "
	09 H	100.1	2860.0	" " " "
5/57	08 J	52.1	2790.0	" " " "
	08 K	55.0	2790.0	" " " "
	08 Q	63.0	2790.0	" " " "
	09 H	98.4	2860.0	" " " "
4/58	K1	37	2781	driller (Ketchum, 1980)
	K2	41	2781	" " " "
5/58	09 H	98.0	2860.0	Calif. D.W.R., (1980)*
7/63	J2	80	2800	driller (C.S.D.P.H., 1980)#
7/66	J3A	22	2843	" " " " "
9/72	J4	20	2840	" " " " "
11/20/79	J3	6.6	2850	author
	J2	72.6	2800	" "
	K3	69.9	2798	" "
11/27/79	J2	72.7 (J1 pumping)	2800	" "
	K1	60.7	2781	" "
	K3	69.8	2798	" "
	Km	49.6	2793	" "

* California Department of Water Resources
# County of San Diego, Department of Public Health

WATER LEVEL RECORDS (Continued)

Date	Well	Depth to Water	Well Elevation	Recorded by
12/11/79	K1	57.5 (feet)	2781 (feet)	author
	K3	69.45	2798	" "
	H1	193.5		" "
2/12/80	J3	5.15	2850	" "
	J2	72.05	2800	" "
	K3	68.6	2798	" "
	K1	56.4	2781	" "
	Km	46.15	2793	" "
	H1	193.2		" "
2/27/80	J3	4.6	2850	" "
	J2	70.7	2800	" "
	K3	68.0	2798	" "
	K1	55.7	2781	" "
	Km	pumping		" "
	H1	193.0		" "
3/12/80	J3	4.5	2850	" "
	J2	70.3	2800	" "
	K3	67.55	2798	" "
	K1	53.55	2781	" "
	Km	33.45	2793	" "
	H1	192.6		" "
4/01/80	J2	69.55	2800	" "
	K3	66.7	2798	" "
	K1	48.5	2781	" "
	Km	24.2	2793	" "
	H1	192.1		" "
	R1	106.3	2847	" "

WATER LEVEL RECORDS (Continued)

Date	Well	Depth to Water	Well Elevation	Recorded by
4/20/80	J3	4.5	2850	author
	J2	68.7	2800	" "
	K3	65.7	2798	" "
	K1	46.7	2781	" "
	Km	pumping		" "
	H1	191.75		" "
	R1	106.2	2847	" "
5/09/80	J2	67.6	2800	" "
	K3	64.5	2798	" "
	K1	45.9	2781	" "
	Km	24.2	2793	" "
	H1	191.3		" "
	R1	102.3	2847	" "
5/29/80	J3	4.5	2850	" "
	J2	66.3	2800	" "
	K3	63.25	2798	" "
	K1	45.3	2781	" "
	Km	pumping		" "
	H1	190.75		" "
	R1	105.6	2847	" "
9/06/80	J3	pumping		" "
	J2	58.8	2800	" "
	K3	55.9	2798	" "
	K1	42.3	2781	" "
	Km	pumping		" "
	H1	188.5		" "
	R1	105.7	2847	" "

APPENDIX I

PUMP TESTS

PUMP TESTS

Quaternary Alluvial Aquifer

A pump test on well J1 was performed in November, 1979. Well J2, located 150 feet from well J1, and well K3, 340 feet from well J1, were used as observation wells. Well J1 is 124 feet deep, well J2 is 140 feet deep, and well K3 is 117 feet deep. The pump test lasted for only four hours due to the limited size of the reservoir the water was being pumped into. The change in water level in each well was monitored. The pumping well, J1, showed a rapid decline in water level, followed by a much slower rate of decline which fluctuated due to some fluctuation of the discharge. The data from this well were not useable and were not included in this report. The data from well J2 were useable and are presented below and in Figure 42. Well K3 showed no change in water level.

Time Since Start of Pumping (minutes)	Depth to Water (feet)	Drawdown (feet)
0	72.13	0
1	72.18	0.05
2	72.18	0
8	72.18	0
33	72.18	0
64	72.20	0.02
116	72.24	0.06
165	72.26	0.08
217	72.26	0.08
248	72.30	0.12
250 stop pump test		

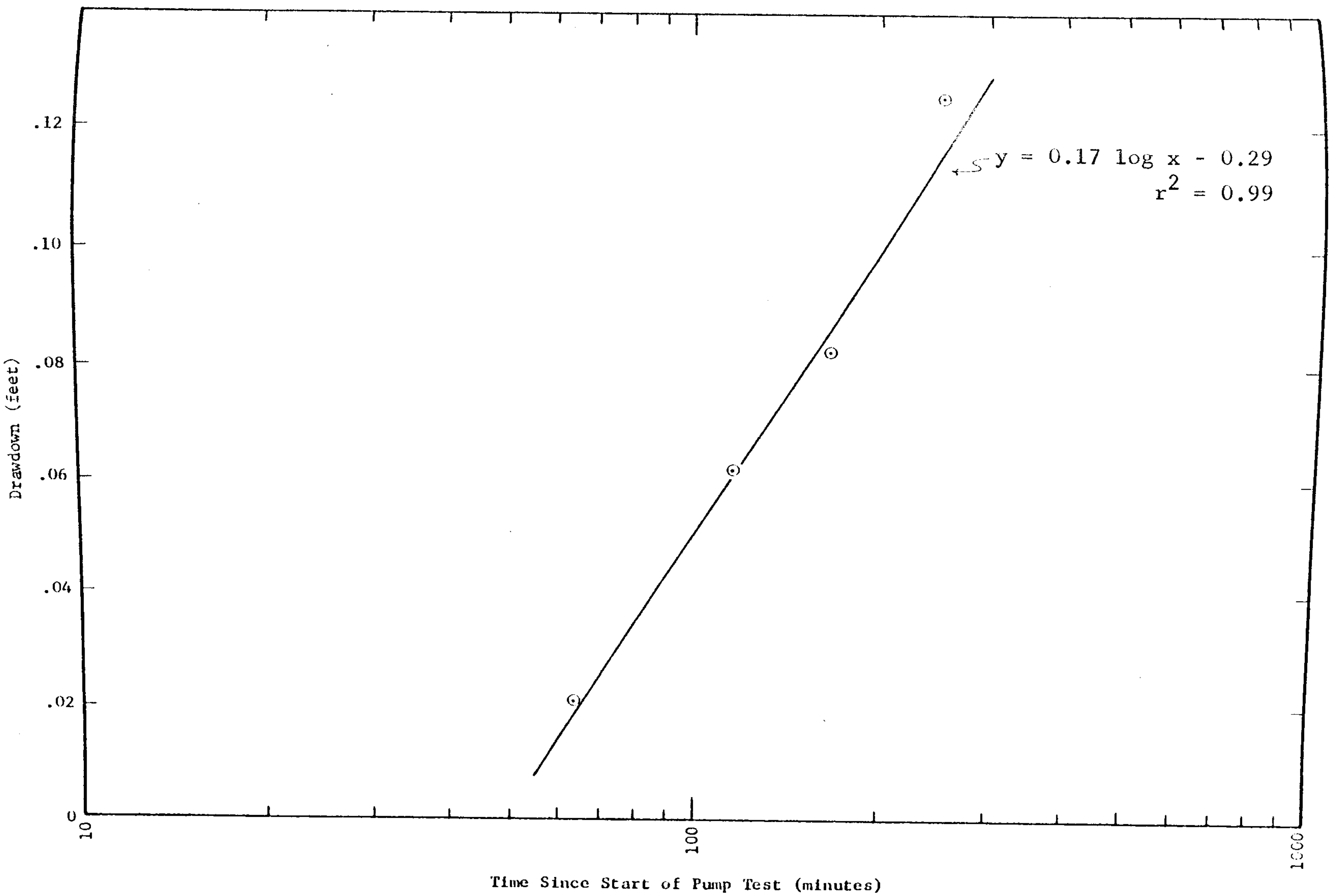

Figure 42. Alluvial Aquifer Pump Test. Observation Well J2.

It was not possible to directly measure the discharge during the pump test on well J1. Instead, the average discharge was calculated in the following manner:

37 kilowatt-hours of electricity was used during the pump test or an average of 0.15 kilowatt-hours/minute (398280 foot-pounds/minute).

A pressure gauge on the head of the pump showed an average of 68 pounds/inch^2 of head during the pump test.

The water level in the pumping well averaged about 76 feet below the ground surface.

The total head = 68 lb/in^2 + 76 ft
= 157 ft of H2O + 76 ft
= 233 feet

$$\frac{\text{Work}}{\text{Time}} = \frac{(\text{unit weight water})(\text{discharge})(\text{head})}{(\text{efficiency})}$$

$$\text{Discharge} = \frac{(\text{efficiency})(\text{work/time})}{(\text{unit weight water})(\text{head})}$$

$$= \frac{(\text{efficiency})(398280 \text{ ft-lb/min})}{(62.2 \text{ lb/ft}^3)(233 \text{ ft})}$$

$$= (\text{efficiency})(27.48 \text{ ft}^3\text{/min})$$

An estimate of the efficiency of the pump was used in the above equation to calculate the discharge. This calculated discharge was compared to the performance graph of efficiency versus discharge supplied by the pump manufacturer, and a new estimate of efficiency was determined. This new estimate of efficiency was used in the above equation. This process was repeated until the value of discharge remained constant. Using this method, the discharge of the pump in well J1 averaged:

148 gallons/minute

or

19.8 feet^3/minute

Error Analysis:

Discharge = 19.8 $feet^3$/minute $\pm$ 10%
slope = 0.17 $\pm$ .02 feet = $\pm$ 12%

T = 21.3 $\pm$ 22% $feet^2$/minute

PUMP TESTS

Table Mountain Aquifer

Two brief pump tests and a recovery test were performed on well R2 in May, 1980. Well R2 is 400 feet deep. The water levels in well R2 and well R1 350 feet away were monitored during the tests. Only well R2 showed a change in the water level. The pump tests were abbreviated because the pump was only about 40 feet below the surface of the water; as a result, the pump began sucking air shortly after the start of the test. The discharge from the pump was measured with a 2.5 gallon bucket and a stop watch. The discharge averaged 8 gallons/minute.

Pump Test #1

$Q = 1.1 \text{ feet}^3\text{/minute} \pm 10\%$
slope = 30.0 feet ± 2%

$$T = \frac{(2.3)(1.1 \text{ ft}^3\text{/min})}{4\Pi \ (30.0 \text{ ft})}$$

$$T = 6.7 \times 10^{-3} \text{ feet}^2\text{/minute} \pm 12\%$$

Recovery Test

$Q = 1.1 \text{ feet}^3\text{/minute} \pm 10\%$
slope = 82.4 feet ± 1%

$$T = \frac{(2.3)(1.1 \text{ ft}^3\text{/min})}{4\Pi \ (82.4 \text{ ft})}$$

$$T = 2.4 \times 10^{-3} \text{ feet}^2\text{/minute} \pm 11\%$$

Pump Test #2

$Q = 1.1 \text{ feet}^3/\text{minute} \pm 10\%$
slope = 41.7 feet $\pm$ 1%

$$T = \frac{(2.3)(1.1 \text{ ft}^3/\text{min})}{4\Pi\ (41.7 \text{ ft})}$$

$$T = 4.8 \times 10^{-3} \text{ feet}^2/\text{minute} \pm 11\%$$

Mean of three tests:

$$T = 4.6 \times 10^{-3} \text{ feet}^2/\text{minute} \pm 12\%, \text{ or}$$

$$T = 4.3 \times 10^{4} \text{ meter}^2/\text{minute}$$

PUMP TEST DATA FOR WELL R2. STATIC WATER LEVEL = 110.8 FEET

Time Since Start of Pump Test (Minutes)	Drawdown (feet)	Time (minutes)	Drawdown (feet)
1	2.4	45	31.1
2	5.3	46	30.5
3	7.6	47	29.8
4.5	11.6	48	29.3
6	13.6	49	28.8
9	19.2	50	28.3
11	21.4	51	27.9
14 pump automatic shut off tripped		52	27.4
		53	26.9
18	20.9	54	26.4
21	26.9	55	25.9
24	32.2	56	25.4
28	38.5	57	24.9
31 pump sucking air, shut off		58	24.5
		59	24.1
Start of Recovery Test		60	23.7
34	38.5	61	23.3
36	37.6	62	22.9
37	36.6	63	22.6
38	35.9	64	22.2
39	35.2	65	21.9
40	34.4	66	21.5
41	33.9	67	21.2
42	33.0	68	20.8
43	32.3	70	20.2
44	31.7		

Time Since Start of Pump Test (Minutes)	Drawdown (feet)
71	20.0
72	19.8
73	19.5
74	19.3
75	19.1
76	18.8
78	18.4
80	17.9
82	17.3
84	16.8
86	16.4
88	15.9
90	15.5
92	15.1
94	14.7
96	14.3
98	13.8
100	13.4
102	13.0
104	12.8
106	12.4
108	12.2
111	11.8
116	11.3
121	10.7
126	10.2

Time (minutes)	Drawdown (feet)
131	9.8
136	9.4
146	8.6
161	7.7
166	7.5
196	6.4
226	5.6
256	5.2
276	4.9

Start Pump Test #2

Time Since Start of Pump Test #2 (minutes)	Total Drawdown (feet)
0	4.9
0.5	6.8
1.0	8.1
1.5	9.4
2.0	11.0
2.5	12.1
3.0	13.3
3.5	15.1
4.0	16.3
5.0	18.7
6.0	20.4
7.0	22.5
8.0	24.9
9.0	27.0
10.0	28.9
11.0	30.7

(Continued)

Time Since Start of Pump Test #2 (minutes)		Total Drawdown (feet)
13.0		34.6
16.0		38.8
17.0	Pump sucking air, end test	

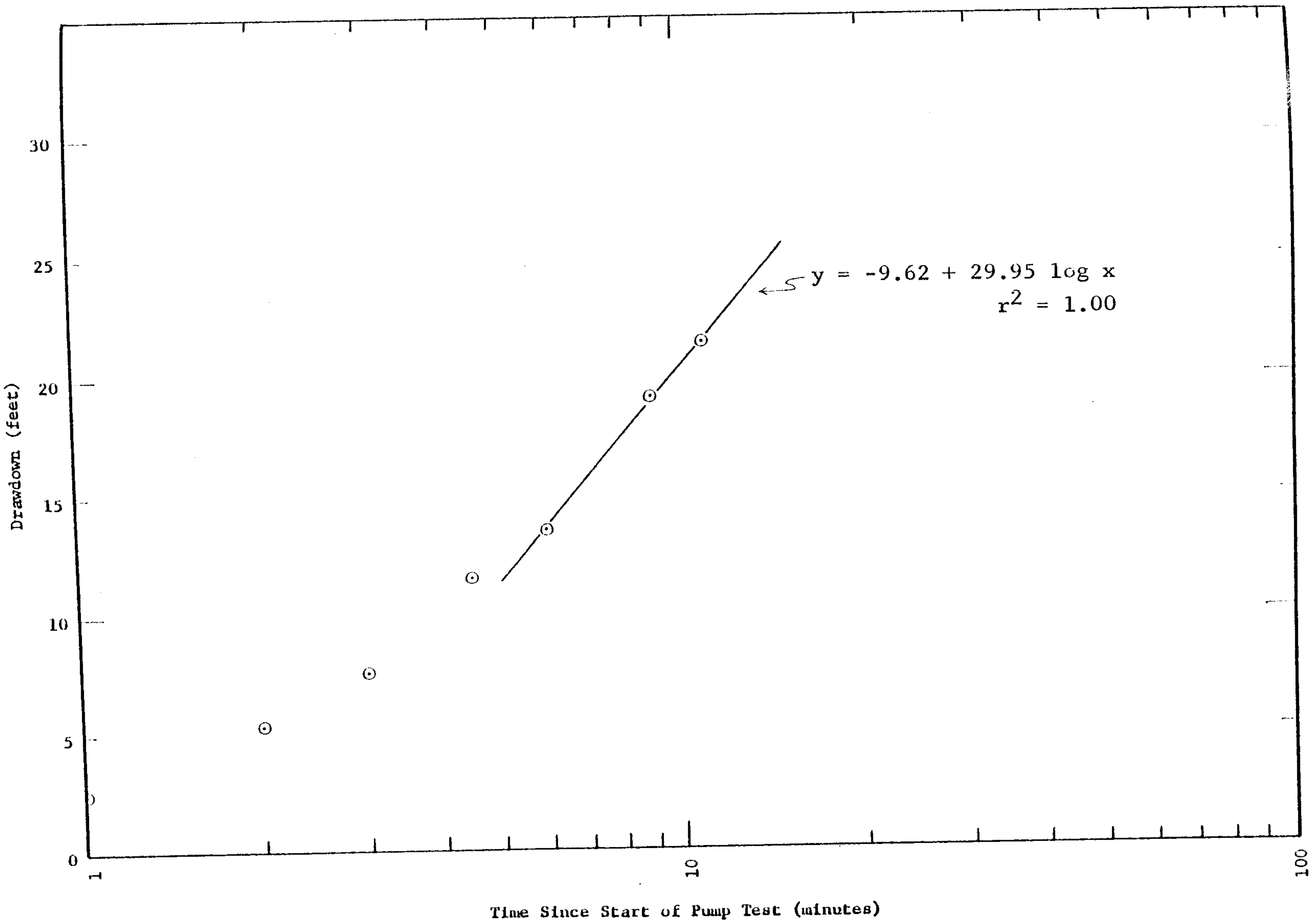

Table 43. Table Mountain Aquifer, Pump Test #1, Well R2

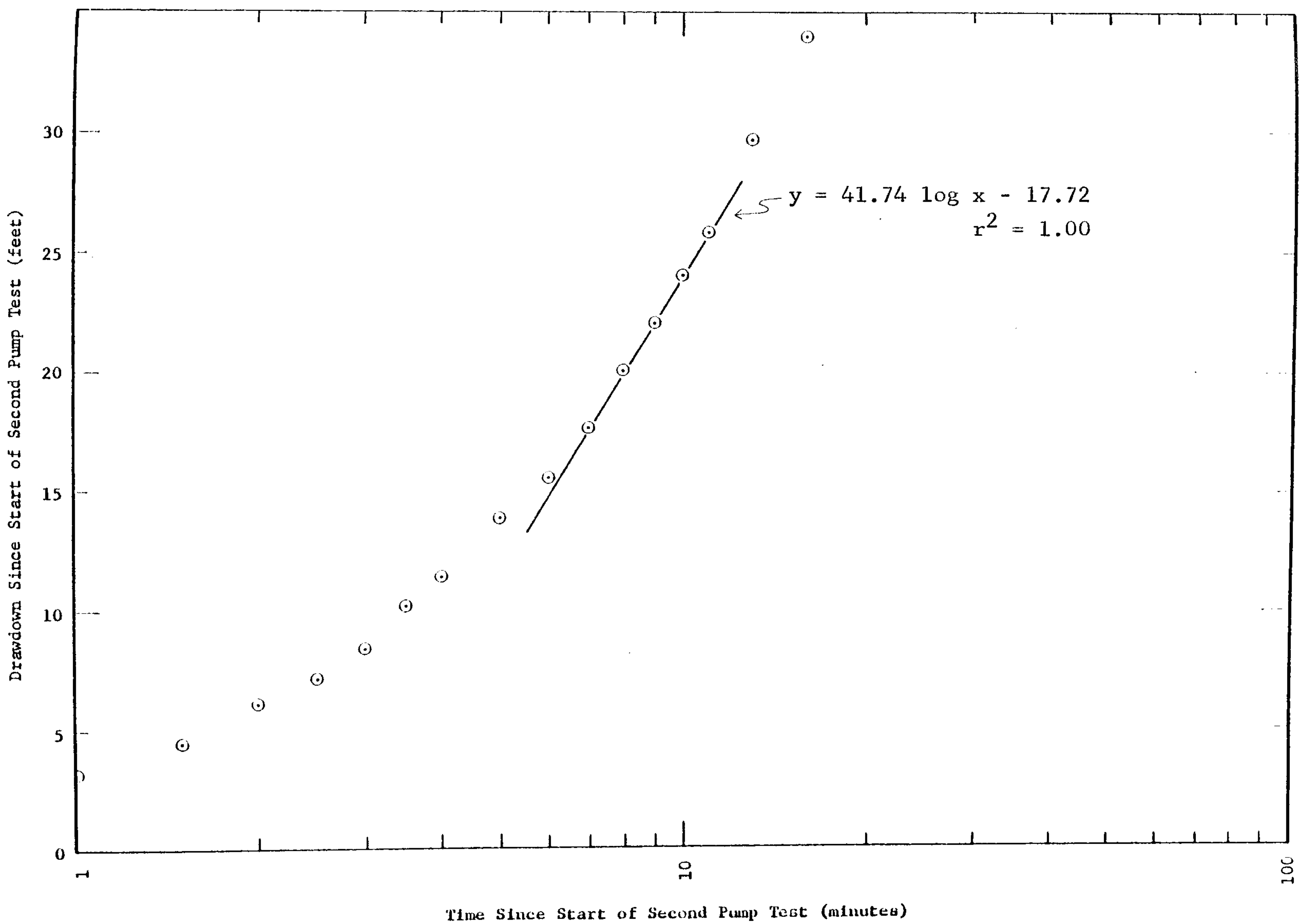

Figure 44. Table Mountain Aquifer, Pump Test #2, Well R2

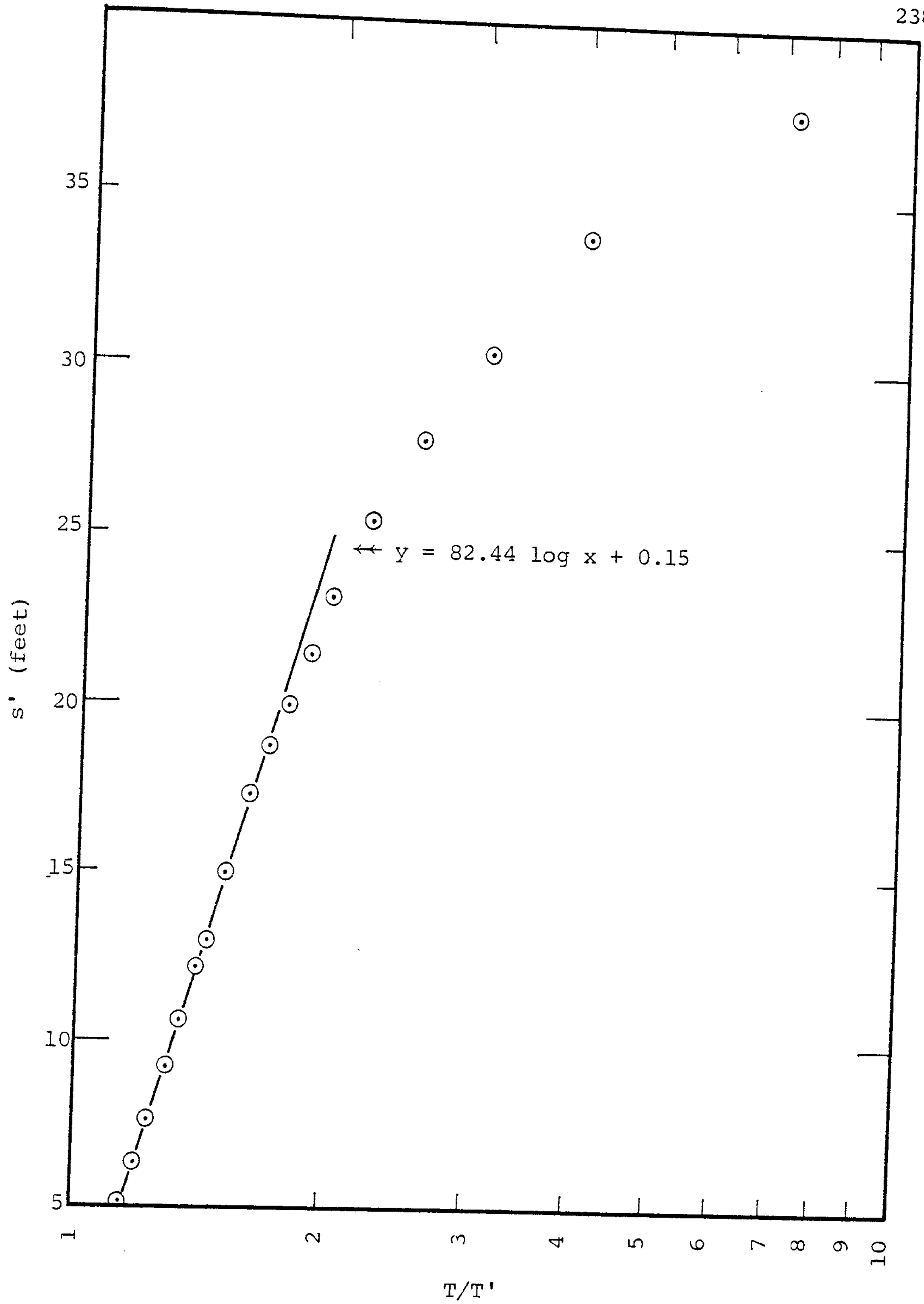

Figure 45. Table Mountain Aquifer, Recovery Test, Well R2

APPENDIX J

ELECTRICAL RESISTIVITY DATA AND ANALYSIS

Electrical Resistivity Soundings

Four successful electrical resistivity soundings were made in Jacumba Valley. A Bison Earth Resistivity Transmitter Model 2390-T50 and a Bison Earth Resistivity Receiver Model 2390 R were used in Schlumberger arrays. Calculation of the apparent resistivity used the following equation:

$$\rho = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \frac{\Delta V}{I}$$

AB = Outer electrode spacing

MN = Inner electrode spacing

ΔV = Potential difference

I = Induced current

Computer interpretation of the data was done with a program (Auto-interpret Ves with Mdz and convolution) by Adel A. R. Zody (1973).

DATA FOR ELECTIFCAL RESISTIVITY SOUNDING #1

Electrical Resistivity Sounding #1

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\overline{\rho}$ (ohm-feet)
10	2	81.7	20.2	305
15	2	30.7	20.2	264
20	2	17.8	20.2	274
25	2	13.3	20.2	321
30	2	10.2	20.2	355
40	2	6.7	20.2	416
50	2	5.7	20.2	553
60	2	4.70	20.2	657
50	10	24.0	20.2	448
60	10	18.1	20.2	493
80	10	12.80	20.2	627
100	10	8.73	20.2	672
125	10	6.59	20.2	796
125	20	11.87	20.2	703
150	20	8.49	20.2	730
175	20	6.82	20.2	801
200	20	5.32	20.2	819
200	40	9.62	20.2	718
250	40	5.19	20.2	614
300	40	2.54	20.2	437
300	60	3.58	20.2	401
350	60	2.11	20.2	325
400	60	1.00	20.2	203
450	60	0.662	20.2	171
450	80	1.355	20.2	258
400	80	0.755	20.2	113

DATA FOR ELECTRICAL RESISTIVITY SOUNDING #1 (Continued)

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\bar{\rho}$ (ohm-feet)
500	80	1.635	20.2	387
600	80	2.27	20.2	780
600	70	1.646	20.2	649
500	70	2.20	20.2	599
400	70	2.86	20.2	493
700	70	5.53	20.2	2980
800	70	7.37	20.2	5200
800	160	16.56	20.2	4945
900	160	23.4	20.2	8920
1000	160	20.7	20.2	9803
1500	160	2.24	20.2	2422

Electrical Resistivity Sounding #1
Computer Interpretation

$\frac{AB}{2}$ (feet)	Calculated VES (ohm-feet)
10.0	274
14.7	281
21.5	310
31.6	377
46.4	491
68.1	640
100.0	803
146.8	944
215.4	1007
316.2	965
464.2	896
681.3	943

Reduced Thickness (feet)	Reduced Depth (feet)	Reduced Resistivity (ohm-feet)
2	2	319
18	20	259
88	108	2020
169	277	300
Infinite	Infinite	4464

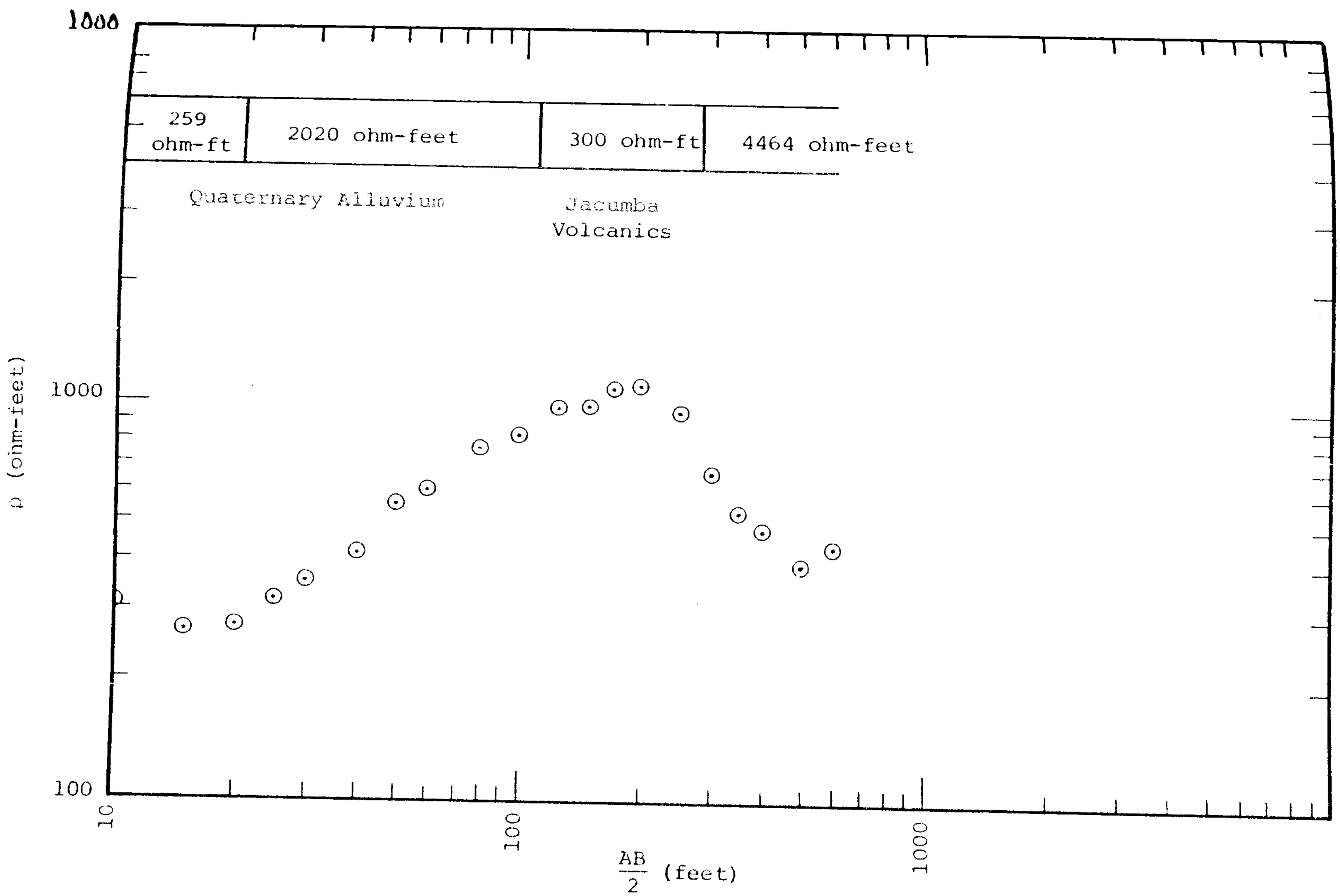

Figure 46. Electrical Resistivity Sounding #1. Corrected data plot and computer interpretation.

DATA FOR ELECTRICAL RESISTIVITY SOUNDING #2

Electrical Resistivity Sounding #2

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\bar{\rho}$ (ohm-feet)
10	2	22.0	20.2	82
15	2	11.0	20.2	95
20	2	7.0	20.2	108
25	2	4.77	20.2	115
30	2	3.49	20.2	122
40	2	2.19	20.2	136
50	2	1.45	20.2	141
50	10	7.13	20.2	133
60	10	4.83	20.2	131
70	10	3.47	20.2	130
80	10	2.57	20.2	126
100	10	1.50	20.2	115
100	20	2.89	20.2	108
125	20	1.581	20.2	94
150	20	1.009	20.2	87
175	20	0.727	20.2	85
200	20	0.556	20.2	86
200	40	1.155	20.2	86
250	40	0.743	20.2	88
300	40	0.511	20.2	88
400	40	0.299	20.2	92
400	80	0.607	20.2	91
500	80	0.423	20.2	100
600	80	0.324	20.2	111
700	80	0.248	20.2	117
700	140	0.416	20.2	109

DATA FOR ELECTRICAL RESISTIVITY SOUNDING #2 (Continued)

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\bar{\rho}$ (Ohm-feet)
800	140	0.388	20.2	134
900	140	0.266	20.2	117
1000	140	0.231	20.2	126
1000	200	0.341	20.2	127
1200	200	0.286	20.2	156
1500	200	0.193	20.2	166

Electrical Resistivity Sounding #2
Computer Interpretation

AB/2 (feet)	Calculated VES (ohm-feet)
10.0	101
14.7	110
21.5	116
31.6	120
46.4	121
68.1	119
100.0	113
146.8	105
215.4	102
316.2	107
464.2	118
681.3	133
1000.0	157
1467.8	198

Reduced Thickness (feet)	Reduced Depth (feet)	Reduced Resistivity (ohm-feet)
3	3	73
56	59	126
81	140	75
674	814	133
Infinite	Infinite	1009

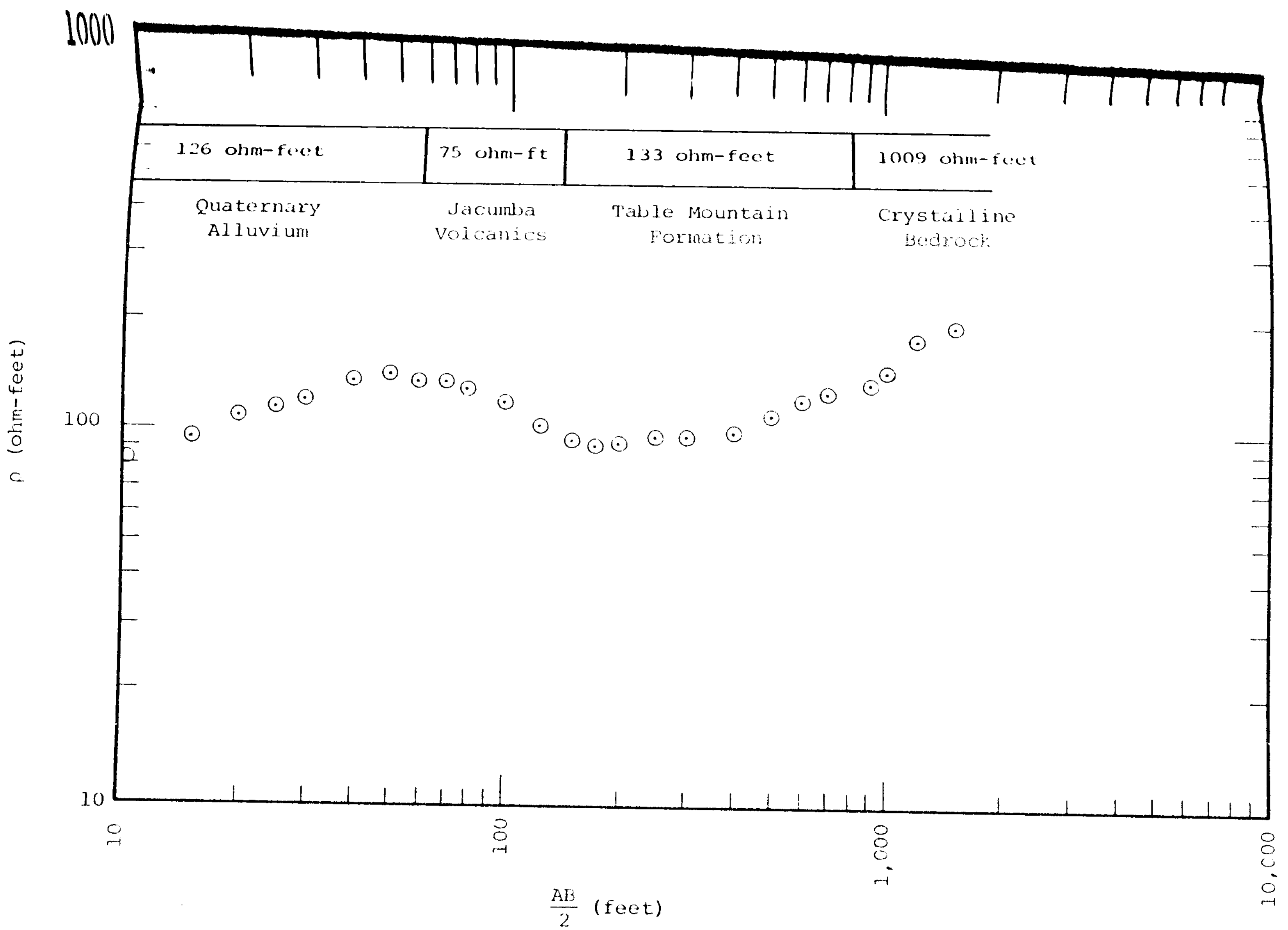

Figure 47. Electrical Resistivity Sounding #2. Corrected data plot and computer interpretation.

DATA FOR ELECTRICAL RESISTIVITY SOUNDING #3

Electrical Resistivity Sounding #3

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\bar{\rho}$ (ohm-feet)
10	2	133.7	20.2	499
15	2	45.8	20.2	394
20	2	23.5	20.2	362
30	2	10.24	20.2	357
40	2	6.13	20.2	380
50	2	4.19	20.2	407
60	2	2.93	20.2	410
70	2	2.16	20.2	411
80	2	1.605	20.2	399
100	2	0.957	20.2	372
100	20	9.30	20.2	347
125	20	5.28	20.2	313
150	20	3.37	20.2	290
200	20	1.624	20.2	250
200	40	3.50	20.2	261
300	40	0.915	20.2	157
400	40	0.426	20.2	131
400	80	0.875	20.2	131
500	80	0.509	20.2	121
600	80	0.338	20.2	116
600	120	0.462	20.2	103
800	120	0.240	20.2	97
1000	120	0.167	20.2	107
1000	200	0.260	20.2	97
1200	200	0.185	20.2	101
1500	200	0.139	20.2	119

Electrical Resistivity Sounding #3
Computer Interpretation

$\frac{AB}{2}$ (feet)	Calculated VES (ohm-feet)
10.0	452
14.7	418
21.5	401
31.6	403
46.4	412
68.1	411
100.0	380
146.8	318
215.4	241
316.2	170
464.2	126
681.3	111
1000.0	119
1467.8	140

Reduced Thickness (feet)	Reduced Depth (feet)	Reduced Resistivity (ohm-feet)
4	4	577
21	24	375
25	49	583
89	138	260
520	659	87
Infinite	Infinite	257

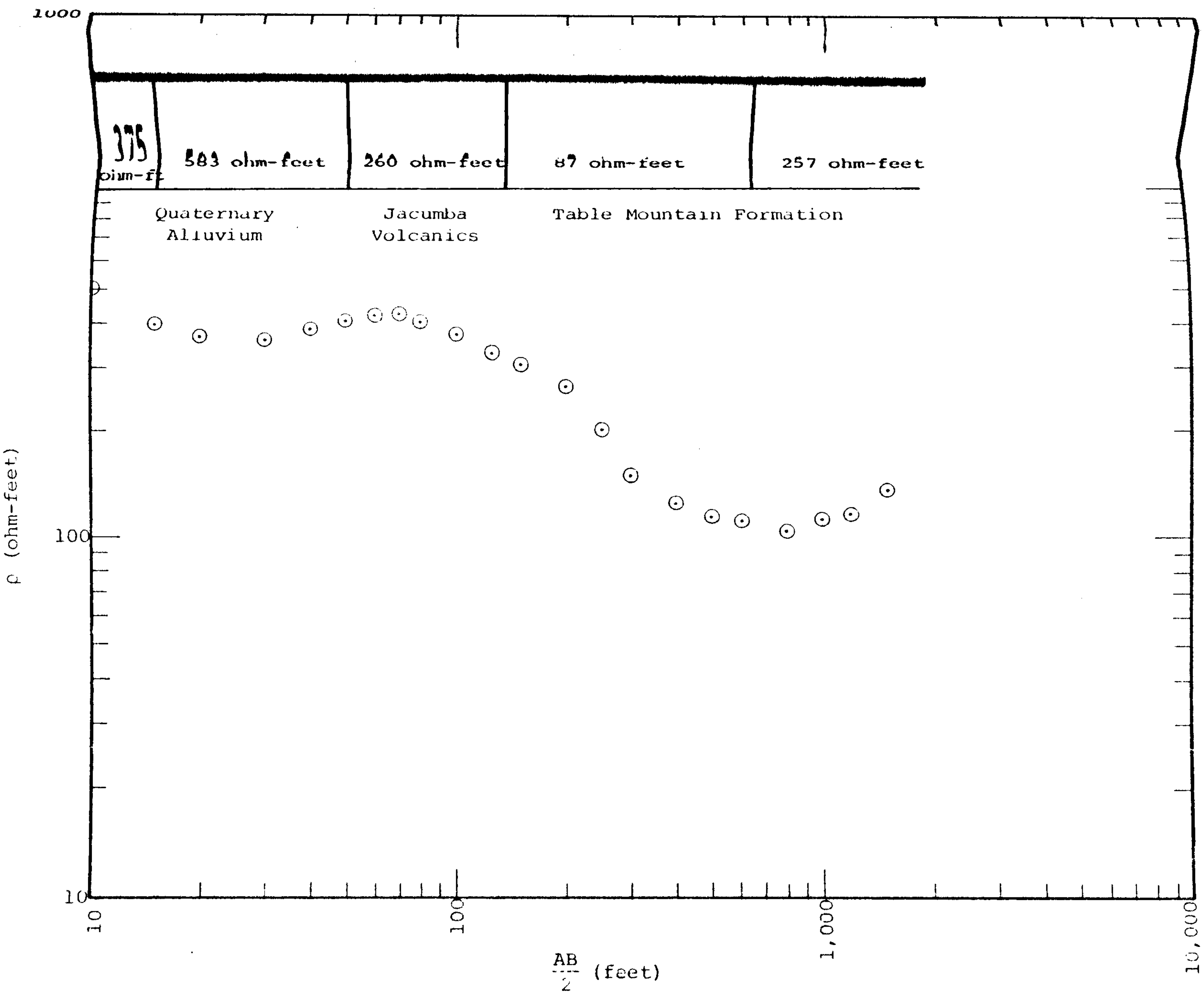

Figure 48. Electrical Resistivity Sounding #3. Corrected data plot and computer interpretation.

DATA FOR ELECTRICAL RESISTIVITY SOUNDING #4

Electrical Resistivity Sounding #4

$\frac{AB}{2}$ (feet)	$\frac{MN}{2}$ (feet)	V (millivolts)	I (milliamps)	$\overline{\rho}$ (ohm-feet)
10	2	56.0	20.2	209
15	2	18.4	20.2	158
20	2	7.88	20.2	121
25	2	3.81	20.2	92
30	2	2.14	20.2	75
40	2	0.841	20.2	52
50	2	0.418	20.2	41
50	10	1.967	20.2	37
60	10	1.139	20.2	31
70	10	0.736	20.2	27
80	10	0.504	20.2	25
100	10	0.287	20.2	22
100	20	0.550	20.2	21
150	20	0.236	20.2	20
200	20	0.136	20.2	21
200	40	0.236	20.2	18
250	40	0.154	20.2	18
300	40	0.112	20.2	19
300	60	0.158	20.2	18
400	60	0.108	20.2	22
500	60	0.084	20.2	27
500	100	0.117	20.2	22
600	100	0.108	20.2	29
800	100	0.077	20.2	38
900	100	0.071	20.2	44

Electrical Resistivity Sounding #4
Computer Interpretation

$\frac{AB}{2}$ (feet)	Calculated VES (ohm-feet)
10.0	206
14.7	156
21.5	106
31.6	70
46.4	48
68.1	33
100.0	25
146.8	22
215.4	24
316.2	29
464.2	39
681.3	56

Reduced Thickness (feet)	Reduced Depth (feet)	Reduced Resistivity (ohm-feet)
7	7	266
20	27	67
226	253	18
Infinite	Infinite	2971

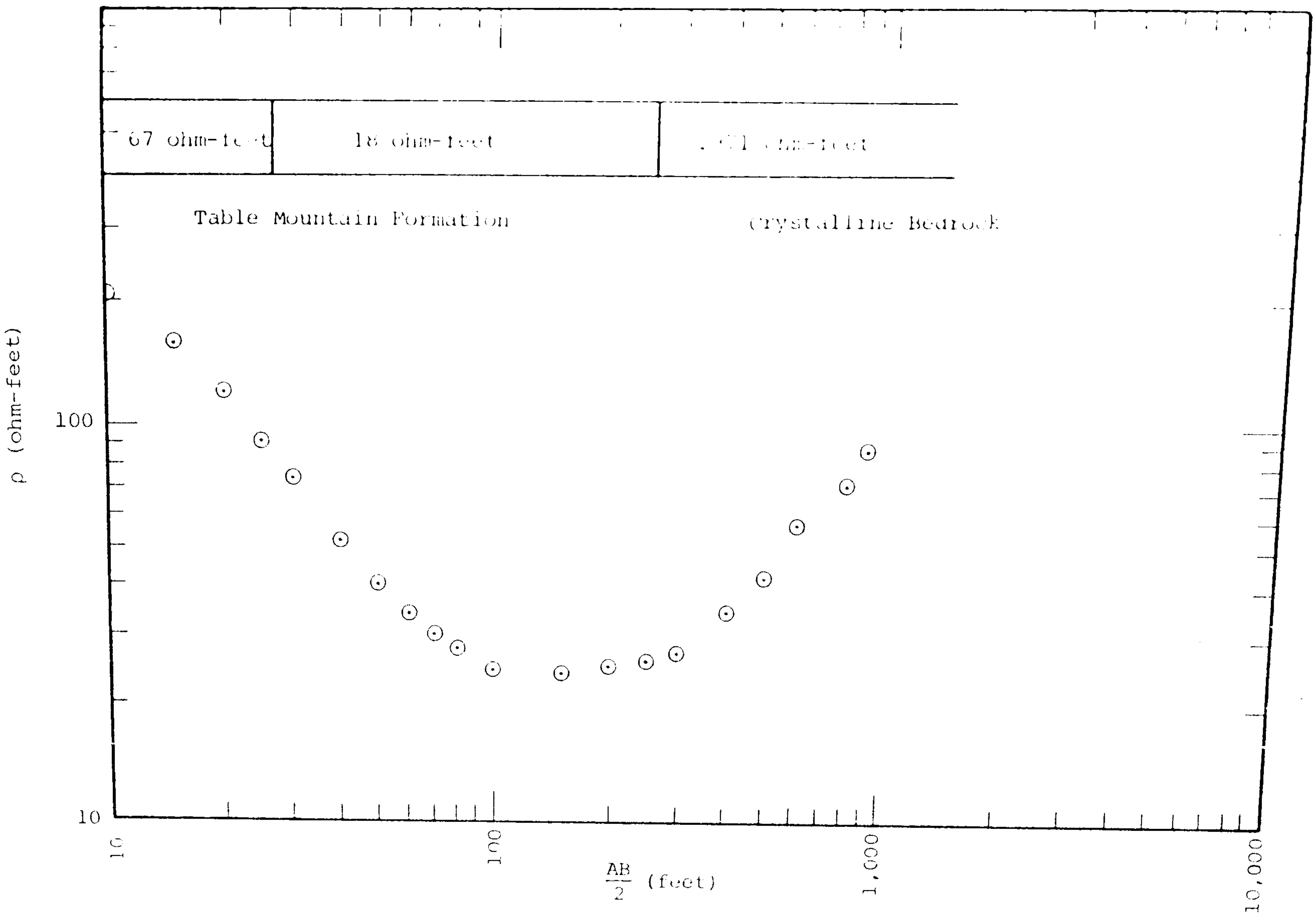

Figure 49. Electrical Resistivity Sounding #4. Corrected data plot and computer interpretation.

GROUND WATER CHEMISTRY

Collection and Analysis of Ground Water Samples

Sample J3A: collected from well head after pumping for 5 minutes.

Sample Km: collected from holding tank.

Sample J1: collected from well head after pumping for 10 minutes.

Sample R2: collected from holding tank.

Sample JHS: collected from well head, pump continuously operating.

Sample Ma: collected from standing pond.

Sample Mb: collected from standing pond.

Field Methods of Analysis (Hach, 1973)

Temperature: 100°C mercury thermometer

pH: pH paper (Hydrion)

Alkalinity: Phenolphthalein-brom cresol green-methyl red titrimetric method (Hach Kit)

H2S:. Has generation method (Hach Kit)

CO2: Titrimetric method for free carbon dioxide (Hach Kit)

Laboratory Methods of Analysis (American Public Health Assn., 1976)

Ca: EDTA titrimetric method

Mg: same as Ca

Total Hardness: Same as Ca

Na: Flame emission (Instrumentation Laboratory aa/ae Model 151)

K: Flame emission (Instrumentation Laboratory aa/ae Model 151)

Laboratory Methods (continued)

Fe:	Atomic absorption (Instrumentation Laboratory aa/ae Model 151)
Mn:	Atomic absorption (Instrumentation Laboratory aa/ae Model 151)
Li:	Flame emission (Instrumentation Laboratory aa/ae Model 151)
SiO2:	Molybdosilicate method (Hitachi Spectrophotometer Model Number 60)
Cl:	Mercuric nitrate titrimetric method
SO4:	Gravimetric method with drying of residue
Br:	Selective ion probe (Bechman Monitor II)
F:	Selective ion probe (Bechman Monitor II)

All constituents were analyzed within the time constraints recommended by the American Public Health Association (1976).

Results of the Chemical Analyses Performed by the Author

	J3A	Km	J1	R2	JHS	Ma	Mb
Cl (mg/1)	80	125	155	68	86	126	99
SO4 (mg/1)	57	83	222	87	17	62	23
HCO3 (mg/1)	159	293	183	183	35	88	150
CO3 (mg/1)	0	0	0	0	35	0	0
Ca (mg/1)	32	53	57	36	2.2	4.2	16
Mg (mg/1)	26.	38	40	32	0.1	1.7	3.0
Na. (mg/1)	70	95	118	56	100	128	95
K (mg/1)	2.1	2.2	3.1	5.6	0.5	4.0	10.5
SiO2 (mg/1)	39	29	38	39	48	51	34
Fe (mg/1)	0.001	0	0.001	0.001	0	0.016	0.031
F (mg/1)	1.15	2.0	2.2	1.1	7.8	7.5	5.2
Br (mg/1)	1.55	2.08	2.80	1.50	30.0	7.0	4.0
Li (mg/1)	0.001	0.001	0.001	0	0.001	0	0
Mn (mg/1)	0	0	0	0	0	0	0.008
CO2 (mg/1)	52	76	34	44	0	-	-
pH	6	6	6	5	8	6	6
calculated TDS (mg/1)	468	722	821	510	362	480	440
total hardness as CaCO3 (mg/1)	185	290	310	220	5	17.	50-55
calcium hardness as CaCO3 (mg/1)	80	133	140	90	5-6	10-11	40
magnesium hardness as CaCO3 (mg/1)	105	157	164	130	0.5	7	10-15
temperature °C	19	-	22	-	38.5	-	-

Ground Water Chemistry from Thesken (1977)

	T1	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Cl (ppm)	94	102	104	1050	129	60	80	350	145	92	350
SO4 (ppm)	29	53	12	420	66	37.5	58	399	296	45	99
HCO3 (ppm)	210	104	24	140	203	170	160	220	70	185	152
CO3 (ppm)	0	0	66	0	0	0	0	0	0	0	0
Ca (ppm)	69	27	1.2	440	77	56	64	232	110	78	142
Mg (ppm)	19	8.1	0.83	182	21	20	36	63	151	22	28
Na (ppm)	27	110	106	350	84	27	27	84	42	32	74
K (ppm)	2	1.8	1.2	7.5	2.5	0.5	0.5	8.7	14	4	2.2
SiO2 (ppm)	42	47	52	46	37	46	47	24	53	40	44
B (ppm)	-	0.50	0.64	-	0.16	-	-	-	-	-	-
Li (ppm)	-	0.046	0.036	-	0.041	-	-	-	-	-	-
Fe (ppm)	0.07	0.17	0.01	0.22	0	0.15	0.05	7.9	3.2	0.21	0.15
TDS (ppm)	492	453	367	2636	620	417	473	1388	884	498	891
pH	6.0	5.7	6.8	6.0	5.9	5.8	5.8	5.5	5.5	6.0	5.8
temperature °C	27	26	38	25	25	20	20	22	22	22	21

Ground Water Chemistry Data from Previous Studies

	Jacumba Cold Sp. (Brown, 1923)	Jacumba Cold Sp., 1951 (C.S.D.P.H.)	Jacumba Cold Sp. (Babcock, 1958)	Well J3, 1964 (C.S.D.P.H.)	Well J3A, 1966 (C.S.D.P.H.)	Well J4, 1972 (C.S.D.P.H.)	Well J1, 1957 (C.S.D.P.H.)	Well J1 (Babcock, 1958)	Well J2, 1963 (C.S.D.P.H.)	Well 18S/8E 9H (Babcock, 1958)	Jacumba Hot Sp. (Waring, 1915)	Well JHS, 1960 (C.S.D.P.H.)
Cl (ppm)	61	92	82	123	123	103	210	151	180	187	77	201
SO4 (ppm)	30	46	35	52	54	78	310	116	320	270	32	260
HCO3 (ppm)	222	202	32	218	212	184	-	320	201	188	42	228
CO3 (ppm)	0	-	29	-	-	0	-	0	-	0	23	-
Ca (ppm)	43	58	0	65	69	64	139	87	113	147	2.4	-
Mg (ppm)	13	18	1	17	18	14	35	24	34	54	0.1	47
Na (ppm)	64	73	105	84	82	83	156	103	152	54	101	140
K (ppm)			0.6	2.4	2.0	3.1	3	2.6	2.4	6.2	1.2	3.2
SiO2 (ppm)	39	-	-	36	35	42	-	-	40	-	56	35
B (ppm)	-	-	0.7	-	-	0.17	-	0.4	-	-	0.6	-
Fe (ppm)	0.2	-	-	0.1	0.1	0.008	0.08	-	0	-	6.0	0
F (ppm)	-	0.4	4.0	0.8	0.3	0.3	1.2	1.3	1.3	0.5	1.8	1.2
CO2 (ppm)	-	-	-	30	14	10	-	-	11	-	-	25
TDS (ppm)	-	-	310	505	490	513	1105	815	940	1135	316	915
pH	-	6.7	8.8	7.1	7.4	7.4	-	7.6	7.5	7.7	9.3	7.2
temperature °C	-	-	-	-	-	-	-	-	-	-	35	-

(C.S.D.P.H.) - County of San Diego, Department of Public Health (1980)

Ground Water Chemistry Data from Previous Studies

	Jacumba Cold Sp. (Brown, 1923)	Jacumba Cold Sp., 1951 (C.S.D.P.H.)	Jacumba Cold Sp. (Babcock, 1958)	Well J3, 1964 (C.S.D.P.H.)	Well J3A, 1966 (C.S.D.P.H.)	Well J4, 1972 (C.S.D.P.H.)	Well J1, 1957 (C.S.D.P.H.)	Well J1 (Babcock, 1958)	Well J2, 1963 (C.S.D.P.H.)	Well 18S/8E 9H (Babcock, 1958)	Jacumba Hot Sp. (Waring, 1915)	Well JHS, 1960 (C.S.D.P.H.)
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SO4 (ppm)	30	46	35	52	54	78	310	116	320	270	32	260
HCO3 (ppm)	222	202	32	218	212	184	-	320	201	188	42	228
CO3 (ppm)	0	-	29	-	-	0	-	0	-	0	23	-
Ca (ppm)	43	58	0	65	69	64	139	87	113	147	2.4	-
Mg (ppm)	13	18	1	17	18	14	35	24	34	54	0.1	47
Na (ppm)	64	73	105	84	82	83	156	103	152	54	101	140
K (ppm)			0.6	2.4	2.0	3.1	3	2.6	2.4	6.2	1.2	3.2
SiO2 (ppm)	39	-	-	36	35	42	-	-	40	-	56	35
B (ppm)	-	-	0.7	-	-	0.17	-	0.4	-	-	0.6	-
Fe (ppm)	0.2	-	-	0.1	0.1	0.008	0.08	-	0	-	6.0	0
F (ppm)	-	0.4	4.0	0.8	0.3	0.3	1.2	1.3	1.3	0.5	1.8	1.2
CO2 (ppm)	-	-	-	30	14	10	-	-	11	-	-	25
TDS (ppm)	-	-	310	505	490	513	1105	815	940	1135	316	915
pH	-	6.7	8.8	7.1	7.4	7.4	-	7.6	7.5	7.7	9.3	7.2
temperature °C	-	-	-	-	-	-	-	-	-	-	35	-

(C.S.D.P.H.) - County of San Diego, Department of Public Health (1980)

ABSTRACT

ABSTRACT

Jacumba Valley and its watershed cover 307 square kilometers in the southeastern corner of San Diego County and northern Baja California.

Jacumba Valley is a graben. The bedrock in the watershed is composed of metamorphics which have been intruded by plutons of the Peninsular Ranges Batholith. Unconformably overlying the bedrock is the Table Mountain Formation. This formation is up to 200 meters thick. It is a medium to coarse-grained, arkosic sandstone and conglomeratic sandstone. The Table Mountain Formation is overlain by the Jacumba Volcanics, a 90-meter-thick sequence of pyroclastics sandwiched between two 40-meter-thick sequences of basaltic lava flows. In Jacumba Valley, Quaternary alluvium overlies the volcanics and Table Mountain Formation to a maximum thickness of 45 meters. The lithology of the alluvium is mixed ranging from gravelly sand to fine sand and silt.

Shallow stress-relief fractures in the bedrock terrain supply ground water to some dwellings in the Jacumba Valley watershed.

Of the two aquifers in the subsurface of Jacumba Valley, the Table Mountain aquifer is the largest but least developed. Based on an assumed specific yield of 5%-10%, this aquifer contains an estimated 1.0×10^8-2.1×10^8 cubic meters of

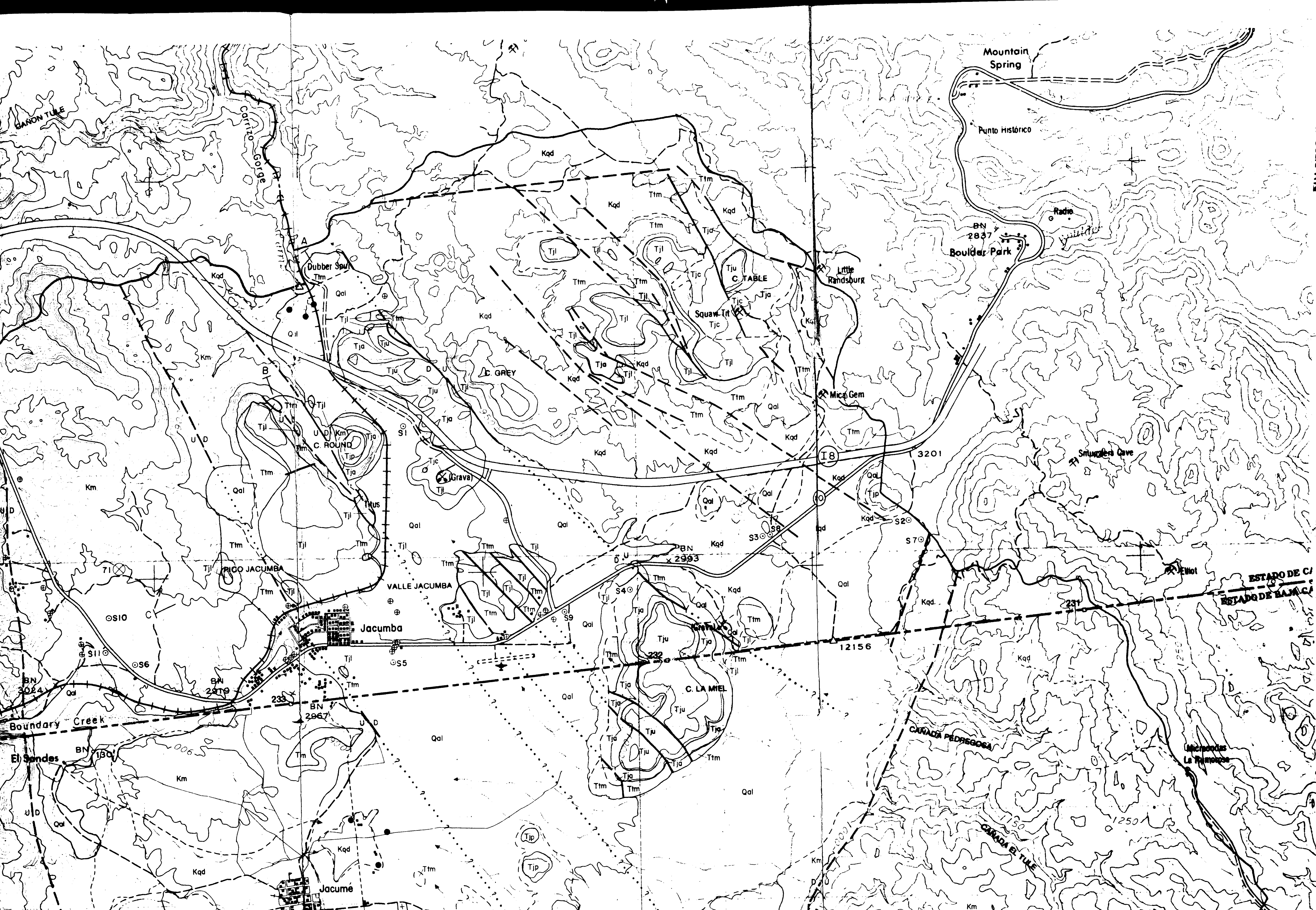
recoverable water. The transmissivity is 4.3×10^{-4} meters^2/minute.

The Quaternary alluvium is currently supplying ground water to the town of Jacumba. The transmissivity of the alluvium is about 2.0 meters^2/minute. In the past, Jacumba's water supply has been threatened because of the small storage capacity of this aquifer. Based on an assumed 5%-10% specific yield, the estimated amount of recoverable water in the alluvium is 3.9×10^6-7.9×10^6 cubic meters.

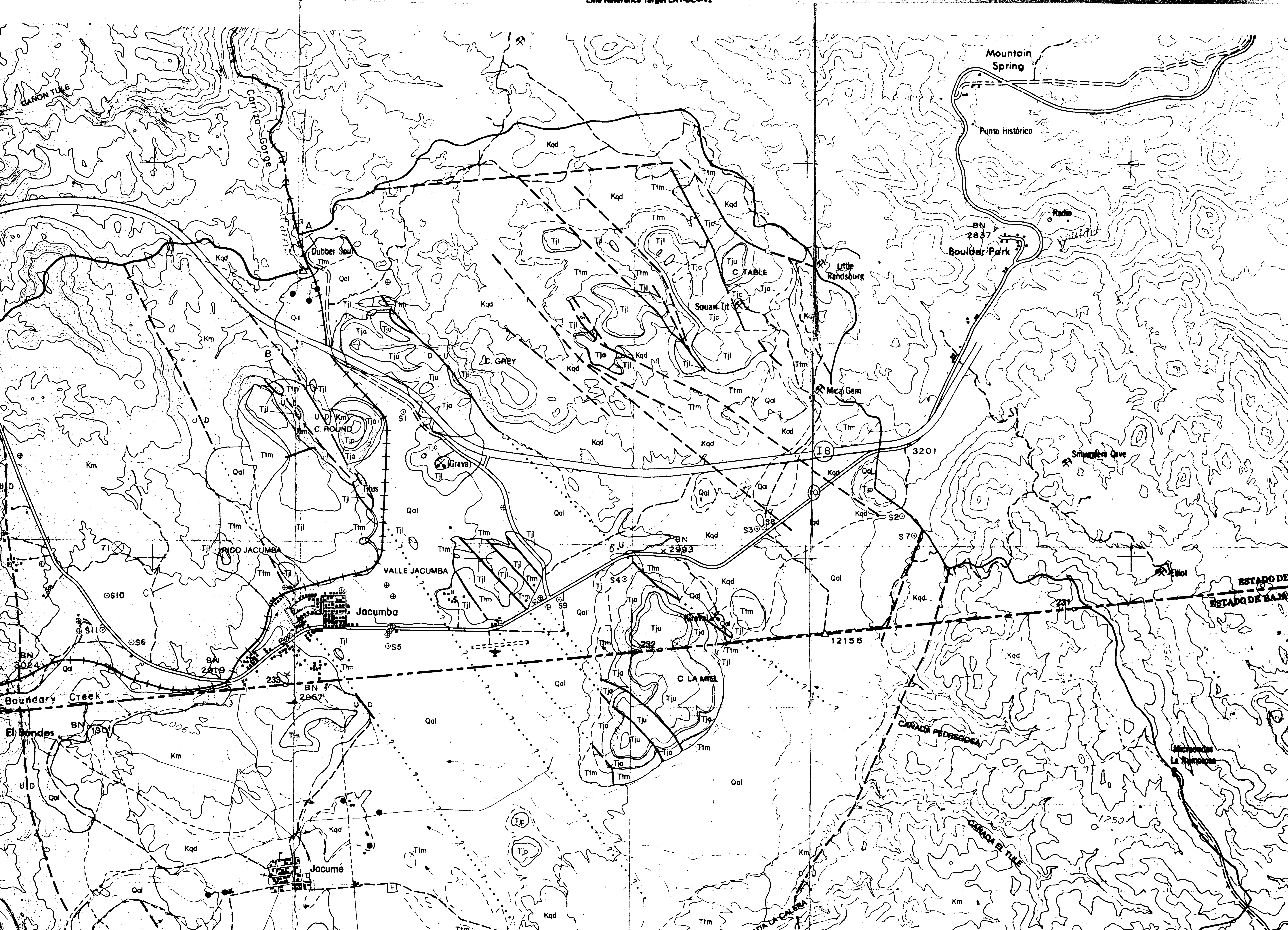
The variables considered in the ground water recharge calculations for Jacumba Valley were: precipitation, potential evapotranspiration, soil moisture deficiency, and surface run-off. The calculated mean annual ground water recharge is 3.39×10^6 cubic meters. Virtually all of the recharge is due to infiltration from precipitation.

About 90% of the calculated ground water recharge for Jacumba Valley occurs in the hills and mountains to the west and south of the valley. This recharge reaches the valley through flow in the bedrock ground water system. The ground water in Jacumba Valley's aquifers flows northward to the head of Carrizo Gorge where it is discharged through evapotranspiration, subsurface flow, and surface flow from springs.

The estimated discharge, due to evapotranspiration and subsurface flow, from the valley's ground water system is 1.19×10^6-1.84×10^6 cubic meters/year. Over long periods of time, the valley's ground water budget is balanced because springs at the north end of the valley are activated when the water table in the valley is high. During shorter periods of time, the budget can fluctuate considerably. If the water table in the valley were artifically maintained below the level that activates the springs, then a long-term ground water budget would show a net increase of between 1.55×10^6 and 2.19×10^6 cubic meters/year.



CAÑON TULE
Carrizo Gorge
Mountain Spring
Punto Histórico
Radio
Boulder Park
Dubber Spur
Little Randsburg
C. TABLE
Squaw Tit
C. GREY
Mica Gem
C. ROUND
Grava
Smugglers Cave
PICO JACUMBA
VALLE JACUMBA
Jacumba
Elliot
ESTADO DE BAJA CA
C. LA MIEL
Boundary Creek
El Sondeo
CAÑADA PEDREGOSA
CAÑADA EL TULE
Jacumé


Mountain Spring
Punto Histórico
Radio
Boulder Park
Little Randsburg
C. TABLE
Squaw Tit
C. GREY
Mica Gem
Smugglers Cave
Elliot
Carrizo Gorge
Dubber Spur
C. ROUND
Titus
(Grava)
PICO JACUMBA
VALLE JACUMBA
Jacumba
C. LA MIEL
Boundary Creek
El Sondes
Jacumé
CAÑADA PEDREGOSA
CAÑADA EL TULE
ESTADO DE C
ESTADO DE BAJA C
I8
3201
12156
BN 2837
BN 2993
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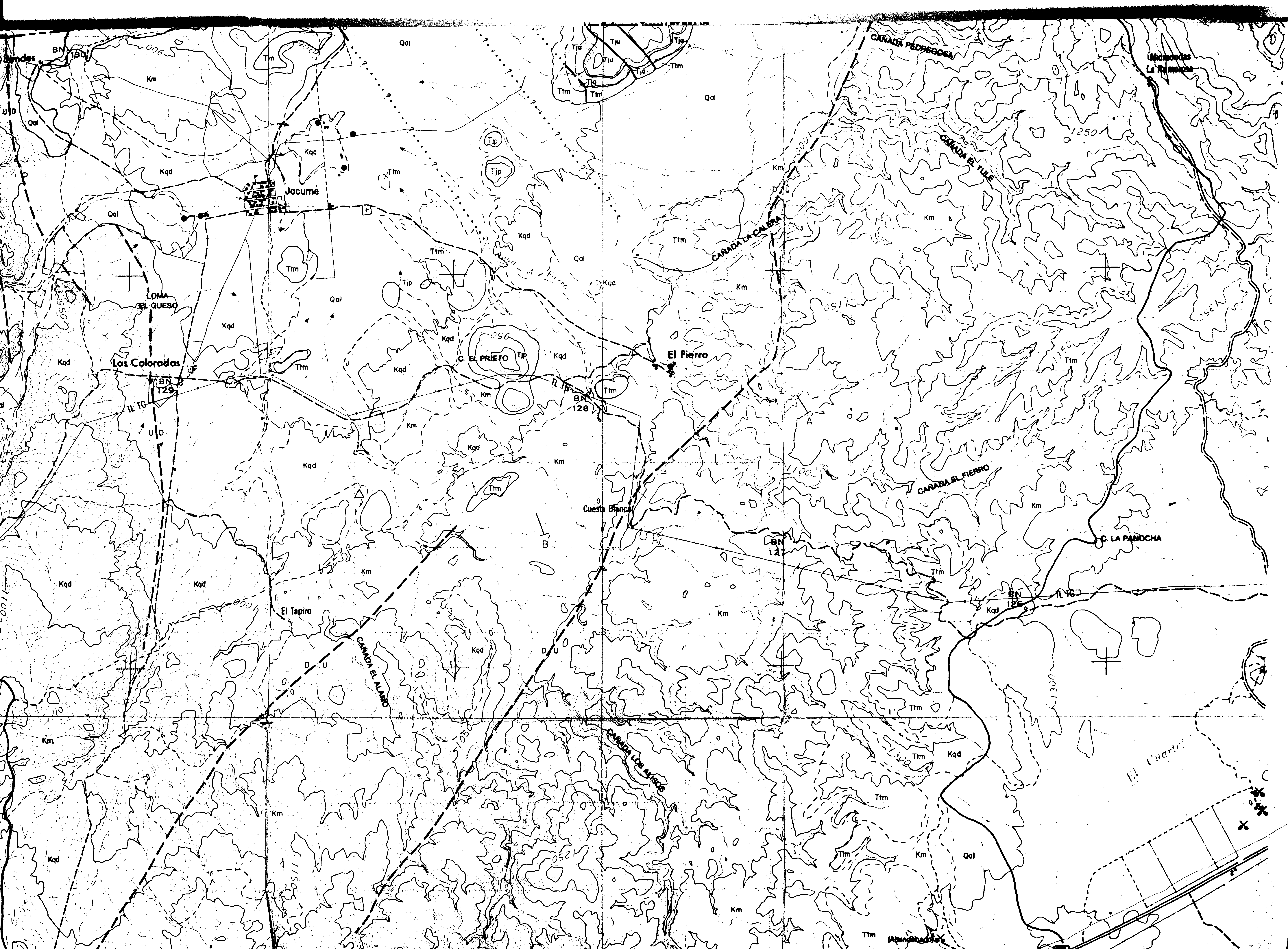
BN 2919
BN 2967
Kqd
Ttm
Tjl
Tja
Tju
Tjc
Tjp
Qal
Km



Jacumé
Los Coloradas
LOMA
EL QUESO
El Fierro
C. EL PRIETO
Cuesta Blanca
El Tapiro
CAÑADA PEDREGOSA
CAÑADA EL TULE
CAÑADA LA CALERA
CAÑADA EL FIERRO
CAÑADA EL ALAMO
CAÑADA LOS ALISOS
C. LA PANOCHA
El Cuartel
BN 130
BN 129
BN 128
BN 127
BN 126
IL TG
Qal
Km
Kqd
Ttm
Tjp
Tja
Tju
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1050
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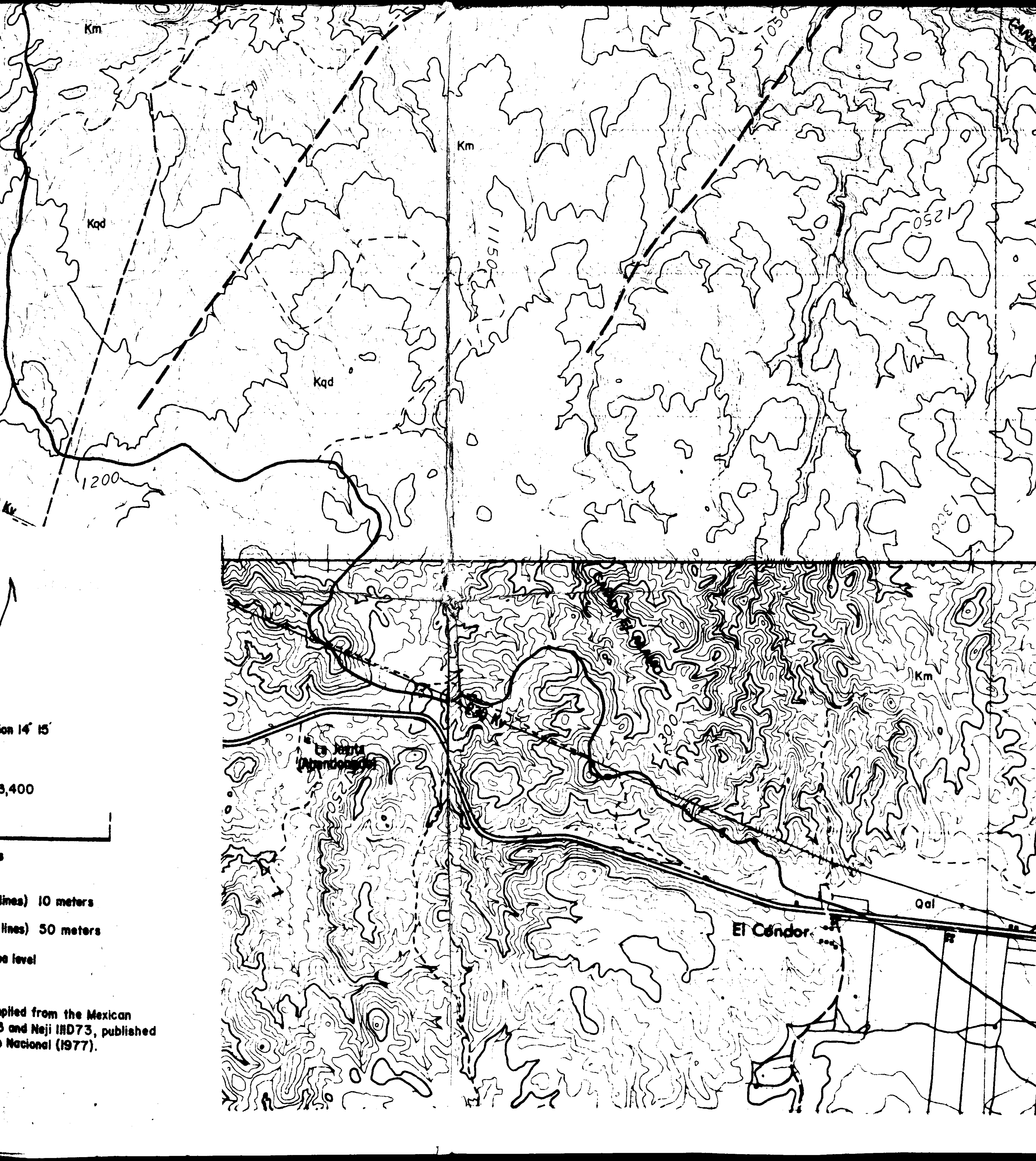
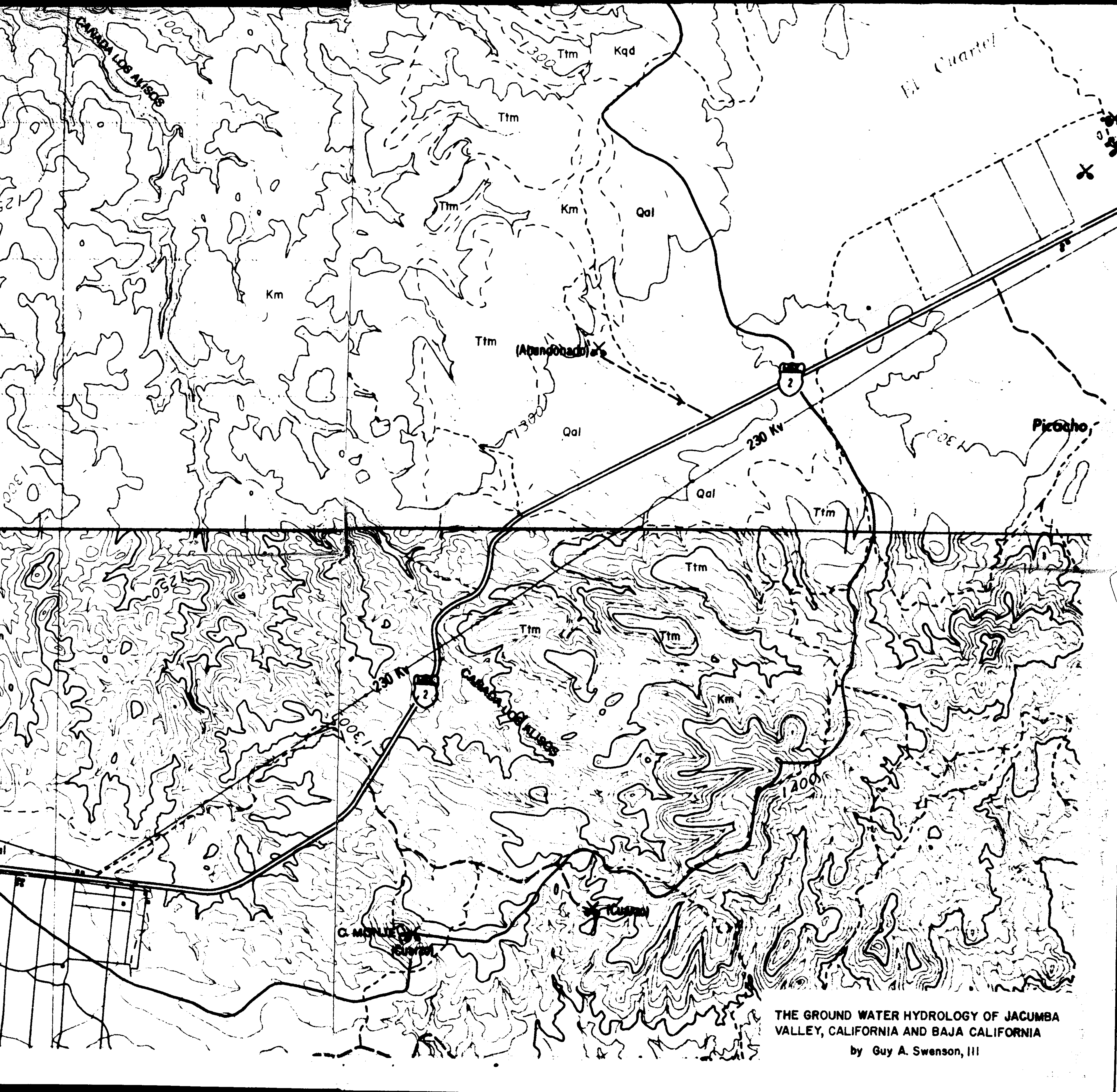
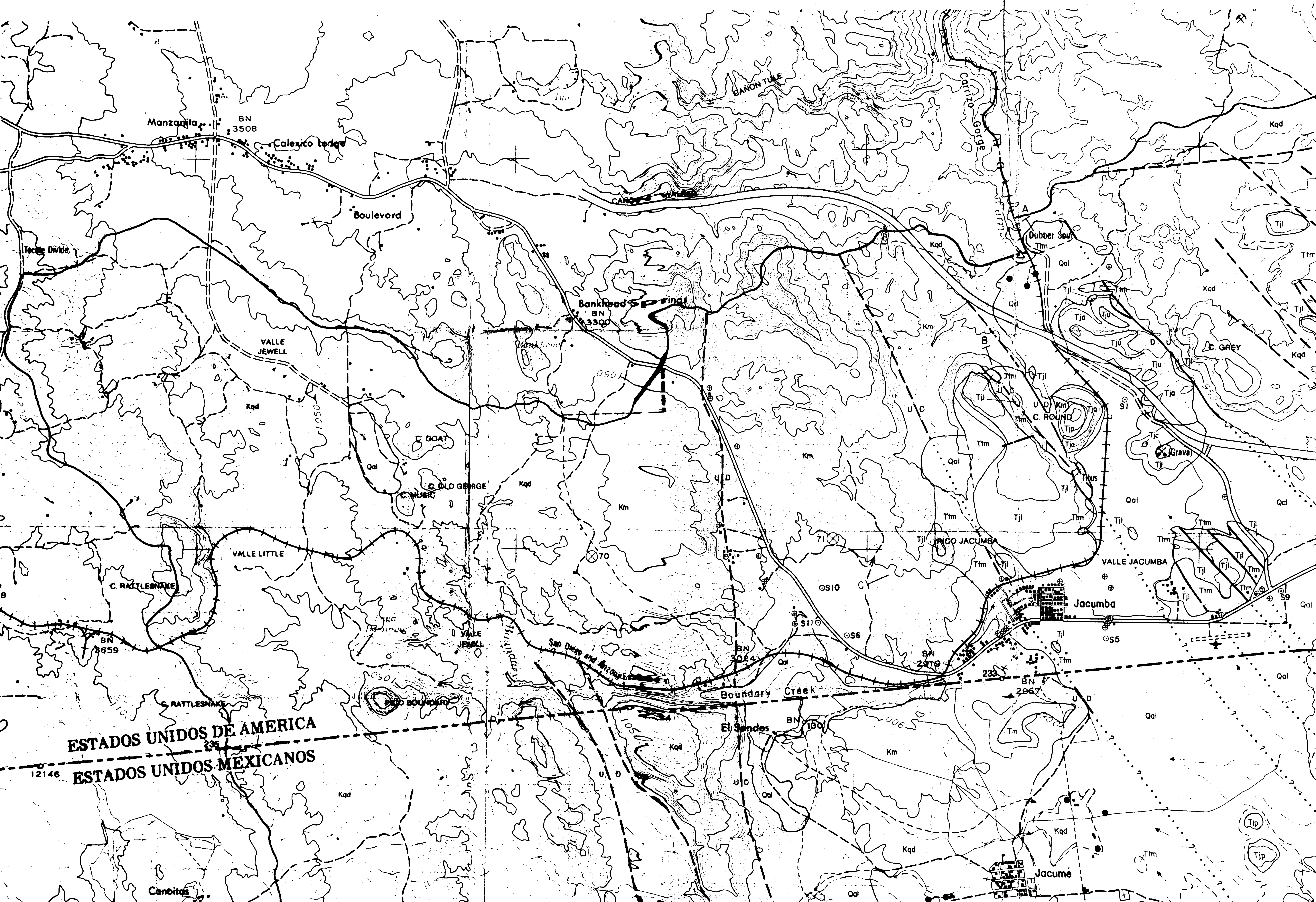
1150
1250
1300
1350


Km
Kqd
Kqd
1200
Kv
1150
1050
1250
1300
Km
Km
Qal
El Cóndor
ion 14° 15'
3,400
lines) 10 meters
lines) 50 meters
a level
piled from the Mexican
3 and Neji I1ID73, published
o Nacional (1977).



THE GROUND WATER HYDROLOGY OF JACUMBA VALLEY, CALIFORNIA AND BAJA CALIFORNIA

by Guy A. Swenson, III


Manzanita
BN 3508
Calexico Lodge
Boulevard
Tecate Divide
CAÑON TULE
Carrizo Gorge
Dubber Spur
Bankhead Springs
BN 3300
VALLE JEWELL
Kqd
Km
Qal
Tjl
Ttm
Tja
Tju
Tjp
C. GREY
C. ROUND
C. GOAT
C. OLD GEORGE
C. MUSIC
(Grava)
PICO JACUMBA
VALLE JACUMBA
Jacumba
VALLE LITTLE
C. RATTLESNAKE
BN 3659
VALLE JEWELL
Boundary
San Diego and Arizona Eastern
BN 3024
BN 2919
BN 2867
Boundary Creek
PICO BOUNDARY
C. RATTLESNAKE
ESTADOS UNIDOS DE AMERICA
ESTADOS UNIDOS MEXICANOS
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El Sandes
Jacumé
Canbitas
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S6
S9
S10
S11
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71
U D

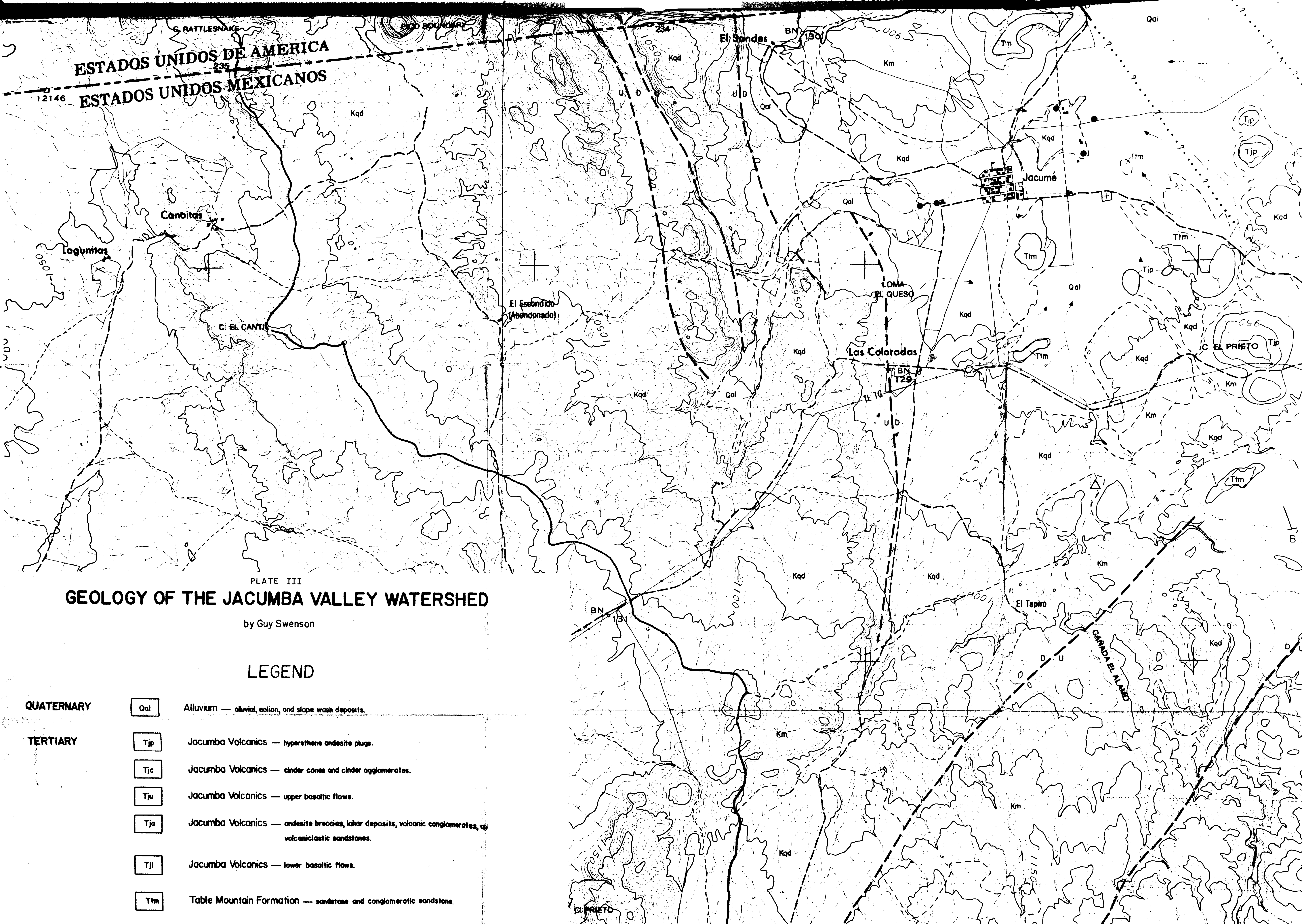

PLATE III

GEOLOGY OF THE JACUMBA VALLEY WATERSHED

by Guy Swenson

LEGEND

QUATERNARY	Qal	Alluvium — alluvial, eolian, and slope wash deposits.
TERTIARY	Tjp	Jacumba Volcanics — hypersthene andesite plugs.
	Tjc	Jacumba Volcanics — cinder cones and cinder agglomerates.
	Tju	Jacumba Volcanics — upper basaltic flows.
	Tja	Jacumba Volcanics — andesite breccias, lahar deposits, volcanic conglomerates, an volcaniclastic sandstones.
	Tjl	Jacumba Volcanics — lower basaltic flows.
	Ttm	Table Mountain Formation — sandstone and conglomeratic sandstone.

TERTIARY

Tjp	Jacumba Volcanics — hypersthene andesite plugs.
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Tju	Jacumba Volcanics — upper basaltic flows.
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Tjl	Jacumba Volcanics — lower basaltic flows.
Ttm	Table Mountain Formation — sandstone and conglomeratic sandstone.

CRETACEOUS

Kqd	Peninsular Ranges Batholith — quartz diorite and granodiorite.
Km	Julian Schist and leucocratic plutonic rocks — schist, gneiss, quartzite, marble, granodiorite, diorite, and pegmatites.

MAP SYMBOLS

FAULTS

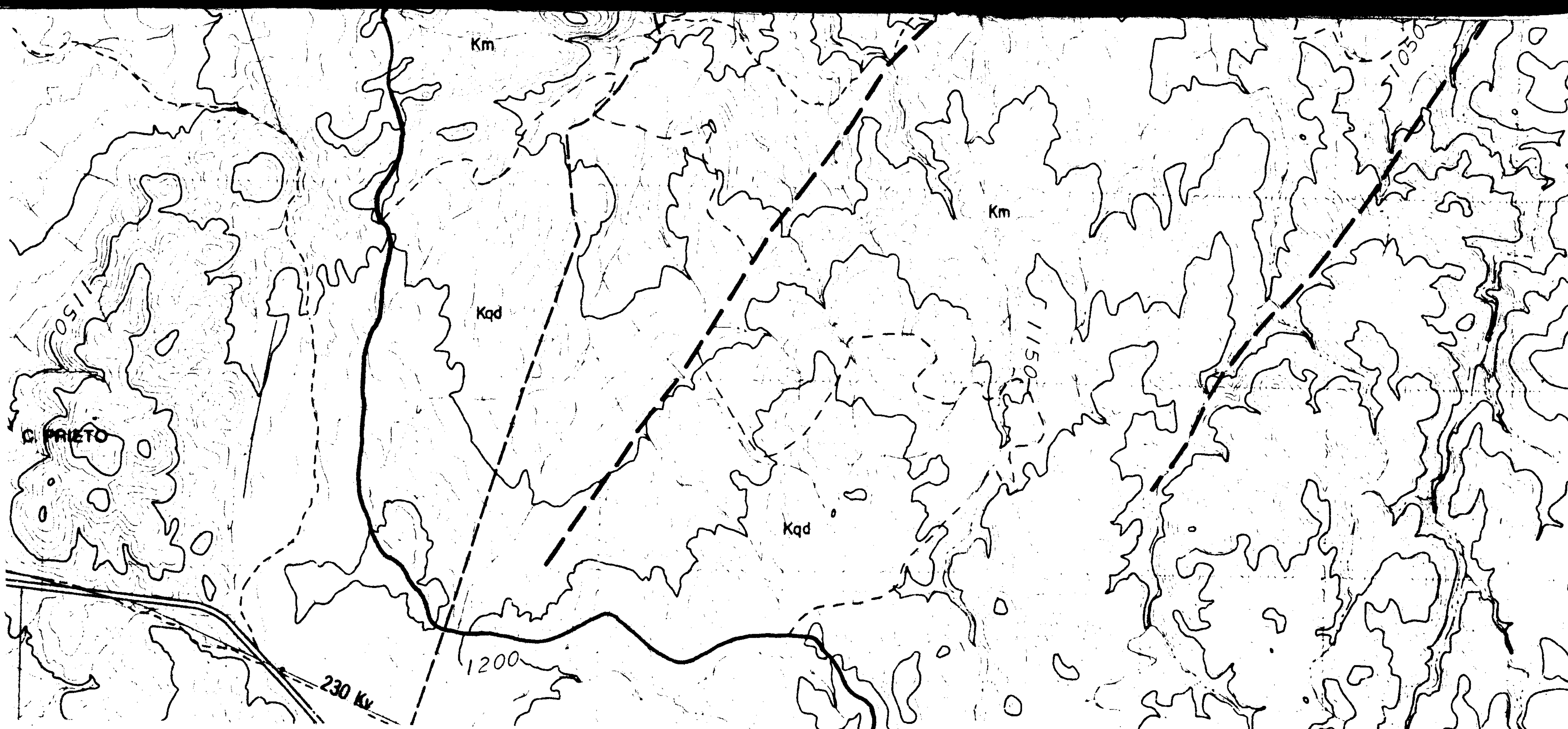
- Definite location.
- Approximate location.
- Covered.
- Covered, existence uncertain.

CONTACTS

- Definite location.
- Approximate location.

- Active or open wells.
- Prominent springs and seeps.
- Ephemeral streams.
- ⊙ S3 Soil sample sites.
- ⊗ 70 Vegetation sites, (Webber, 1979).
- △ Dams.
- Interstate highway.
- Paved roads.
- Unpaved roads.
- Railroad.

The geology of the Table Mt. area is after Minch and Abbott (1973). The geology of the metamorphic and plutonic terrain south of the international border is after the Mexican geologic maps La Rumorosa I11D63 and Neji I11D73, published by the Comision de Estudios del Territorio Nacional (1977).



N

Magnetic Declination 14° 15′

Scale 1:23,400

.5 0

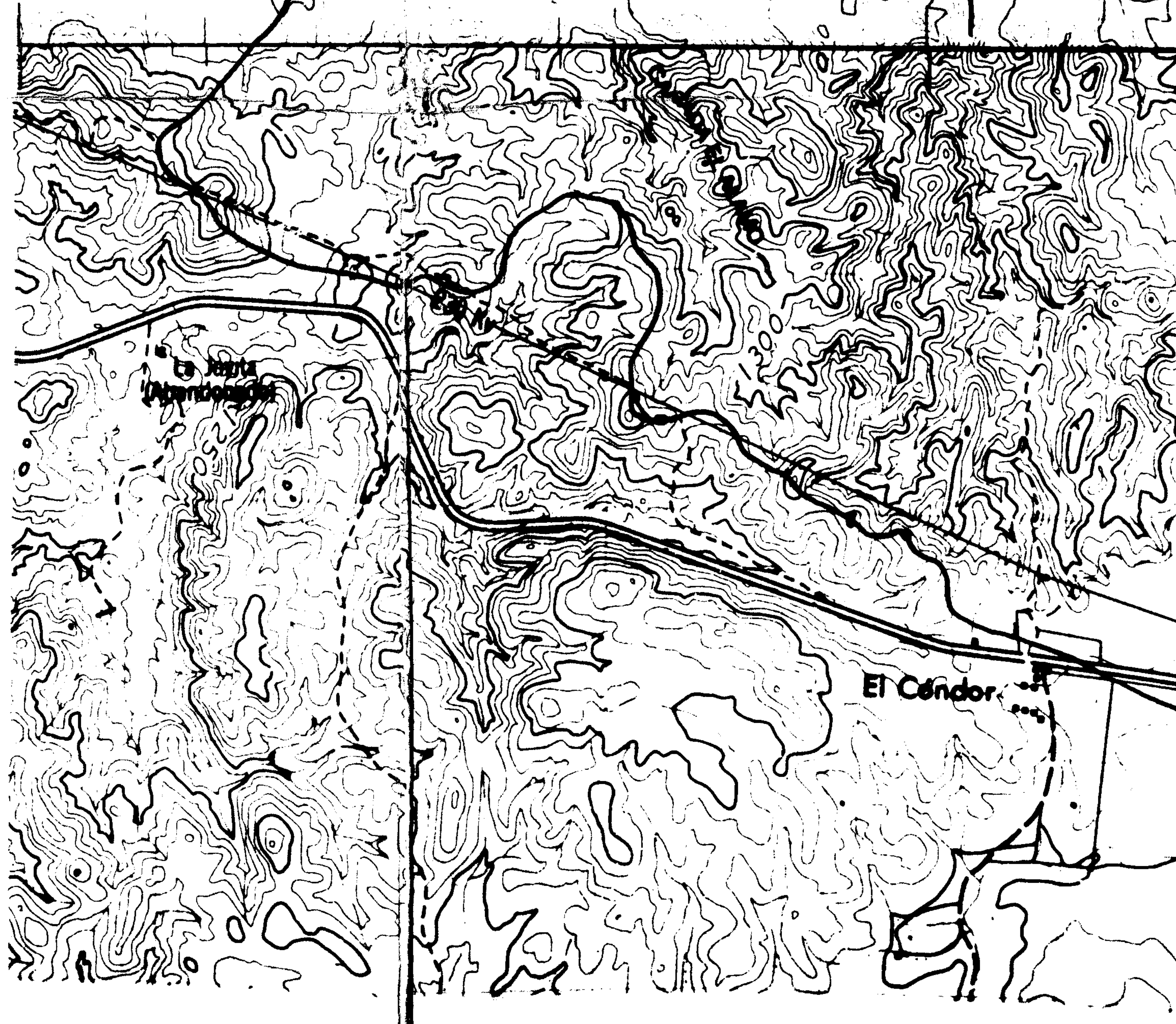
Kilometers

Contour Interval (light lines) 10 meters

(dark lines) 50 meters

Datum is mean sea level

The topographic base map was compiled from the Mexican 1:50,000 scale maps La Rumorosa I11D63 and Neji I11D73, published by the Comision de Estudios del Territorio Nacional (1977).



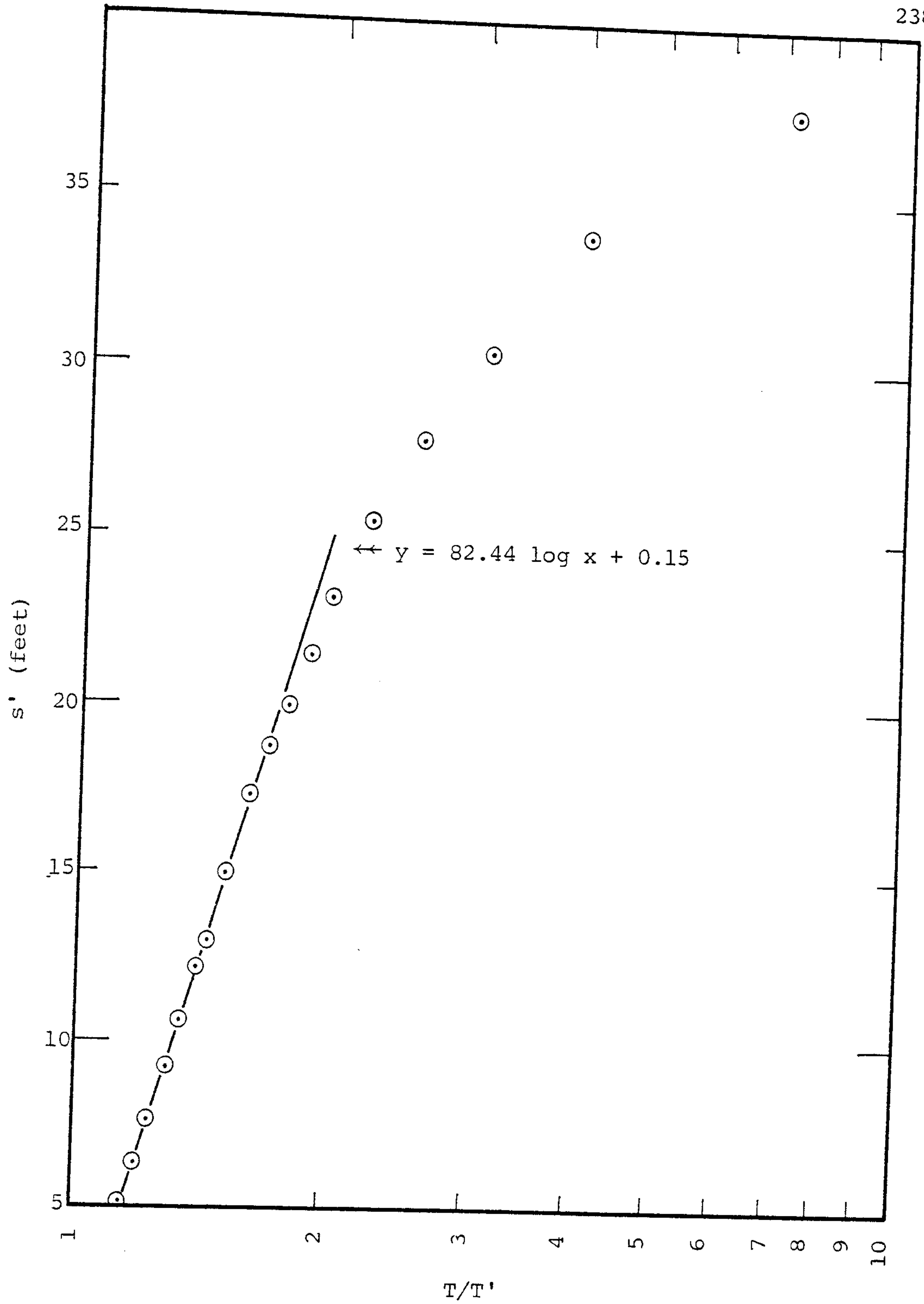


Figure 45. Table Mountain Aquifer, Recovery Test, Well R2