UNITED STATES
DEPARTMENT OF THE INTERIOR

WATER LEVEL MONITORING ALONG SAN ANDREAS AND SAN JACINTO FAULTS, SOUTHERN CALIFORNIA, DURING FISCAL YEAR 1979

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TECHNICAL REPORT 79-5

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by

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PREFACE

Lamar-Merifield, Geologists (formerly California Earth Science Corporation) has had contracts from the U.S. Geological Survey, Office of Earthquake Studies, to monitor water levels along the San Andreas and San Jacinto faults in southern California since September 1976. The first two years of research were accomplished under Contract No. 14-08-0001-15881, and the results were described by Merifield and Lamar (1978) and Lamar and Merifield (1978). Work during Fiscal Year 1979 described in this report was accomplished under Contract No. 14-08-0001-17680. To avoid repetition, much of the background and other data included in the final report (Merifield and Lamar, 1978) for Contract No. 14-08-0001-15881 has been omitted from this report. Location maps and charts describing the observation wells and precipitation stations have been updated to reflect the current status of the program.

The following reports present additional material prepared during FY 1979 under Contract No. 14-08-0001-17680:

Water level anomalies prior to the Izu-Oshima earthquake, January 14, 1978, by Yasue Oki and Shiro Hiraga; translated from Japanese by Betsy Silberman, Lamar-Merifield Technical Report 79-2.

Progress report on water level monitoring along San Andreas and San Jacinto faults, southern California; Lamar-Merifield Technical Report 79-3.

Water level measurement instructions for volunteer monitoring program along San Andreas and San Jacinto faults, southern California; Lamar-Merifield Technical Report 79-4.

Research on this project during FY 1980 is being continued on Contract No. 14-08-0001-18358.

ABSTRACT

A program of water-level monitoring of abandoned water wells along the San Andreas fault was initiated in October 1976. During October-November 1977, the program was extended southeastward along the San Andreas fault to the Valyermo area and along the San Jacinto fault zone in San Jacinto Valley, Anza, Borrego Valley and Ocotillo Wells. Currently about 35 wells are being monitored. Eight wells are monitored continuously with Stevens Type F recorders and a ninth well by a recorder developed during this program. The remaining wells are probed weekly, or in some cases semi-weekly, by volunteers or employees. Weekly water-level data are displayed on computer-generated hydrographs for each well. Rainfall and earthquakes are plotted on the graphs for direct comparison with water levels.

During the current reporting period, several earthquakes of magnitude 3.0 or above occurred within 25 miles of our observation wells along the San Jacinto fault zone. An earthquake of M4.1 occurred on 22 August 1979 within the San Jacinto fault zone approximately midway between, or 15 to 22 miles from, our observation wells in Anza and San Jacinto Valley. Water levels in two of the three wells in San Jacinto Valley showed anomalous behavior two to four weeks prior to the earthquake, and levels in the deepest of the three observation wells in Anza also showed anomalous behavior. A well in Borrego Valley showed four spikes which may be precursors to earthquakes which occurred within 25 miles. The significance of these spikes is questionable because several earthquakes occurred without similar spikes. The largest earthquake which could be related to an anomalous rise in water level in this well had a magnitude of 4.2 on 12 February 1979, approximately midway between our observation wells in Anza and Borrego Valley. No change in water level precursory to this earthquake was observed in the other two wells in Borrego Valley nor in three of the four wells being monitored in Anza. However, an apparently anomalous 1.2-foot drop in the deepest well in Anza occurred in mid-January 1979, about one month before the earthquake.

Two wells, one in Ocotillo Wells and another in Anza, showed particularly anomalous behavior during the past few months. The possible relation between these anomalies and the strong earthquake in Imperial Valley on 15 October 1979 should be considered. Preliminary reports place the earthquake near the

U.S.-Mexico border on the Imperial fault, which is generally considered to be a strand in the San Jacinto fault zone. A preliminary estimate of the magnitude is MS=6.8 (K. C. McNally, Caltech, 22 October 1979). The deepest well in Ocotillo Wells, located about 60 miles (100 km) northwest of the epicenter, showed an abrupt drop in water level of 1.7 feet in mid-July 1979, followed by an abrupt rise of 2.3 feet in water level to 0.6 foot above previous levels. Recent measurements subsequent to those on the hydrograph indicate that the water levels in this well have returned to levels similar to those before the anomalous drop in mid-July.

In contast, neither of the other two wells being monitored in the Ocotillo Wells area showed such an anomaly. However, water levels in two other wells in Ocotillo Wells showed a rise in mid-July of about 0.06 foot and about 0.03 foot. These rises would not be considered anomalous by themselves; however, it is perhaps significant that they occurred at the same time as the unusual drop and immediate rise in water level in the other well at Ocotillo Wells. Water levels in the well which showed the greatest anomaly could be expected to be more responsive to strain than those in the other two wells in the Ocotillo Wells area because of greater depth. This well has a depth of 374 feet, which is at least 174 feet deeper than the other two wells.

An alternate hypothesis for the abrupt rise in water level in the deepest well at Ocotillo Wells is based upon the rainstorm of 20 July 1979, which amounted to 1.65 inches at a station a little over a mile to the southwest. This well had not shown a significant response to prior rainstorms; for example, that of 24 November 1978 (1.35 inches). The well is in lacustrine sediments which would be expected to have impervious strata in the interval penetrated by the well. If, however, the rainfall occurred within a brief time period, resulting in flooding, surface water may have entered the gravel pack between the casing and sidewall and could account for an abrupt rise in water level. If this alternative is correct, the low reading made on 20 July 1979 is unexplained. We consider it possible, although unlikely, that this measurement was in error. The small rises in water levels in the other two wells in Ocotillo Wells would also be related in some way to the rainstorm in this alternative. However, water levels in these wells showed less response to previous rainstorms of comparable magnitude.

As mentioned previously, the deepest well in Anza showed large unexplained fluctuations in water level during 1979. The abrupt drop of 8 feet in June is particularly unusual. If the anomalous behavior of the deepest well in Ocotillo Wells in July is related to the Imperial Valley earthquake, that of the deepest well in Anza may be also.

It should also be noted that none of the wells in the Borrego Springs area, located between Anza and Ocotillo Wells, showed any anomalous water-level changes which could be considered precursors to the Imperial Valley earthquake. By analogy with other wells in the San Jacinto fault zone, the absence of precursory water-level changes in two of the wells could be explained by their relatively shallow depths of 116 and 71 feet; however, if the anomalies in the deepest wells in Ocotillo Wells and Anza are both earthquake precursors, the absence of a precursory water-level change in a third well in Borrego Springs is unexplained, because it is 330 feet deep and located about the same distance from a strand of the San Jacinto fault zone as the deepest well in Anza.

In summary, certain of the deeper wells along the San Jacinto fault zone have shown anomalous water-level changes prior to earthquakes of M4 or greater occurring along the fault zone. Although the results are encouraging, the data are not sufficiently consistent to confirm that the water-level changes represent actual earthquake precursors.

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INTRODUCTION

Observations and theory indicate that anomalous water-level changes in wells precede earthquakes (Merifield and Lamar, 1978). Japanese scientists (Oki and Hiraga, 1978) have also reported more than 200 examples of unusual water-level fluctuations before 40 "felt" earthquakes during the period May 1976 to January 1978, including the following three destructive earthquakes: July 16, 1976, M5.5, eastern Yamanashi; August 18, 1976, M5.4, Izu-Kawazu; and January 14, 1978, M7.0, west off Izu-Oshima. The latter earthquake was widely felt throughout Honshu and seriously damaged the town of Kawazu, with 25 victims. Volunteers of the Catfish Club (Hot Spring Research Institute, Hakone, Kanagawa, Japan) observed 30 examples of water-level anomalies prior to this earthquake. Unusual changes in water level were very pronounced in wells within 50 km of the earthquake epicenter, and many wells between 50 and 100 km from the earthquake yielded fairly good anomalies before the earthquake. More recently, Oki and Hiraga (1979) have reported water-level anomalies before the main shock (December 3, 1978, M5.4) of the November 23 to December 20, 1978 earthquake swarm off Ito City, Izu Peninsula. Numerous anomalies were observed from two to ten days prior to the main earthquake.

Beginning in October 1976, a program of water-level monitoring of abandoned water wells was initiated in the Palmdale area. In October 1977, the program was expanded southeastward along the San Andreas fault to Valyermo. In late 1977 and early 1978, water-level monitoring of wells along the San Jacinto fault zone from San Jacinto Valley to Ocotillo Wells was also initiated. The present program includes about 40 wells located in a variety of rock types and aquifers within and adjacent to the San Andreas and San Jacinto fault zones (Fig. 1).

WATER WELL DATA

Many abandoned water wells suitable for monitoring have been located; water wells in the Palmdale area are unused because in the past few years the Palmdale Water District has installed water lines to serve the area. Many of the wells in the Palmdale area will only be used if the domestic water system fails. Because farms and ranches have been abandoned and new wells have been drilled, many suitable wells have also been found along the San Andreas fault in the Valyermo area and along the San Jacinto fault zone.

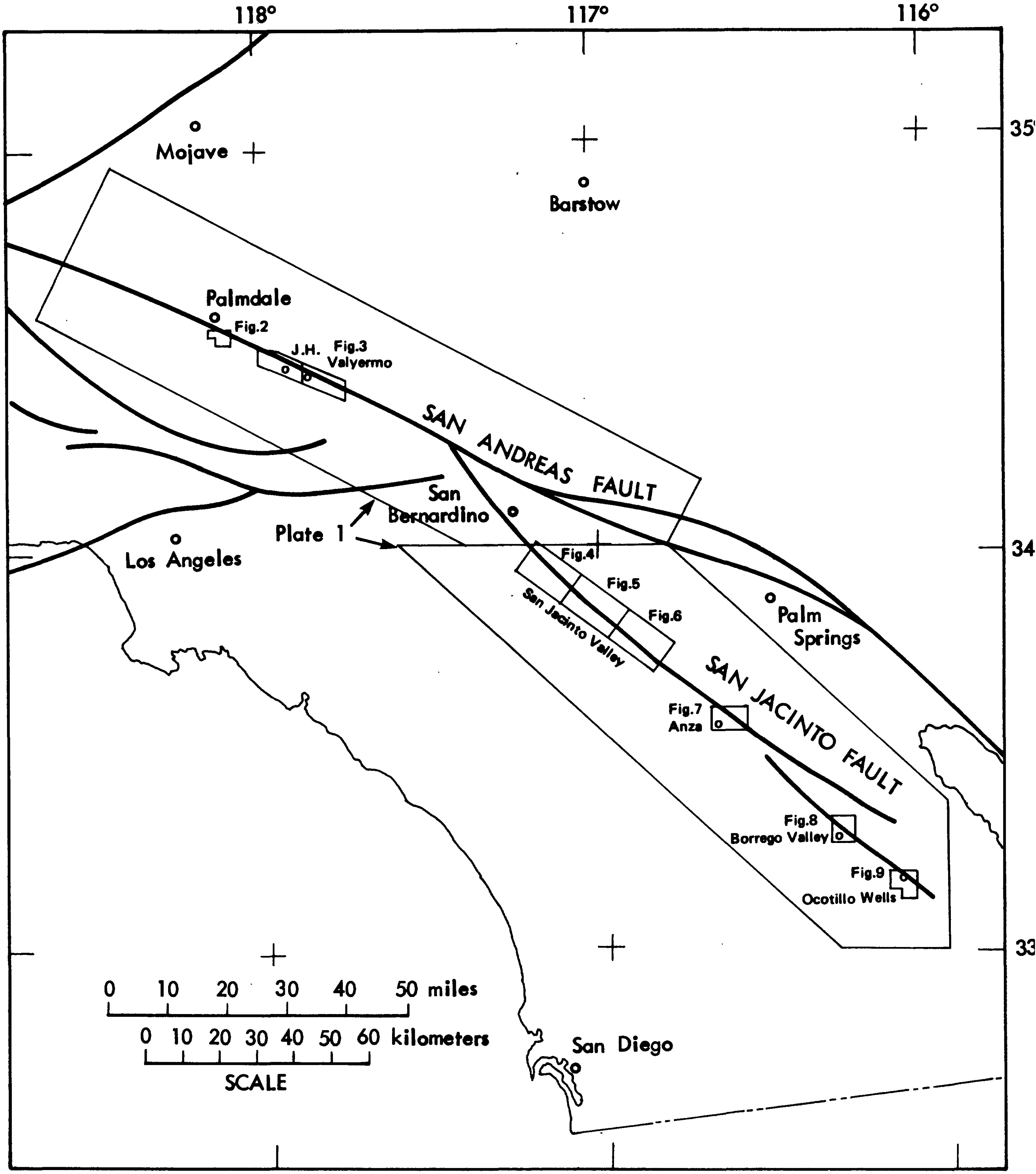

Fig. 1 - Index map showing locations of detailed maps (Figs. 2-9) of observation wells along San Andreas and San Jacinto faults and area of earthquake coverage (Plate 1).

To prepare these wells for monitoring, unused pumps, pipes and other debris must be removed and locking caps welded to the tops of the casings for protection from vandals who dump trash down unprotected wells. Unless wells are cleaned out, it is difficult to accurately probe the depth, because measuring probes commonly will not pass obstructions, and Stevens water level recorders cannot be installed.

The wells being monitored are shown on Plate 1 and Figs. 2 to 9; Table 1 lists data on the wells. Additional data on all of the wells located under this project were previously reported (Merifield and Lamar, 1978). Most of the information was obtained by direct observation and by interviews with present owners.

PRECIPITATION STATIONS

Because of the effect of rainfall on water levels and large local variations in storm intensity, several additional rainfall stations have been added to the program. Table 2 summarizes data on the precipitation stations now being used, and Plate 1 shows their locations. Fig. 10 is an example rainfall data set. Computer programs have been written which will plot daily rainfall on individual well hydrographs from either the closest precipitation station or, if the well is located between stations, the daily rainfall at the well is derived from a combination of adjacent stations. Fig. 11 is an example computer data set for a well; line 7 lists the combination of precipitation stations used to generate the daily rainfall plot for this particular well. Table 1 lists the precipitation station or combination of stations used to generate the daily rainfall at each observation well. Most of the precipitation data is obtained from records at the Los Angeles County Flood Control District office or from NOAA Climatological Data publications. A time lag exists in filing or publishing the data; therefore, our records are not all complete through the period covered by the well hydrographs. Table 2 indicates the most recent month for which rainfall data were available at each station.

MONITORING PROGRAM

Table 3 summarizes the causes, amplitudes and durations of water-level changes in wells. In this study we are looking for changes in the state of stress or strain premonitory to earthquakes; the other effects must be identified and separated to the maximum extent possible. Each well record has

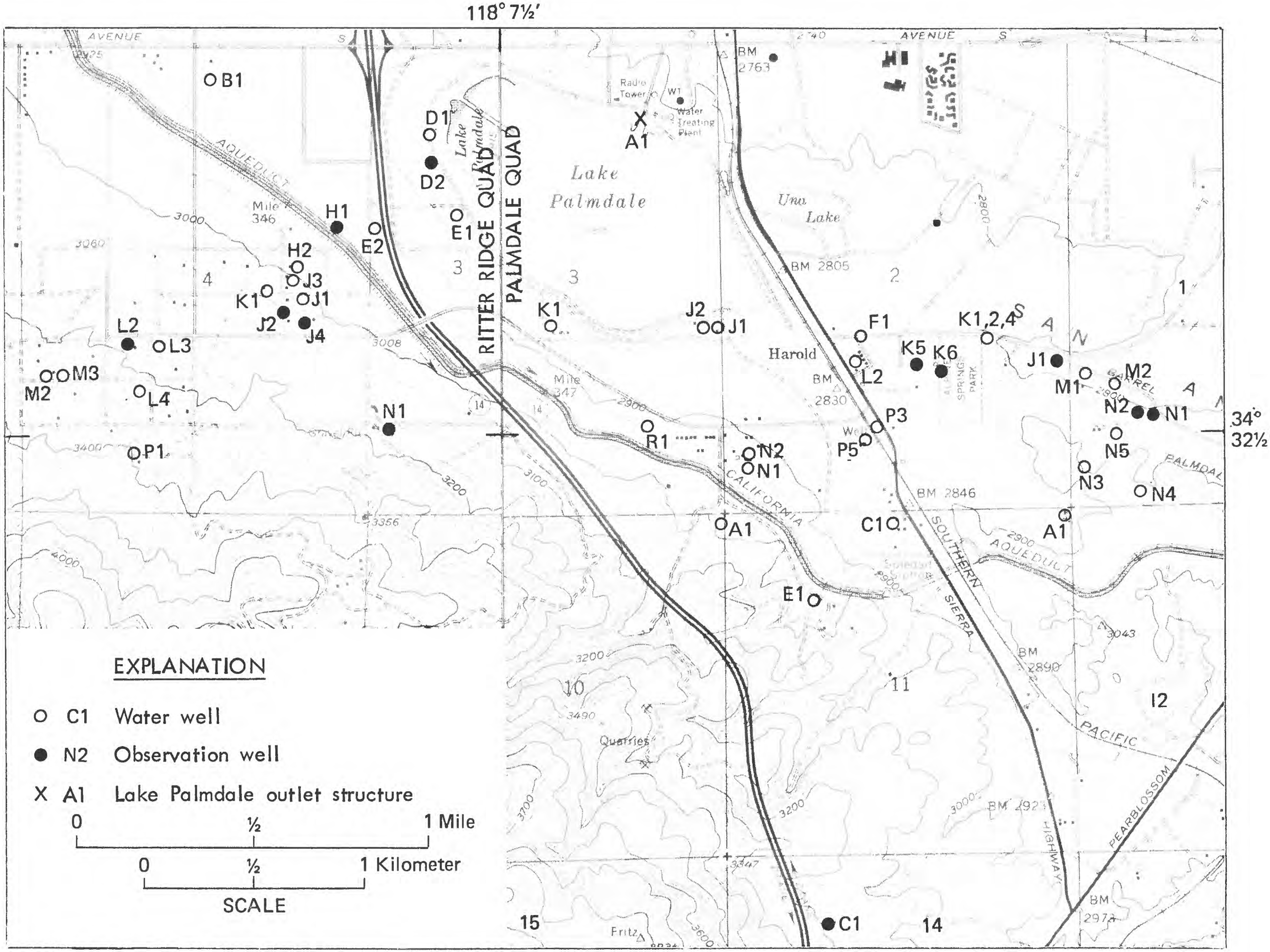

Fig.2 -- Map showing location of water and CalESCO observation wells along San Andreas Fault Zone directly south of Palmdale, California. Topography from U.S. Geological Survey, Palmdale and Ritter Ridge Quadrangles. All wells are located in Township 5 North, Range 12 West.

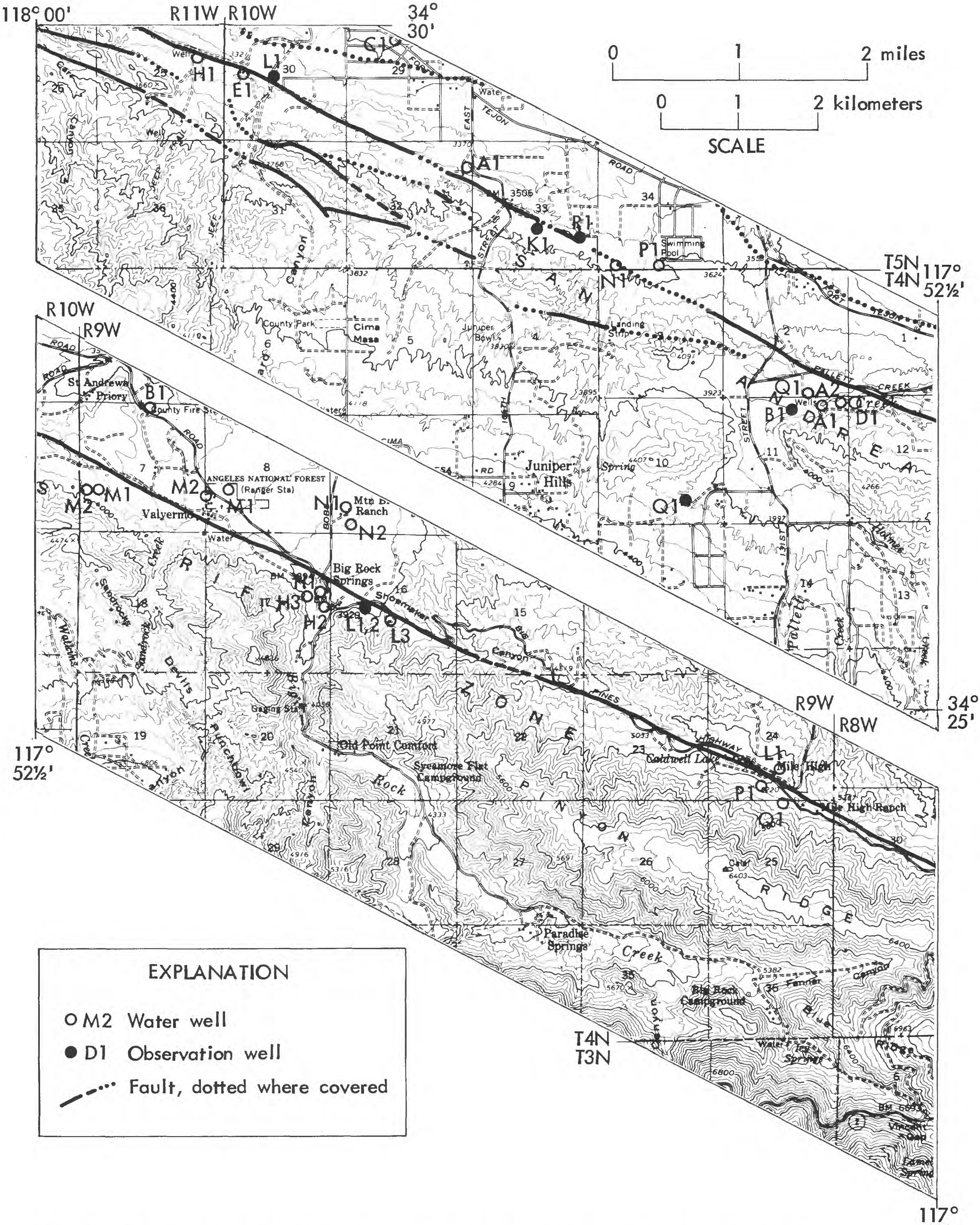

Fig. 3 - Map showing location of water and observation wells along San Andreas fault in Valyermo area. Topography from U.S. Geological Survey, 1 inch = 1 mile, Valyermo Quadrangle. Fault locations from Koehler (1966).

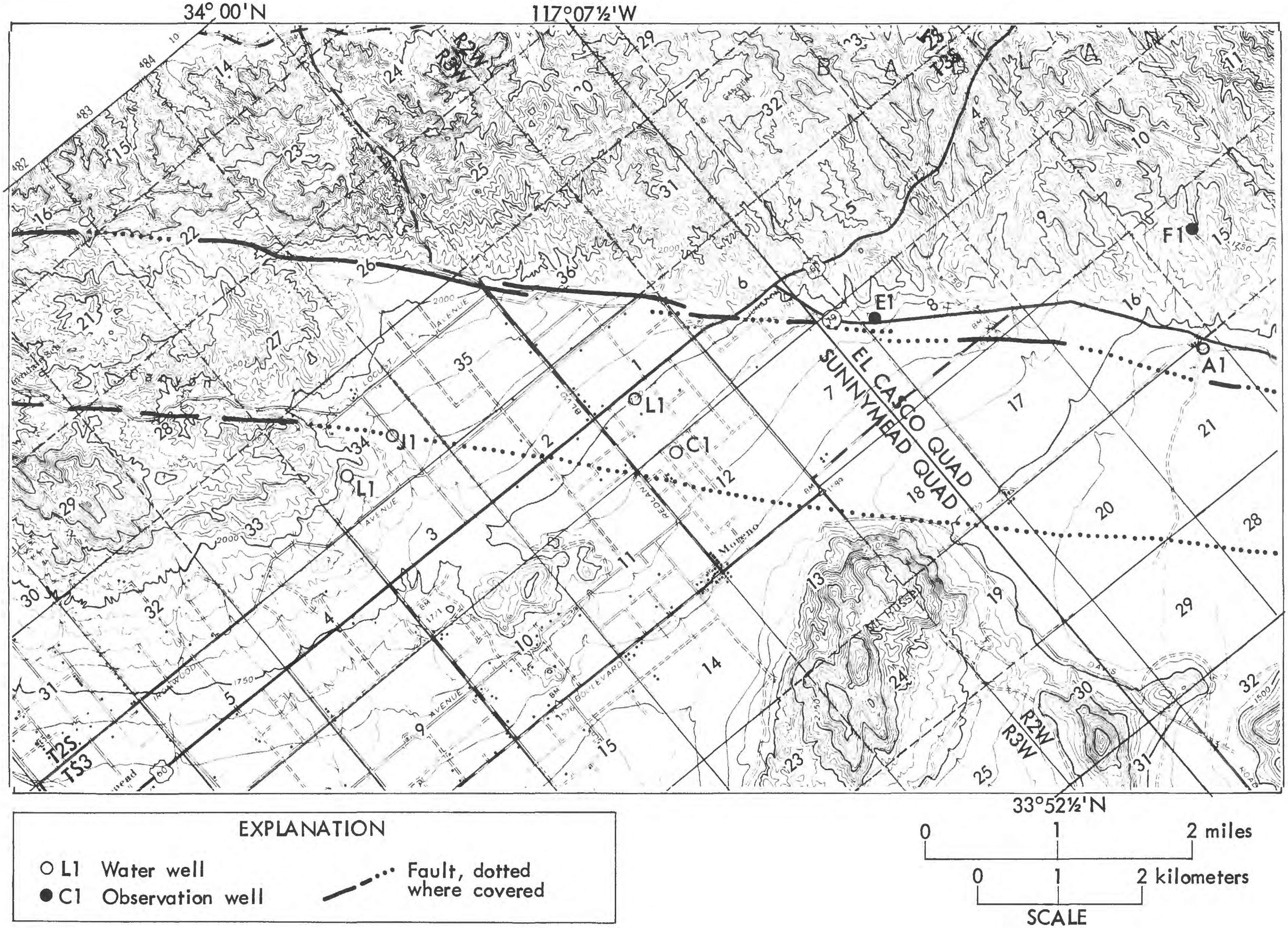

Fig. 4 - Map showing location of water and observation wells along San Jacinto fault zone at north end of San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Perris Quadrangle. Faults from Sharp (1972) and Rogers (1965).

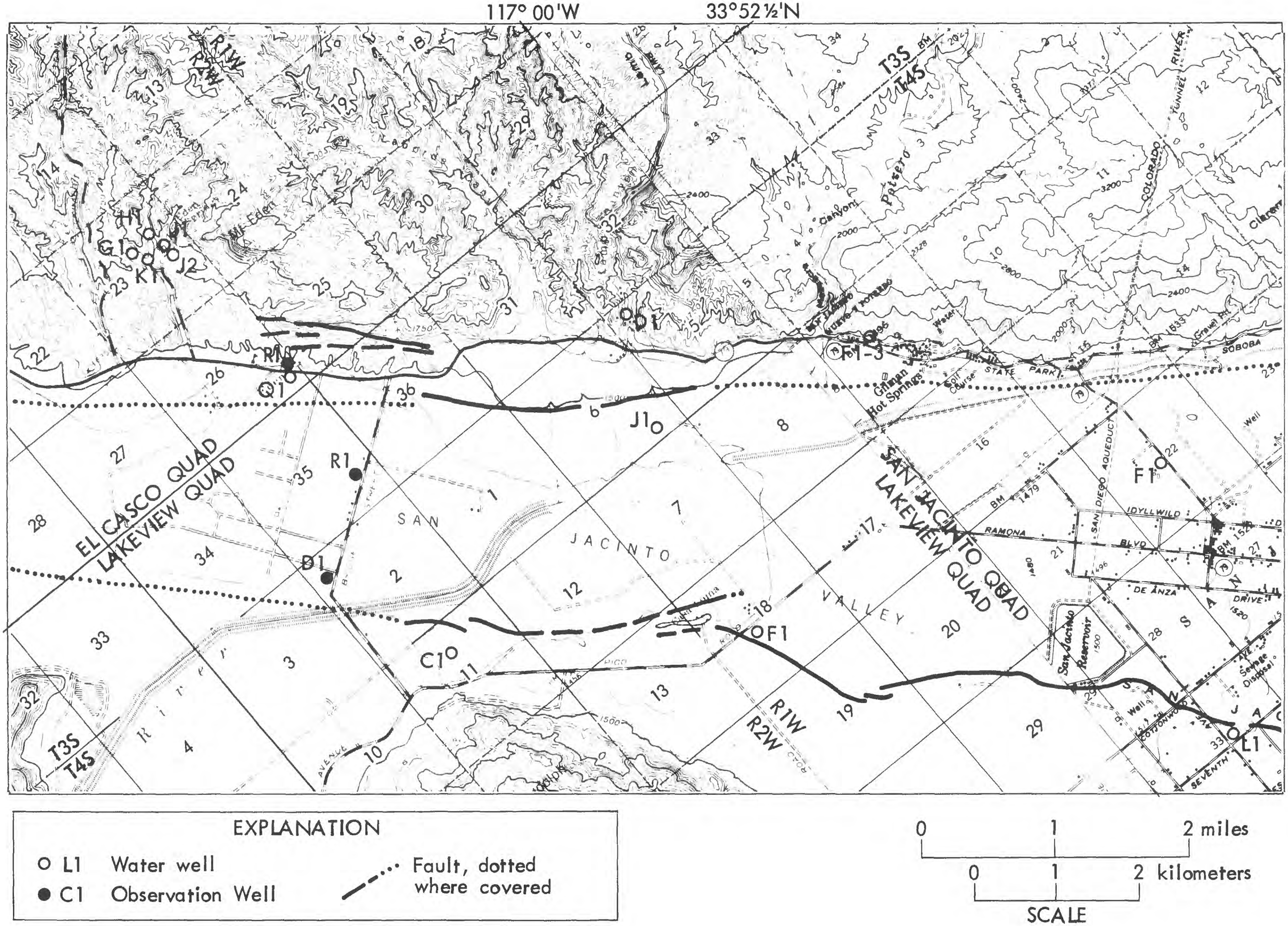

Fig. 5 - Map showing location of water and observation wells along San Jacinto fault zone in central San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Perris and Banning Quadrangles. Faults from Sharp (1972) and Rogers (1965).

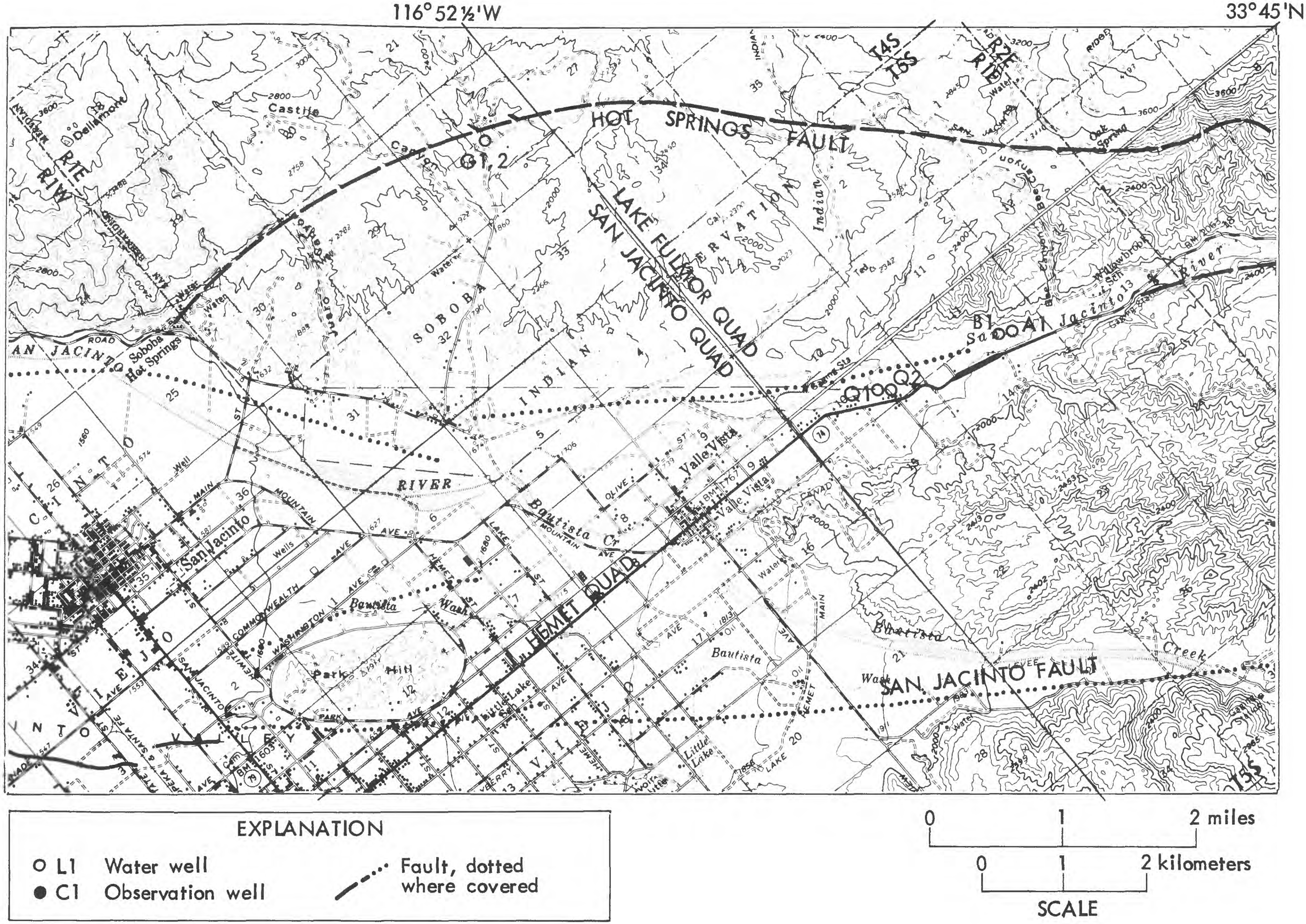

Fig. 6 - Map showing location of water and observation wells along San Jacinto fault zone at south end of San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Banning and Hemet Quadrangles. Faults from Sharp (1972) and Rogers (1965).

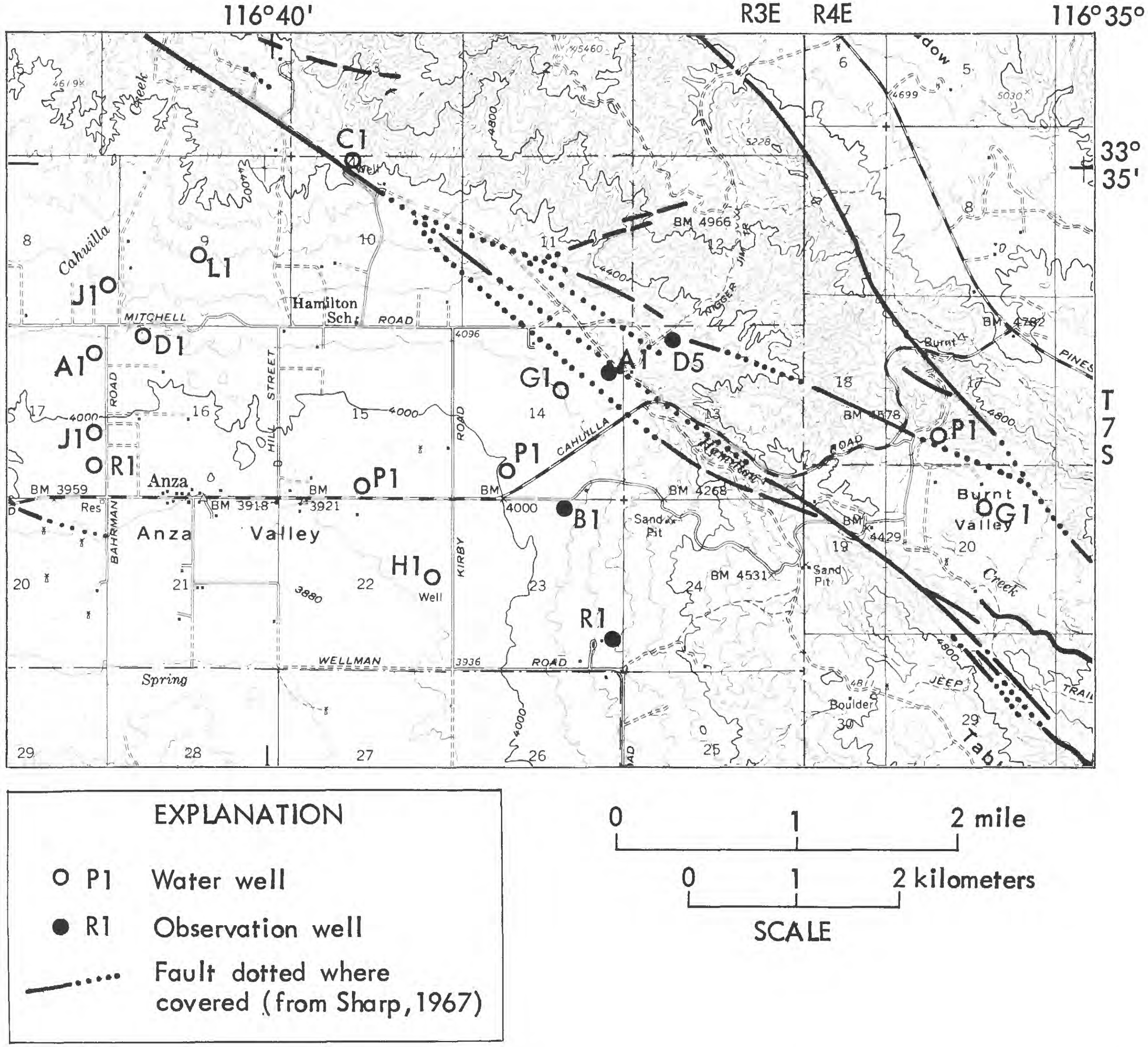

Fig. 7 - Map showing location of water and observation wells along San Jacinto fault zone in Anza area. Topography from U.S. Geological Survey, 1 inch = 1 mile, Idyllwild Quadrangle.

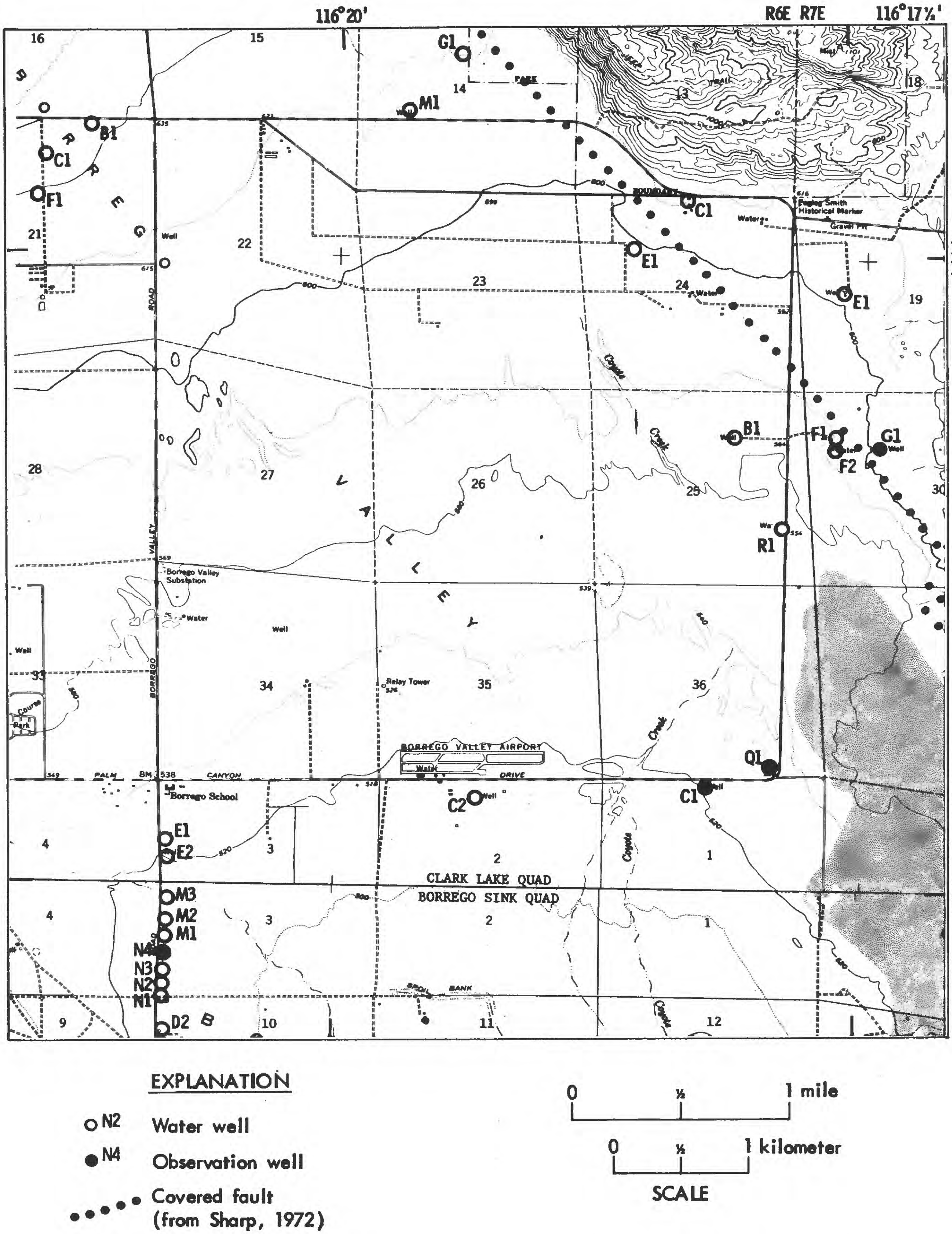

Fig. 8 - Map showing location of water and observation wells along Coyote Creek fault in Borrego Valley. Topography from U.S. Geological Survey, 1 inch = 2000 feet, Clark Lake and Borrego Sink Quadrangles.

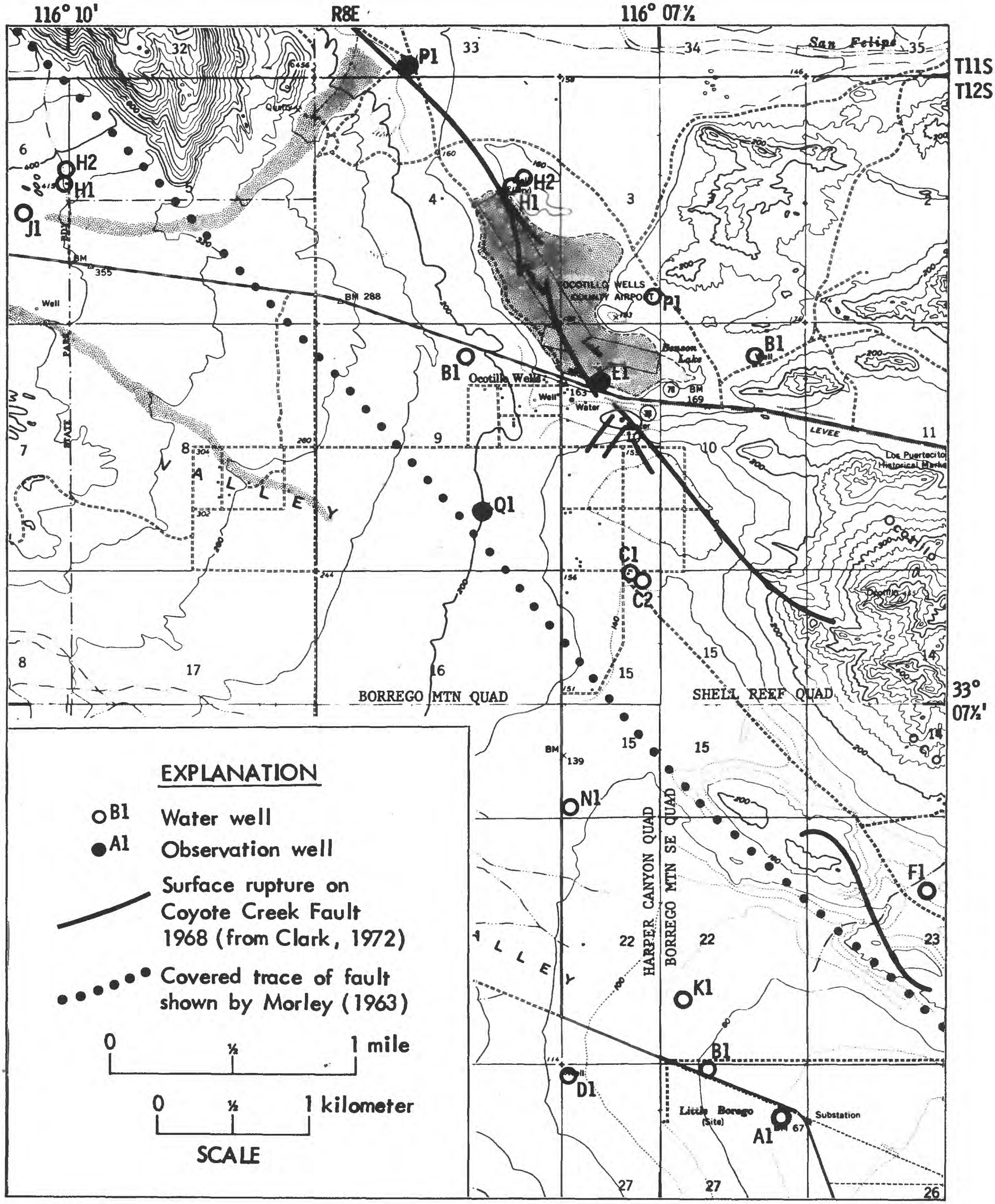

Fig. 9 - Map showing location of water and observation wells along San Jacinto fault zone in Ocotillo Wells area. Topography from U.S. Geological Survey, 1 inch = 2000 feet, Borrego Mountain, Shell Reef, Harper Canyon and Borrego Mountain SE Quadrangles.

Table 1 - Description of water wells along San Andreas and San Jacinto faults, southern California

State Well Number: An asterisk following well number indicates well being monitored by continuous recorders maintained by William R. Moyle, Jr., U.S. Geological Survey. Preliminary numbers have been assigned to the wells according to the U.S. Geological Survey well numbering system described by Koehler (1966). Well numbers are omitted where well location and number shown on California Division of Water Resources Well Location Base Maps, dated April 14, 1962 (copies from W. R. Moyle, Jr.) were not located during the present investigation. Numbers for those wells located by Koehler (1966), Moyle (1968) and Giessner and Mermod (1974) have been used where appropriate. Authority for final assignment of numbers rests with the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California (personal communication, W. R. Moyle, Jr., 1976).

Quadrangle: All wells are located on 1 inch = 2000 feet quadrangles with the exception of Hemet and Idyllwild, 1 inch = 1 mile, Quadrangles. Abbreviations: B.E.: Borrego Mountain SE; B.M.: Borrego Mountain; B.S.: Borrego Sink; C.L.: Clark Lake; E.C.: El Casco; H: Hemet; H.C.: Harper Canyon; I: Idyllwild; J.H.: Juniper Hills; L: Lakeview; L.R.: Littlerock; P: Palmdale; R.R.: Ritter Ridge; S: Sunnymead; S.J.: San Jacinto; S.R.: Shell Reef; S.V.: Sleepy Valley; V: Valyermo.

Owner or User: Name and address verified by personal or telephone contact.

Depth: Depth in quotes was obtained from owner, previous owner or other source. A "$\pm$" or range in depth indicates uncertainty. Entry without quotes is depth probed by Lamar-Merifield personnel.

Diameter: Inside diameter of well casing determined by Lamar-Merifield personnel.

Measuring Point: The point from which water-level measurements are made is described as follows: Tap: top of access pipe; Tc: top of casing; Tg: top of grate. Distance above land-surface datum (lsd) is given in tenths of a foot.

Table 1 (continued)

Altitude of lsd: Figure given indicates the altitude, in feet above mean sea level, of the land-surface datum (lsd). Altitudes were interpolated from U.S. Geological Survey topographic maps.

Precipitation Stations: Indicates station or combination of stations used for rainfall plots on hydrographs for each well. See Table 2 for data on precipitation stations.

State Well Number	Quad-rangle	Owner or User	Depth (feet)	Dia-meter (in.)	Measuring Pt. De-scrip-tion	Measuring Pt. Dist. above lsd (feet)	Alti-tude of lsd (feet)	Precipitation Stations
Palmdale Area								
5N/12W-								
1N1	P	Mr. Edward DeSteiguer 2000 E. Barrel Springs Rd. Palmdale, CA 93550	"191" 149.3	8.0	Tc	0.7	2815	0.40 PSPA19N + 0.60 PSPM24L
1N2	P	Mr. Edward DeSteiguer	"52",47.3	8.0	Tc	0.8	2815	"
2J1	P	-	91.0	9.5	Tc	0.7	2790	"
2K5	P	Palmdale Water District 2005 East Avenue Q Palmdale, CA 93550	-	-	-	0.15	2820	"
2K6	P	-	56.8	8.0	Tap	2.0	2825	"
3A1	P	Palmdale Water District	-	-	Tg	0.0	2820	"
3D2	R.R.	Mr. Harry L. Markowitz 451 21st Street Santa Monica, CA 90402	"60" 26.0	6.0	Tc	1.5	2825	"

Table 1 (continued)

State Well Number	Quad- rangle	Owner or User	Depth (feet)	Dia- meter (in.)	Measuring Pt. De- scrip- tion	Measuring Pt. Dist. above lsd (feet)	Alti- tude of lsd (feet)	Precipitation Stations
3N1	R.R.	Mr. Peter Galier 391270 Ocotillo P.O. Box 1269 Palmdale, CA 93550	"260" 442.0	7.5	Tc	0.9	3145	0.40 PSPA19N + 0.60 PSPM24L
4H1	R.R.	Mr./Mrs. Robt. C. Leahy 11801 Brookhurst Garden Grove, CA 92640	130.8	8.0	Tc	0.7	2930	"
4J2	R.R.	Mr. Robert Wilson 36640 Vista del Lago P.O. Box 726 Palmdale, CA 93550	"250" 69.1	8.0	Tc	0.0	3042	"
4J4	R.R.	Mrs. Pauline McCourtnay 3108 Menlo Drive Glendale, CA 91208	"325" 222.3	6.5	Tc	0.7	3022	"
4L2	R.R.	Mrs. Grace Oliver 36547 Oliver Lane P.O. Box 1179 Palmdale, CA 93550	142.0	7.5	Tc	1.2	3185	"
14C1	P	Mr. Jerry M. Nemiroff 16534 Bosque Drive Encino, CA 91436	646.0	18.0	Tc	0.7	3195	"
5N/11W-								
7G2*	P	-	-	-	-	1.0	2855	"
24G1*	LR	-	-	-	-	1.75	3068	0.50 PSLR12G + 0.50 PSJH04J

Table 1 (continued)

State Well Number	Quadrangle	Owner or User	Depth (feet)	Diameter (in.)	Measuring Pt. Description	Measuring Pt. Dist. above lsd (feet)	Altitude of lsd (feet)	Precipitation Stations
Valyermo Area								
5N/10W-								
30L1	J.H.	Larry Scattaglia	196	10	Tc	0.0	3340	0.40 PSLR12G + 0.40 PSJH04L + 0.20 PSJH19E
33K1	J.H.	Pete Krueger P.O. Box 356 Littlerock, CA 93543	44	8	Tc	0.0	3520	0.50 PSJH04L + 0.25 PSJH19E + 0.25 PSJH24E
33R1	J.H.	Will Clark 1655 Rubio Drive San Marino, CA 91108	-	10	Tc	3.0	3570	"
4N/10W-								
10Q1	J.H.	Tom Somermeier 9599 Sunset Blvd. Beverly Hills, CA 90210	868	14	-	-	4120	0.50 PSJH04L + 0.25 PSJH24E + 0.25 PSVY19K
11B1	J.H.	James Shannon	260	-	Tc	0.0	3835	0.35 PSJH24E + 0.35 PSVY19K + 0.30 PSVY28M
4N/9W-								
16L1	V	Frank M. Bixenstein 17332 Coventry Lane Yorba Linda, CA 92686	152	10	Tc	0.0	4000	"
San Jacino Valley Area								
3S/2W-								
8E1	E.C.	Vincent J. Paino 3028 Roberta Drive Orange, CA 92669	181	12.5	Tc	0.5	1676	1.0 PSSJ35D

Table 1 (continued)

State Well Number	Quad-rangle	Owner or User	Depth (feet)	Dia-meter (in.)	Measuring Pt. De-scrip-tion	Measuring Pt. Dist. above lsd (feet)	Alti-tude of lsd (feet)	Precipitation Stations
15F1	E.C.	Oliver Elliot 35748 Highway 79 San Jacinto, CA	-	-	Tc	1.0	1640	1.0 PSSJ35D
26R1	E.C.	Oliver Elliot	-	35	Tc	0.5	1440	"
35R1	L	Forest Bebouger	190	12	Tc	3.4	1425	"
4S/2W-								
2D1		Bodger Seed	83	18	Tc	0.0	1430	"
Anza Area								
7S/3E-								
13D5	I	Cleo Hodges	83	10.5	Tc	0.7	4250	0.50 PSID16Q + 0.50 PSID23R
14A1	I	Cleo Hodges	27	6	Tc	0.9	4160	"
23B1	I	Romona Water Co.	185	8	Tap	0.6	4070	"
23R1	I	Jack McGehee 39775 Terwilleger Rd. Anza, CA 92306	94	10	Tc	1.1	4220	"
Borrego Valley Area								
10S/6E-								
36Q1	C.L.	Albert E. Jones Northwest Avenue Billingham, WA 98225	330	11	Tc	2.2	535	1.0 PSBP01A

Table 1 (continued)

State Well Number	Quad-rangle	Owner or User	Depth (feet)	Dia-meter (in.)	Measuring Pt. De-scrip-tion	Measuring Pt. Dist. above lsd (feet)	Alti-tude of lsd (feet)	Precipitation Stations
10S/73-								
30G1	C.L.	Matt S. Browning P.O. Box 2166 Ogden, Utah 87404	-	14	Tc	0.45	600	1.0 PSBP01A
11S/6E-								
1C1	C.L.	Southern Pacific Co.	116	18	Tc	0.5	520	"
3N4	B.S.	Dr. John Rumsey 5437 Caminto Aqua La Jolla, CA	71	11	Tc	0.8	515	"
Ocotillo Wells Area								
11S/8E-								
33P1	B.M.	Margery Treeleven Box 74 Rochelle, TX 79872	374	6	Tc	2.0	165	0.50 PSPM06H + 0.50 PSBM15E
12S/8E-								
9Q1	B.M.	Dr. Hetterman	±200	10	Tc	0.0	-	"
10E1	B.M.	Milton Clark 10767 Jamacha Blvd. Spring Valley, CA 92077	110	8	Tc	4.8	160	"

Table 2 - Description of precipitation stations along San Andreas and San Jacinto faults, southern California

Number: Prefix PS identifies data set as precipitation station. Next two letters are abbreviation for quadrangle: BM: Borrego Mountain; BP: Borrego Palm Canyon; DS: Del Sur; ID: Idyllwild; JH: Juniper Hills; LR: Littlerock; PA: Palmdale; PM: Pacifico Mountain; RR: Ritter Ridge; SJ: San Jacinto; VY: Valyermo. Next two numbers refer to section; final letter refers to 40-acre square within section based on the U.S. Geological Survey well numbering system described by Koehler (1966).

Latitude and Longitude: Locations of Los Angeles County Flood Control District (LACFCD) wells not checked; coordinates from LACFCD.

Elevation: In feet from adjacent benchmark or contours on U.S. Geological Survey Quadrangle. Elevations of LACFCD stations from their data sheets. In some cases, elevation does not match with elevation at station coordinates plotted on topographic maps.

Notes: A: data obtained directly from individual at station; B: data obtained from LACFCD; C: NOAA, Climatological Data. The most recent month in 1979 for which rainfall data were available is indicated.

Number	Township	Latitude(N)	Longitude(W)	Elevation (ft.)	Description	Notes
San Andreas Fault, Palmdale-Juniper Hills-Valyermo Area						
PSDS02J	T6N,R14W	34°37.87'	118°19.37'	3200	LACFCD No. 122G, Leona Valley-Rackett Ranch	B/April
PSRR11M	T6N,R13W	34°37.38'	118°13.91'	2880	LACFCD No. 722C, Belleview	B/July
PSPA19N	T6N,R12W	34°35.28'	118°5.58'	2598	Palmdale Irrigation Dist. Headquarters	A/Sept.
PSPM24L	T5N,R12W	34°29.53'	118°5.47'	3520	LACFCD No. 1063, Soledad Pass	B/July
PSLR12G	T5N,R11W	34°32.20'	117°58.72'	2800	LACFCD No. 299F, Little Rock-Schwab	B/July
PSJH04L	T4N,R10W	34°27.67'	117°55.85'	3960	LACFCD No. 460C, Pleasant View Mesa	B/April
PSJH19E	T4N,R10W	34°25.03'	117°58.22'	4000	LACFCD No. 1060B, Little Rock-Sycamore Camp	B/April

Table 2 (continued)

Number	Township	Latitude(N)	Longitude(W)	Elevation (ft.)	Description	Notes
PSJH24E	T4N,R10W	34°25.20'	117°53.18'	4615	LACFCD No. 517B, Lewis Ranch	B/July
PSVY19K	T4N,R10W	34°24.80'	117°51.42'	4760	LACFCD No. 1111C, Devil's Punch Bowl	B/April
PSVY28M	T5N,R9W	34°29.22'	117°50.03'	3390	LACFCD No. 564C, Llano	B/July
San Jacinto Fault, San Jacinto Valley, Anza, Borrego Springs, Ocotillo Wells Area						
PSSJ35D	T4S,R1W	33°47.20'	116°57.50'	1560	California Division of Forestry Fire Station, San Jacinto	C/May
PSID16Q	T7S,R3E	33°33.30'	116°40.48'	3920	California Division of Forestry Fire Station, Anza	C/May
PSID23R	T7S,R3E	33°32.59'	116°37.85'	4200	Jack McGehee, 39775 Terwilleger Road, Star Route, Anza	A/Aug.
PSBP01A	T10S,R5E	33°15.36'	116°24.12'	810	California State Park Headquarters, Borrego Springs	A/Aug.
PSBM06H	T12S,R8E	33°9.35'	116°10.04'	390	California State Park Ranger Residence, Ocotillo Wells	A/Aug.
PSBM15E	T12S,R8E	33°7.89'	116°7.89'	158	Bud Good, Ocotillo Wells	A/April

PRECIPITATION STATION: PSID23R IDYLLWILD QUAD
MCGEHEE RESIDENCE, ANZA CALIFORNIA
LATITUDE: 33-32.59 N LONGITUDE: 116-37.87 W
LAND SURFACE ELEVATION: 4200 FEET
DRAINAGE SUB-BASIN

MO/DA/YR	JULIAN DA/YR	OBSERV.	PRECIP. (INCHES)
01/15/78	15/78	JM	2.00
01/16/78	16/78	JM	1.00
01/19/78	19/78	JM	1.25
02/06/78	37/78	JM	1.00
02/08/78	39/78	JM	.50
02/12/78	43/78	JM	1.25
03/01/78	60/78	JM	2.00
03/02/78	61/78	JM	1.50
03/04/78	63/78	JM	.75
03/05/78	64/78	JM	1.00
03/11/78	70/78	JM	.50
03/31/78	90/78	JM	.55
04/15/78	105/78	JM	.25
04/25/78	115/78	JM	.25
08/03/78	215/78	JM	.10
08/08/78	220/78	JM	.15
08/10/78	222/78	JM	1.50
01/05/79	5/79	JM	.55
01/09/79	9/79	JM	.35
01/15/79	15/79	JM	.25
01/16/79	16/79	JM	1.00
01/17/79	17/79	JM	1.55
01/18/79	18/79	JM	.35
01/25/79	25/79	JM	.25
02/03/79	34/79	JM	1.55
02/20/79	51/79	JM	.35
02/22/79	53/79	JM	1.05
03/01/79	60/79	JM	.55
03/15/79	74/79	JM	.20
03/17/79	76/79	JM	.35
03/20/79	79/79	JM	1.55
03/27/79	86/79	JM	.15
05/19/79	139/79	JM	.20
06/03/79	154/79	JM	.05
08/07/79	219/79	JM	.50
08/16/79	228/79	JM	6.00
08/17/79	229/79	JM	.15
08/19/79	231/79	JM	.25

Fig. 10 - Printout of daily rainfall (inches) for precipitation station PSID23R, Anza.

WELL NUMBER: 07S/03E-13D05 IDYLLWILD QUAD(ID13D05)
HEIGHT REFERENCE POINT ABOVE LAND SURFACE: 0.700 FT
LAND SURFACE ELEVATION: 4250.0 FT
TOTAL DEPTH OF WELL:83.0 FT
YMAX= -68.0 YMIN= -65.0
LATITUDE: 33-34.10 N LONGITUDE: 116-37.59 W
PRECIP STATIONS: 0.50 PSID16Q + 0.50 PSID23R

DATE MO/DA/YR	JULIAN DA/YR	TIME (PST)	TEMP (F)	OBSERVER	PROBE DEPTH BELOW REF. SURFACE (FT)	WATER DEPTH BELOW LAND SURFACE (FT)	NOTES
01/12/79	12/79	08:00		SR	66.980	66.280	
01/19/79	19/79	08:00		SR	67.015	66.315	
01/26/79	26/79	08:00		SR	66.987	66.287	
02/03/79	34/79	10:30		DD	66.925	66.225	
02/09/79	40/79	08:00		SR	66.922	66.222	
02/16/79	47/79	08:00		SR	66.867	66.167	
02/23/79	54/79	08:00		SR	66.838	66.138	
03/03/79	62/79	13:32		DD	66.890	66.190	
03/09/79	68/79	08:00		SR	66.778	66.078	
03/16/79	75/79	08:00		SR	66.747	66.047	
03/23/79	82/79	08:00		SR	66.809	66.109	
03/31/79	90/79	12:30	62.0	JG	66.790	66.090	
04/07/79	97/79	08:00		SR	66.737	66.037	
04/14/79	104/79	08:00		SR	66.728	66.028	
04/21/79	111/79	08:00		SR	66.715	66.015	
04/26/79	116/79	10:30	62.0	DD	66.705	66.005	
05/03/79	123/79	08:00		SR	66.679	65.979	
05/10/79	130/79	08:00		SR	66.661	65.961	
05/17/79	137/79	08:00		SR	66.589	65.889	
05/26/79	146/79	10:11	61.5	DD	66.570	65.870	
06/02/79	153/79	08:00		SR	66.551	65.851	
06/09/79	160/79	08:00		SR	66.578	65.878	
06/15/79	166/79	08:00		SR	66.494	65.794	
06/25/79	176/79	11:50		DD	66.480	65.780	
07/07/79	188/79	08:00		SR	66.410	65.710	
07/09/79	190/79	08:00		SR	66.399	65.699	
07/16/79	197/79	08:00		SR	66.397	65.697	
07/19/79	200/79	11:25		DD	66.340	65.640	
07/26/79	207/79	08:00		SR	66.311	65.611	
08/02/79	214/79	08:00		SR	66.273	65.573	
08/09/79	221/79	08:00		SR	66.232	65.532	
08/17/79	229/79	11:42		DD	66.220	65.520	
08/24/79	236/79	08:00		SR	66.151	65.451	
08/31/79	243/79	08:00		SR	66.103	65.403	
09/07/79	250/79	08:00		SR	66.065	65.365	

Fig. 11 - Example printout of well data for well 7S/3E-13D5.

Table 3 - Summary of causes, amplitudes and durations of water level changes in wells.

Cause	Amplitude (Order of Magnitude)	Duration
Vehicles, wind, sonic booms, objects falling in well or hitting enclosure	centimeters	Instantaneous (spikes)
Earthquakes	centimeters	spikes, sharp rises or drops followed by recovery in hours
Barometric pressure, temperature, earth tides	millimeters to centimeters	diurnal, semidiurnal
Evapotranspiration (shallow water table only)	centimeters	diurnal
Rainfall (direct influence), ephemeral influent streams	centimeters	rise and gradual decay, hours to weeks
Pumping wells in same aquifer	decimeters	drop followed by recovery in days
Deformation of aquifer (may or may not be earthquake precursor)	decimeters to meters	days, weeks
Seasonal and secular changes of water in storage	meters	annual and longer

its peculiarities owing to differing aquifer characteristics, local environment (e.g., nearby wells, roads, wind exposure) and instrument idiosyncrasies. A period of time is required to establish the changes that constitute a normal record, as well as man-made influences (See Table 3). Typical periods for the fluctuations vary from instantaneous to annual, and the nature of changes premonitory to earthquakes is poorly understand. The duration of such changes may be proportional to the magnitude of the earthquake (Scholz et al, 1973). Thus, it is essential to our research to have records of both short-term and long-term variations. The methods and equipment used for water level measurement have been described previously (Merifield and Lamar, 1978).

Volunteer Program

Water wells not equipped with continuous recorders are probed once a week or, in some cases, twice a week by volunteers. Measurement of water levels is a task particularly well-suited to local volunteers because of its simplicity and the necessity for monitoring many wells spread over a wide geographic area. Each volunteer probes the depth and occasionally the temperature in three to five wells. Probe data are entered on computer printouts and mailed each week to our office in stamped envelopes provided by us. In general, the volunteer program has been effective and is an economical means of obtaining observations over a wide area (Merifield and Lamar, 1978). The instruction manual for volunteers has been improved (Lamar, Merifield and Douglass, 1979). Ideas for improvement of the volunteer program are discussed below under Future Plans.

WATER LEVEL CHANGES

Continuous recorders are being installed on as many suitable wells as possible to determine their response to atmospheric pressure and tidal forces and, therefore, their sensitivity as strain meters (Bodvarsson, 1970). Data so far obtained indicate that deeper wells in bedrock are more responsive to changes in atmospheric pressure and tidal forces, and shallow wells in alluvium are relatively unconfined and less responsive.

A computer program (Appendix A) generates hydrographs of weekly water levels and temperatures for each well from the data set on disk. Rainfall data are also plotted on the same computer-generated figures for direct comparison with water levels.

Palmdale Area

Several wells in the Palmdale area have been continuously monitored since October 1976; water levels of most of the wells show an annual cycle. Hydrographs of water levels for the first two years of monitoring are presented in Merifield and Lamar (1978). Figs. 12-26 are hydrographs of observation wells in the Palmdale area for the past year. Figs. 12 and 13 in this report and Figs. 25-28 in Merifield and Lamar (1978) show that water levels at Lake Palmdale (Location 5N/12W-3A1) and well 5N/12W-3D2 have fluctuated in unison. This well is located in Quaternary sediments directly west of the lake and good hydrologic continuity is believed to exist between the well and the lake. Water levels rose following the storm of December 1978 and continued to rise during the rainfall period which ended in March 1979; since then water levels have dropped during a relatively dry period.

Wells 5N/12W-1N1 (Fig. 14), -2J1 (Fig. 15), -2K6 (Fig. 16) and -1N2 (Fig. 17) are located in the San Andreas fault zone east of Lake Palmdale. Water levels for the first two years of monitoring are shown in Merifield and Lamar (1978, Figs. 29-36). These wells continue to show a clear annual cycle which appears to be related to the level of Lake Palmdale and seasonal rainfall. Water levels during the past three years have been at a minimum during July-November and have been the highest during February-June. In addition to the annual cycle, a gradual rise in water levels in these wells has occurred in apparent response to unusually heavy rainfall during the 1977-78 season. No effect of individual storms on these wells can be seen, and most of the curves are relatively smooth.

A Stevens recorder was operated on well 5N/12W-2K5 from October 1976 through October 1977 by William R. Moyle, Jr. of the U.S. Geological Survey. Merifield and Lamar (1979, Fig. 27) present a hydrograph of weekly water levels for the period October 1976 through September 1977. This well was not monitored from October 1977 until July 25, 1979 when Lamar-Merifield personnel and volunteers began weekly monitoring. As shown in Fig. 18, water levels in -2K5 have dropped since July, similar to other wells in the adjacent area.

Levels in well 5N/12W-3N1 also show an annual cycle superimposed on a gradual rise in water level. Water levels gradually rose from November 1976,

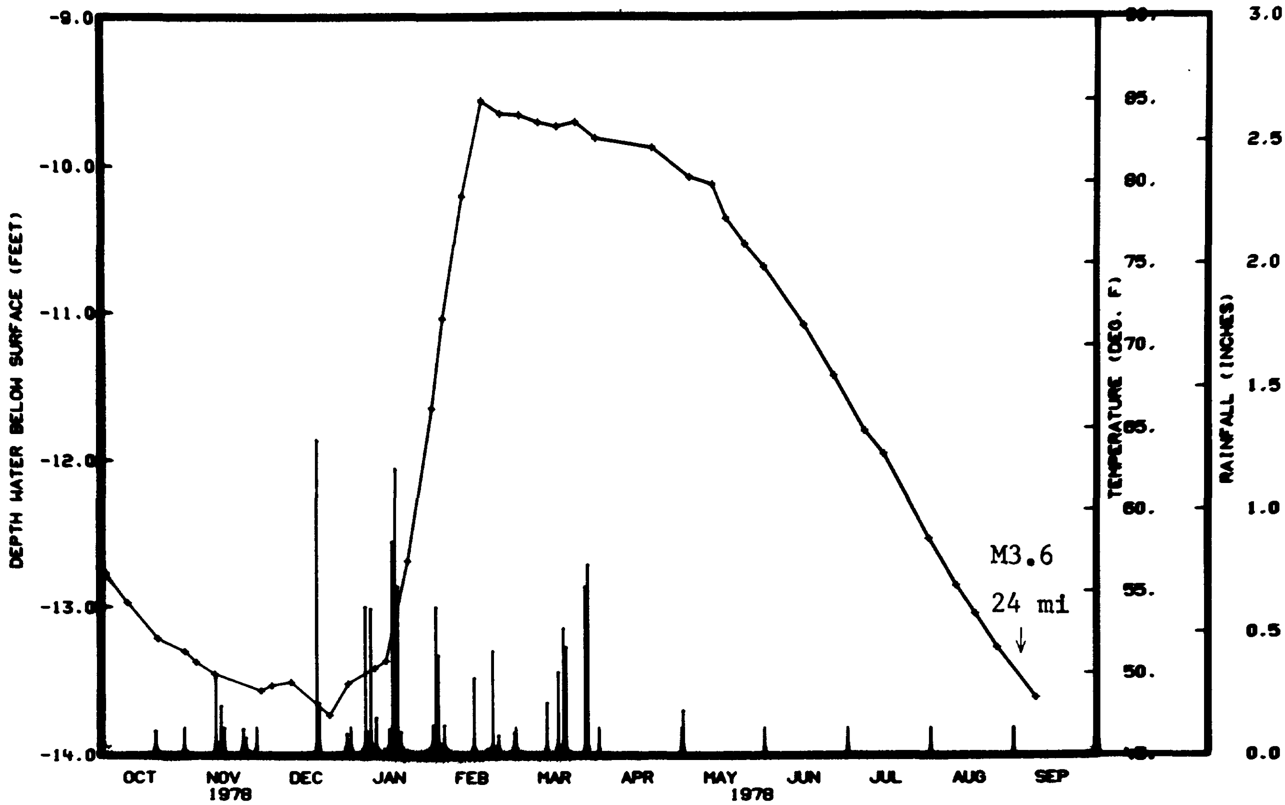

FIGURE 12 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-03A01 AND RAINFALL (.) DURING 1978-1978, PALMDALE AREA

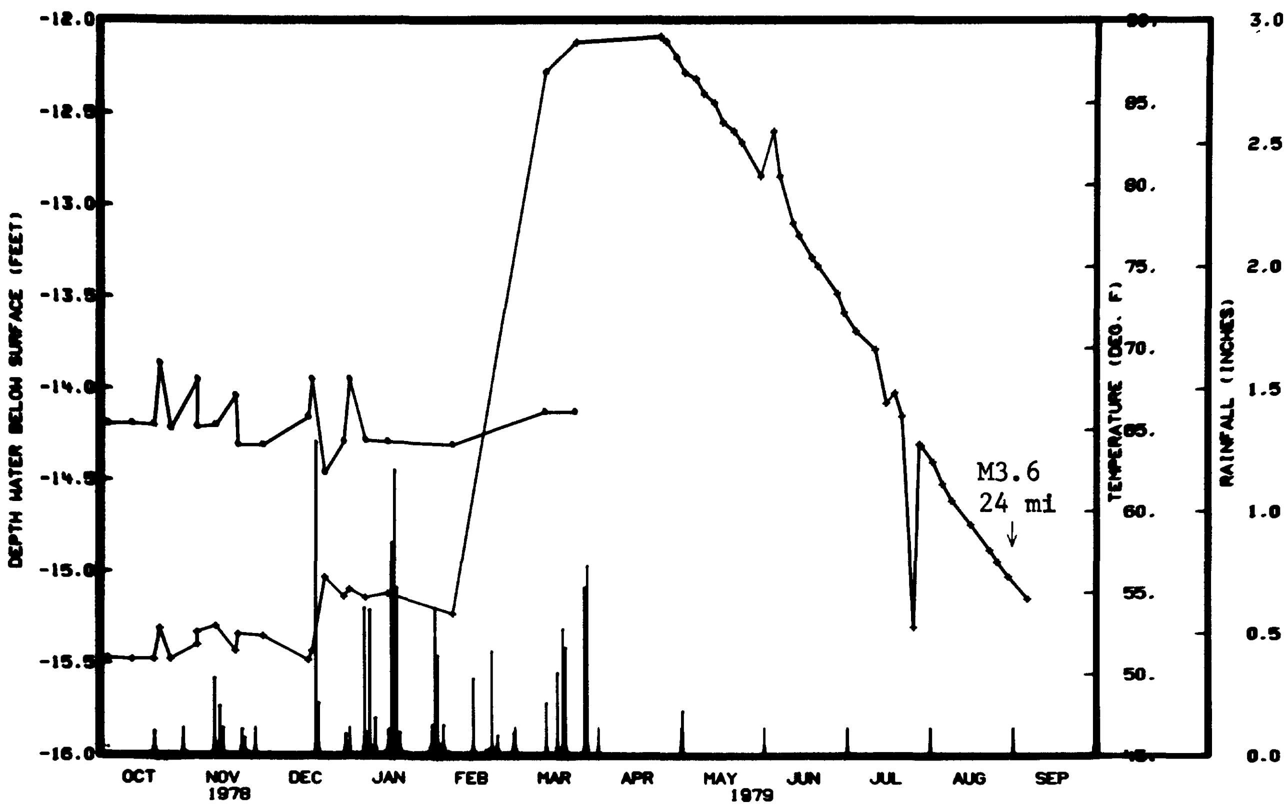

FIGURE 13 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-03D02 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

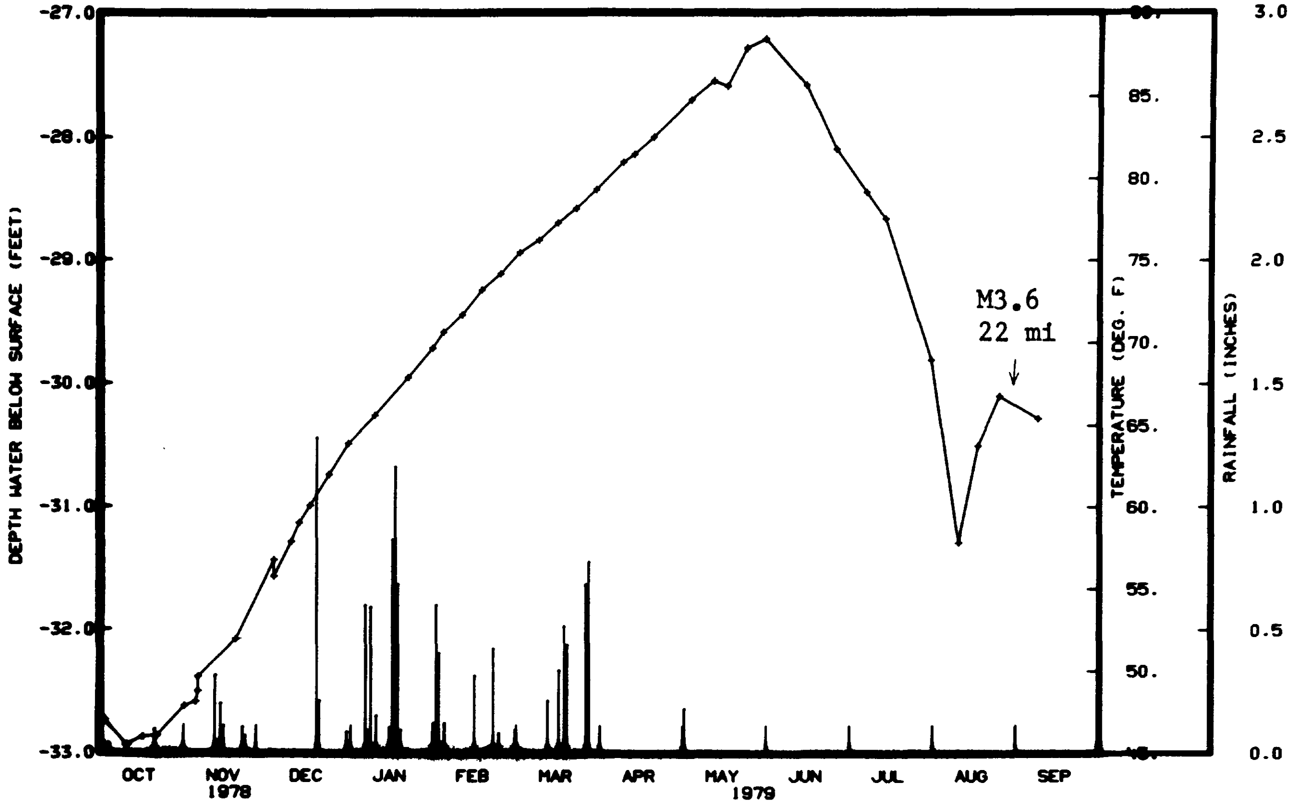

FIGURE 14 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-01N01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

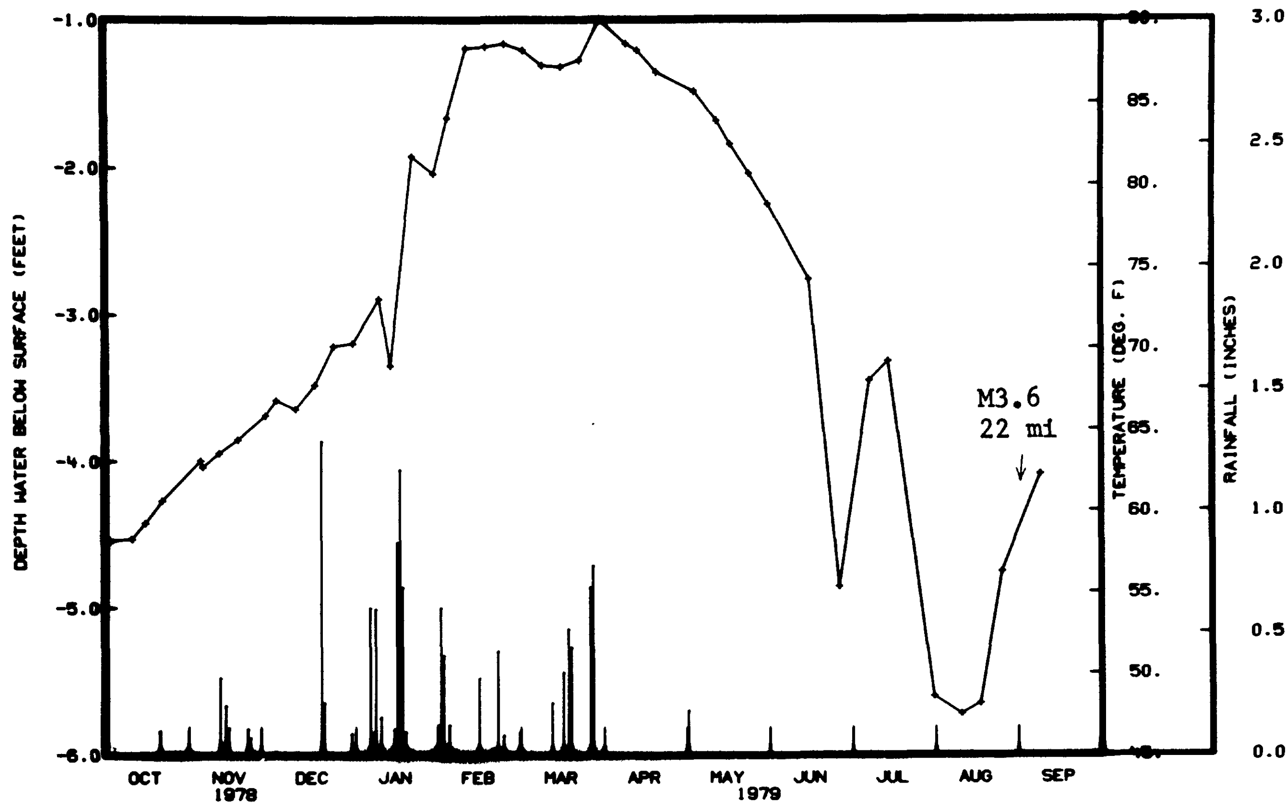

FIGURE 15 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-02J01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

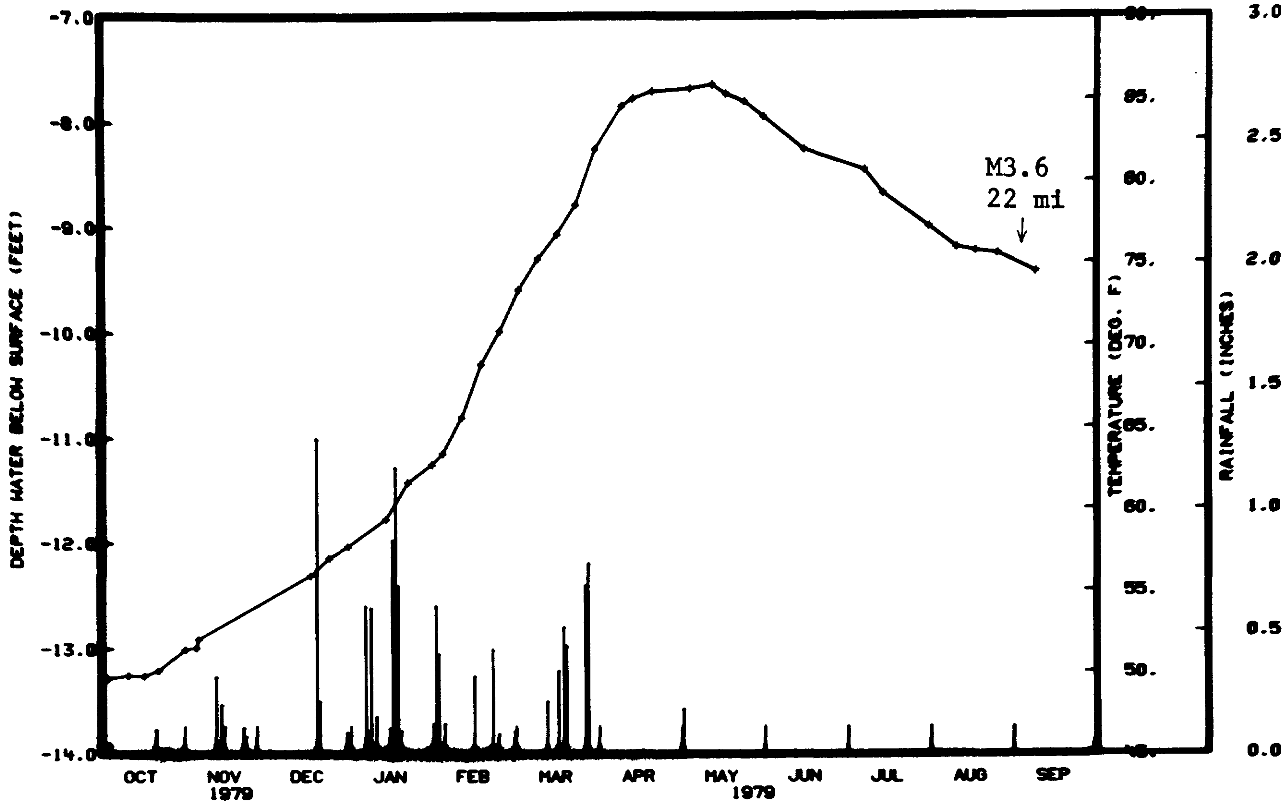

FIGURE 16 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-02K06 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

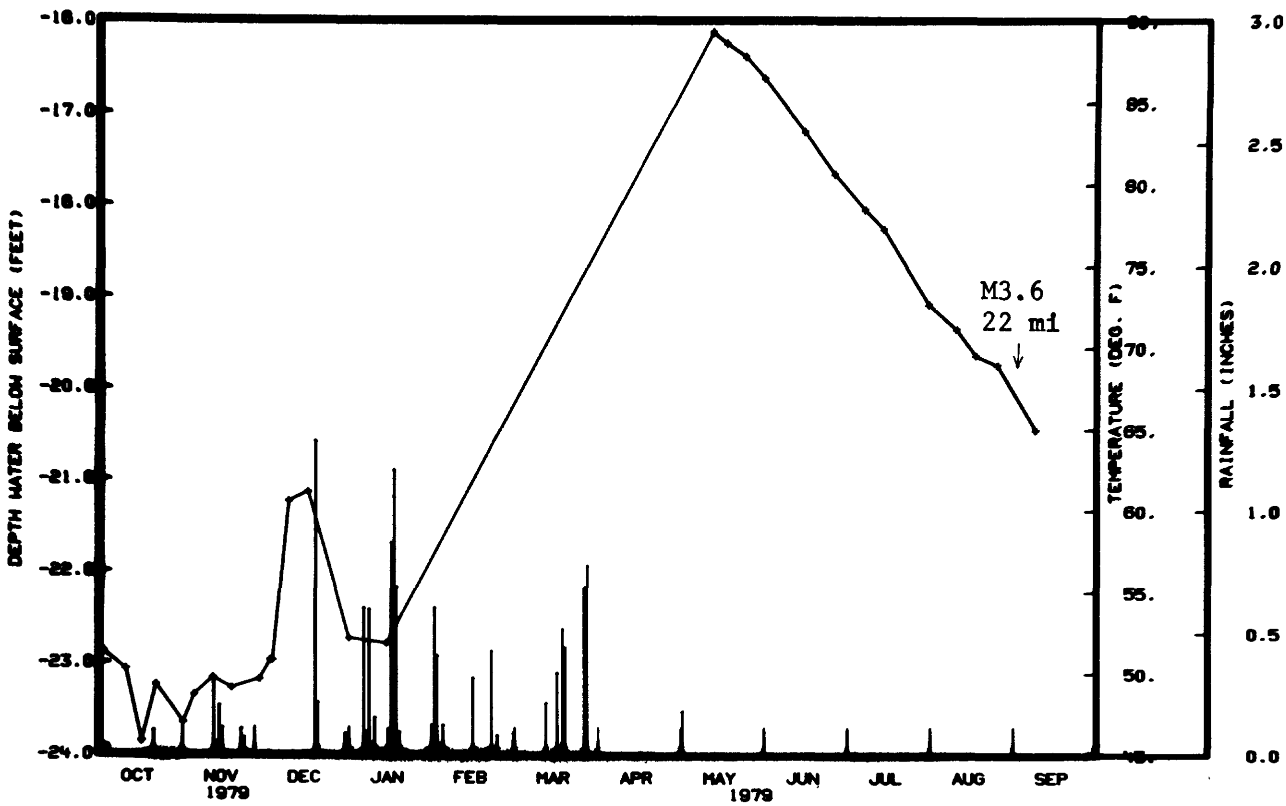

FIGURE 17 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-01N02 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

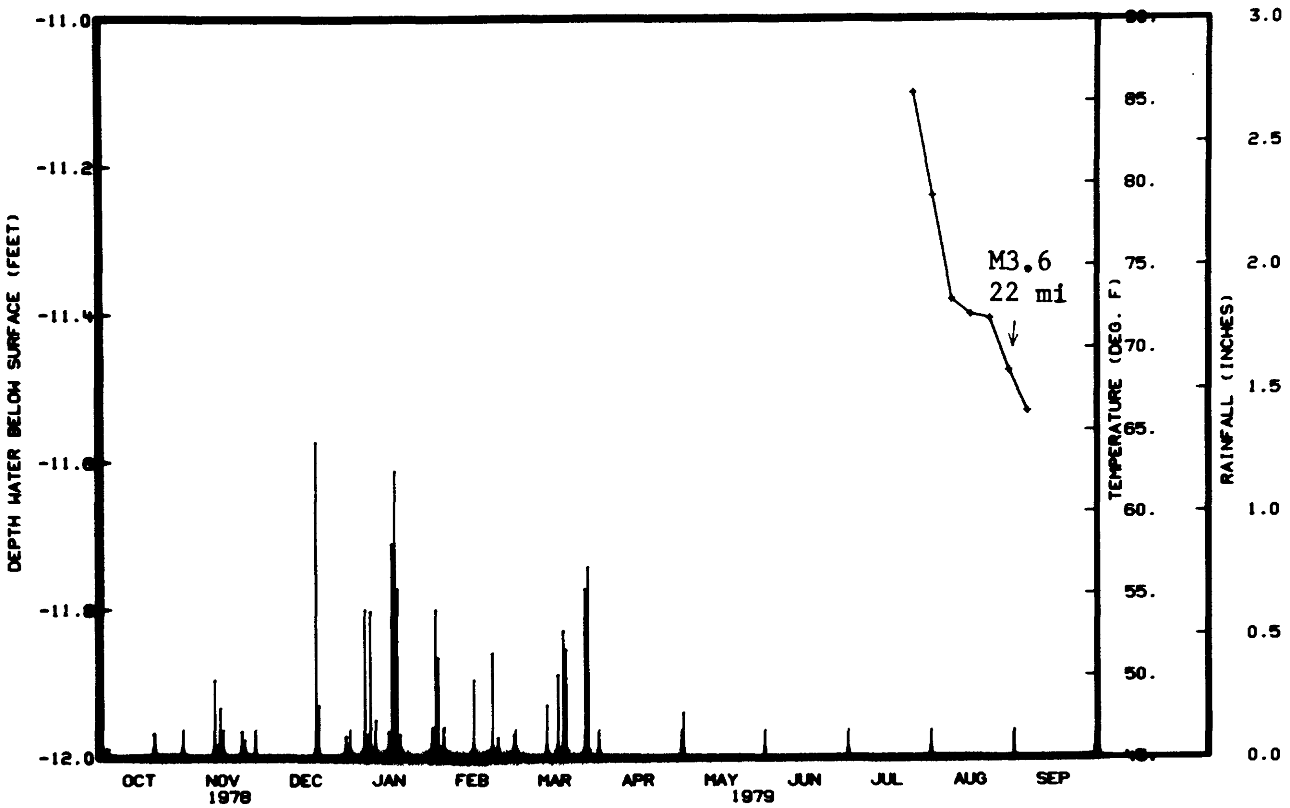

FIGURE 18-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-02K05 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

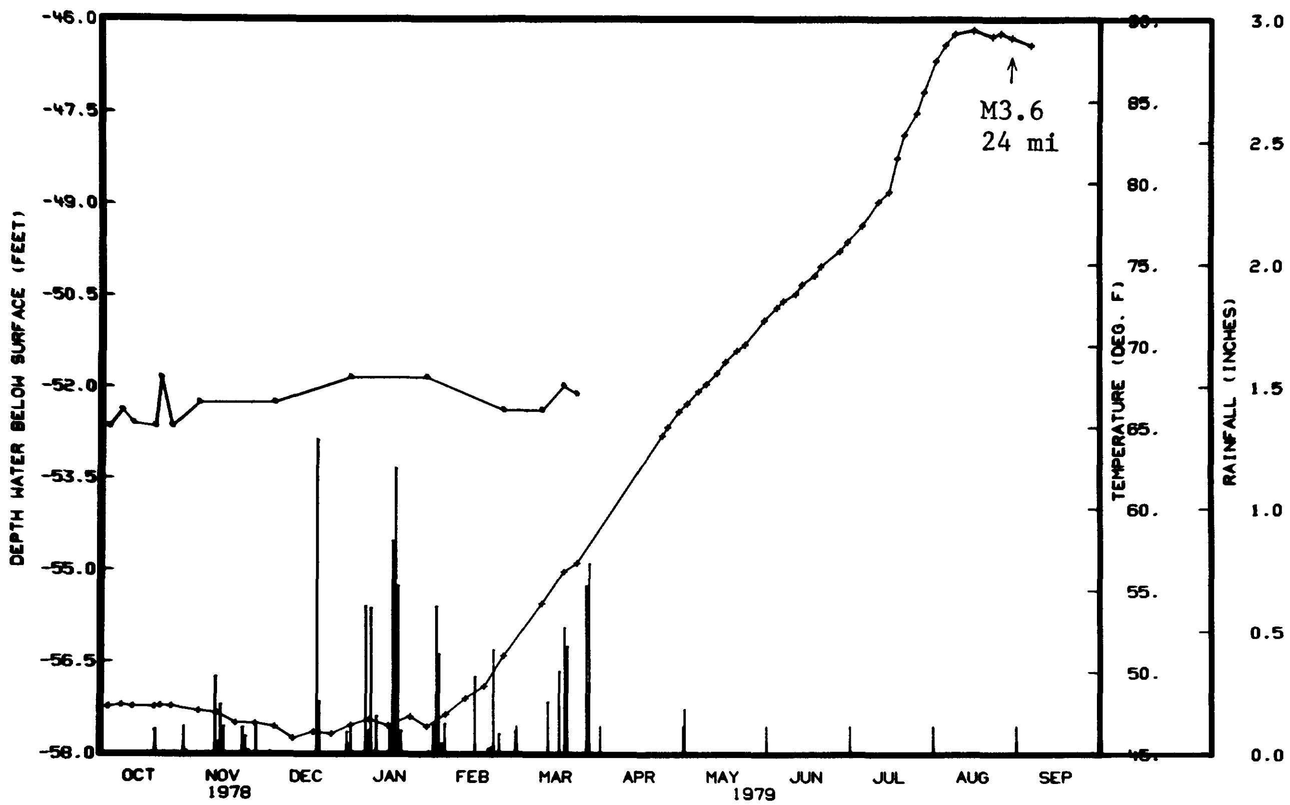

FIGURE 19-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-03N01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

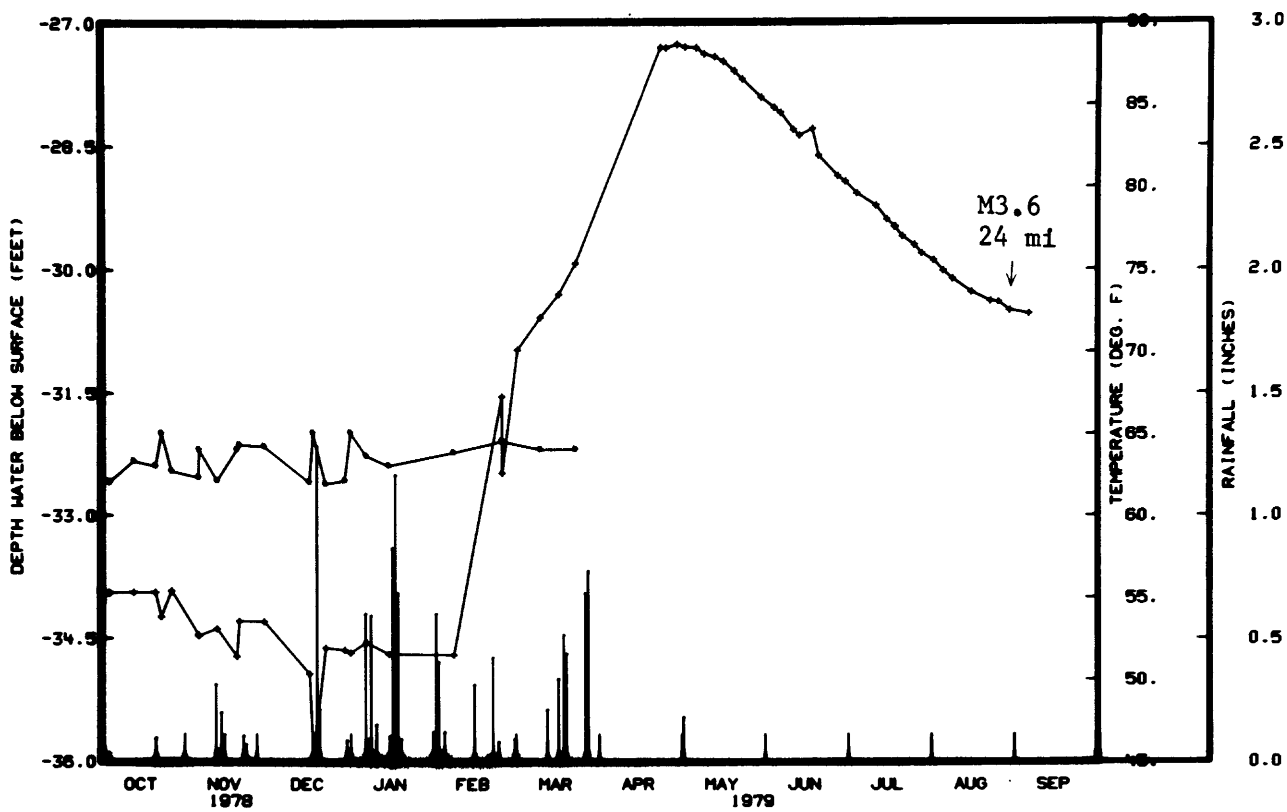

FIGURE 20 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-04L02 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

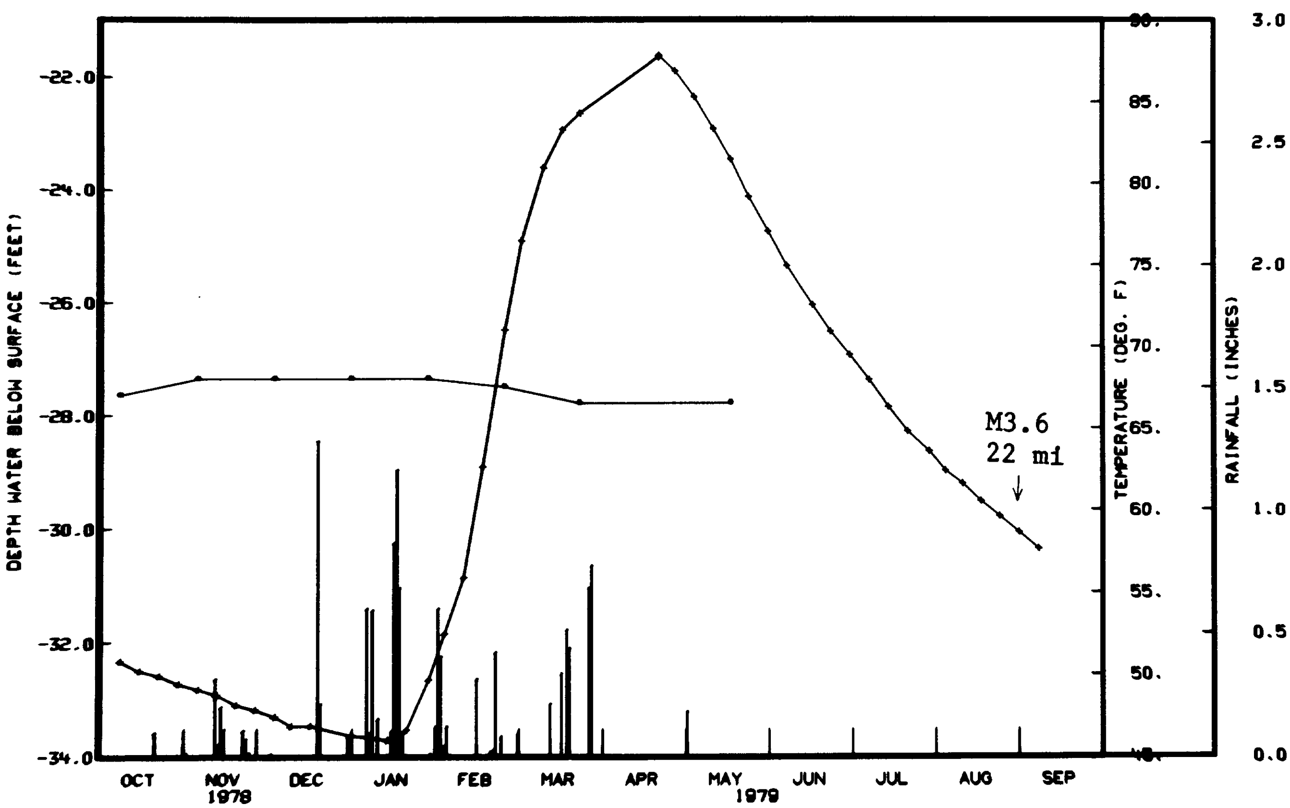

FIGURE 21 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-14C01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

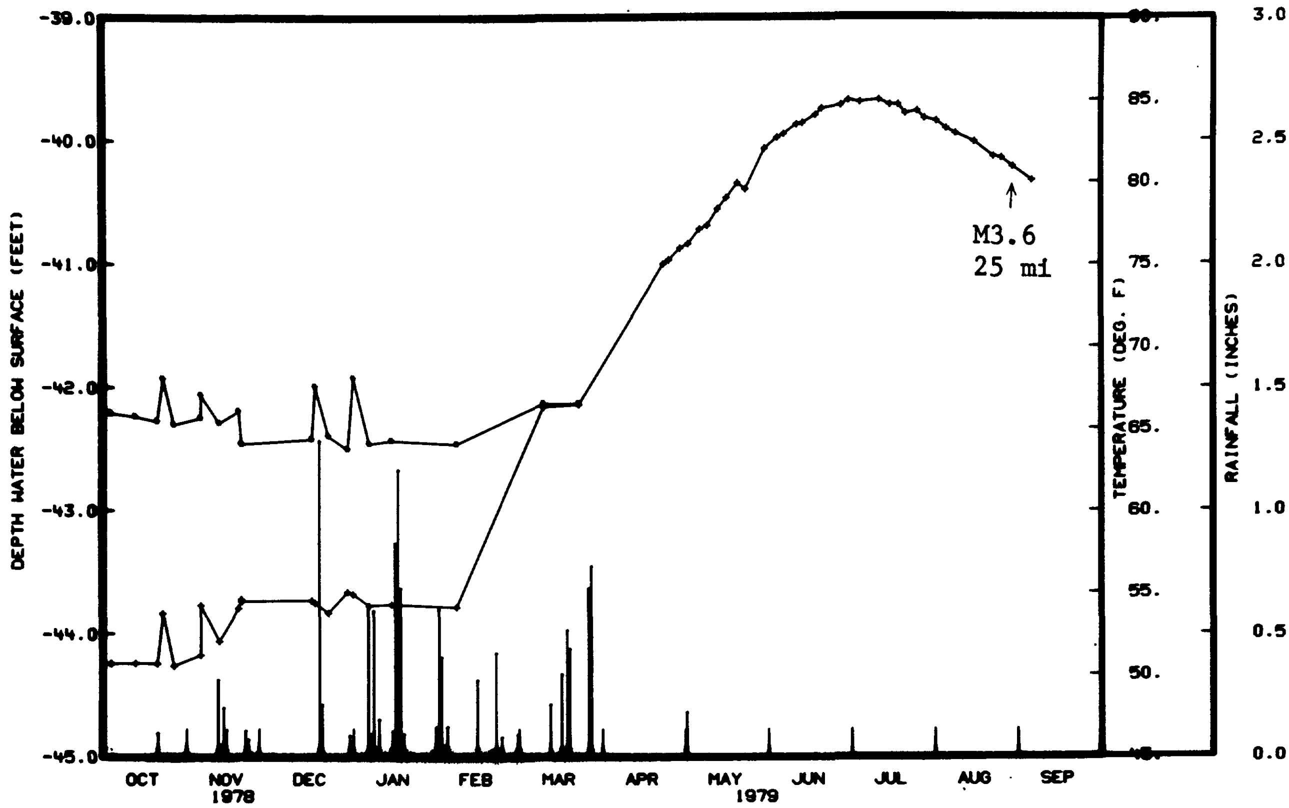

FIGURE 22 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-04J04 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

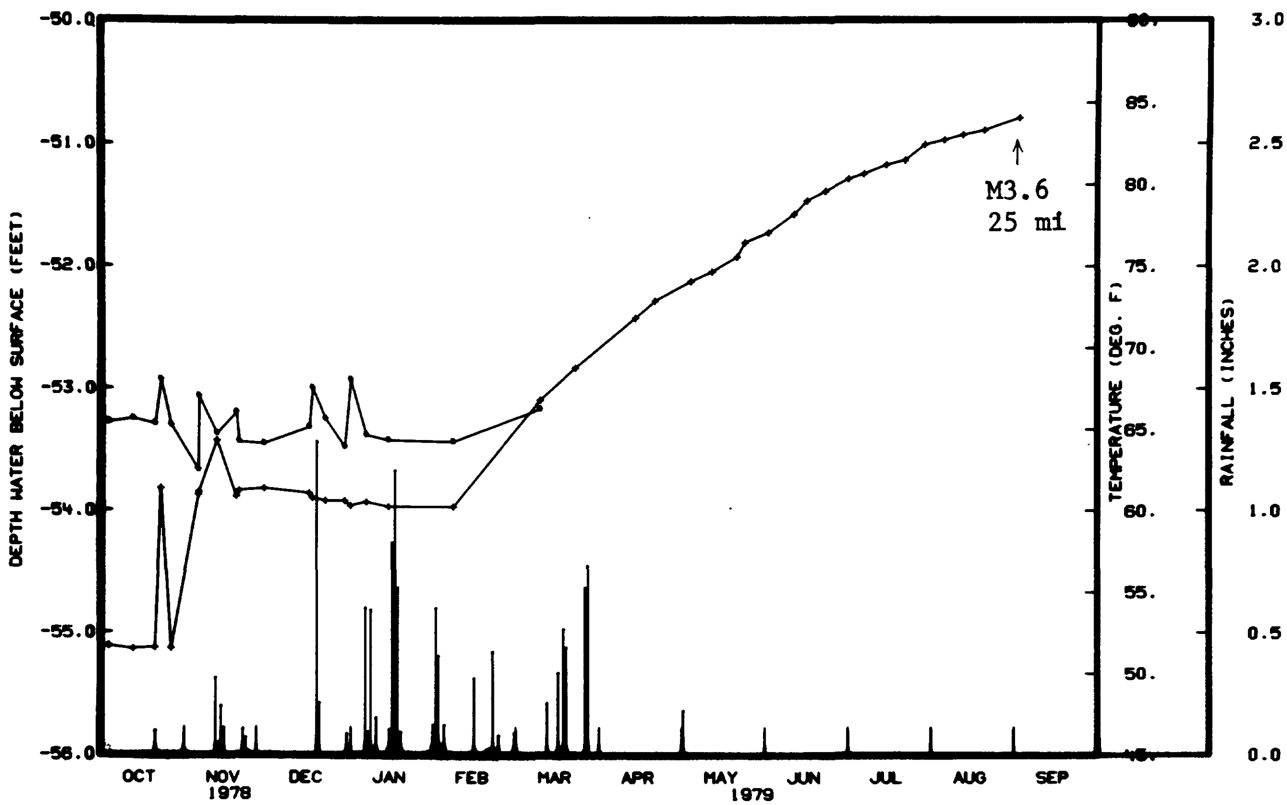

FIGURE 23 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/12W-04J02 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

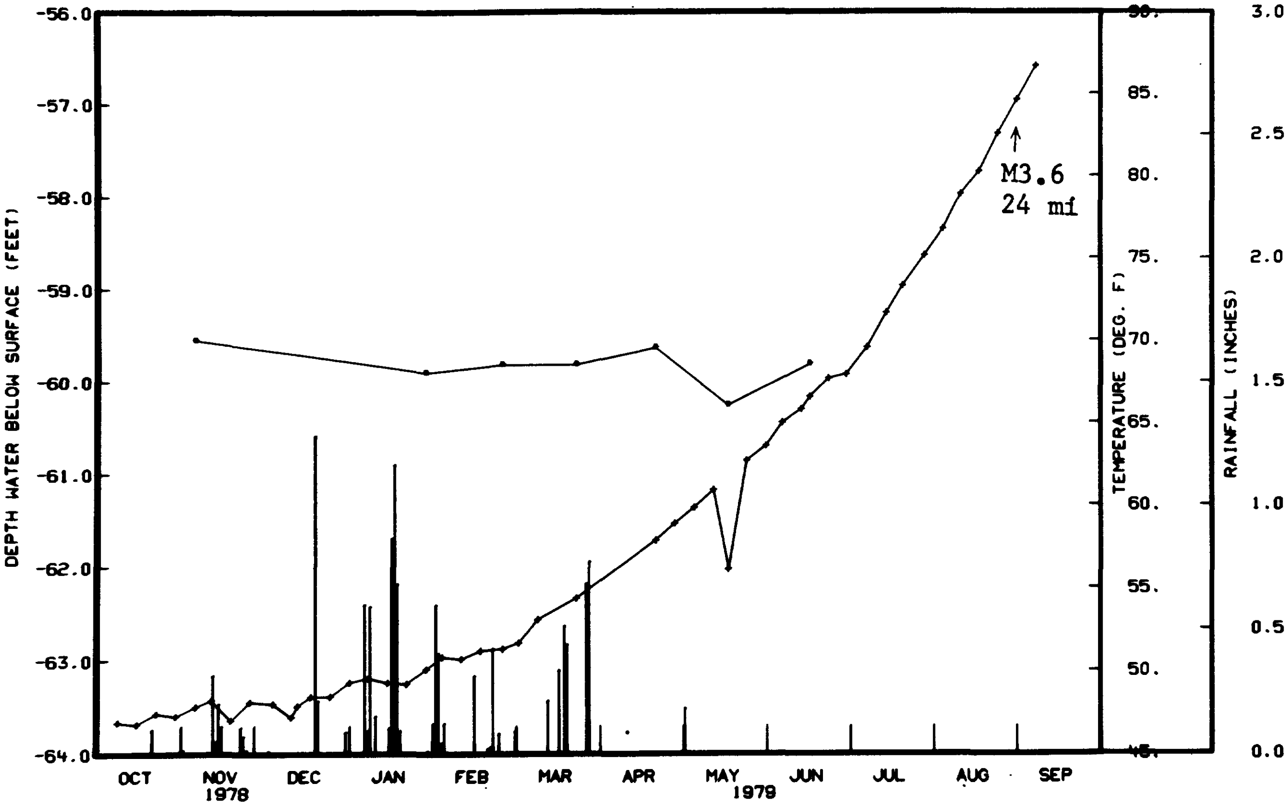

FIGURE 24-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (•) IN WELL NUMBER 05N/12W-04H01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

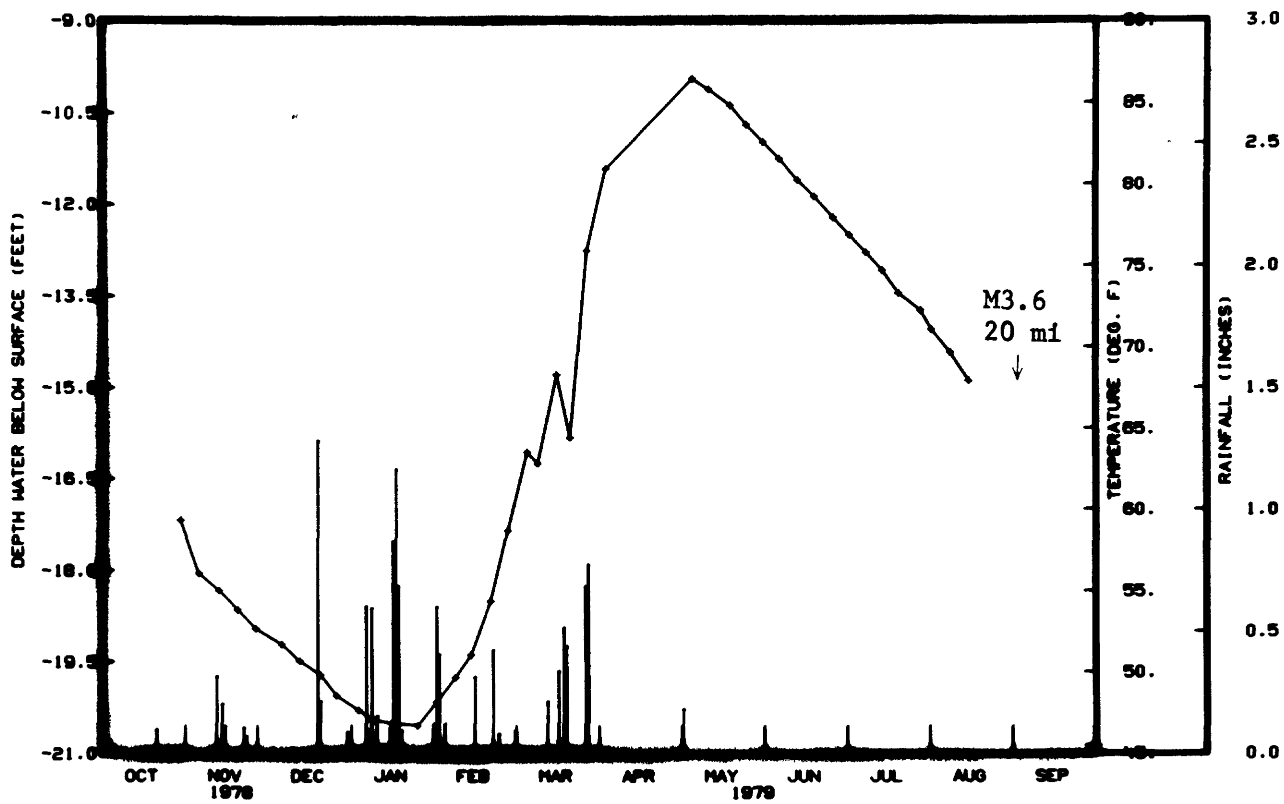

FIGURE 25-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (•) IN WELL NUMBER 05N/11W-07002 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

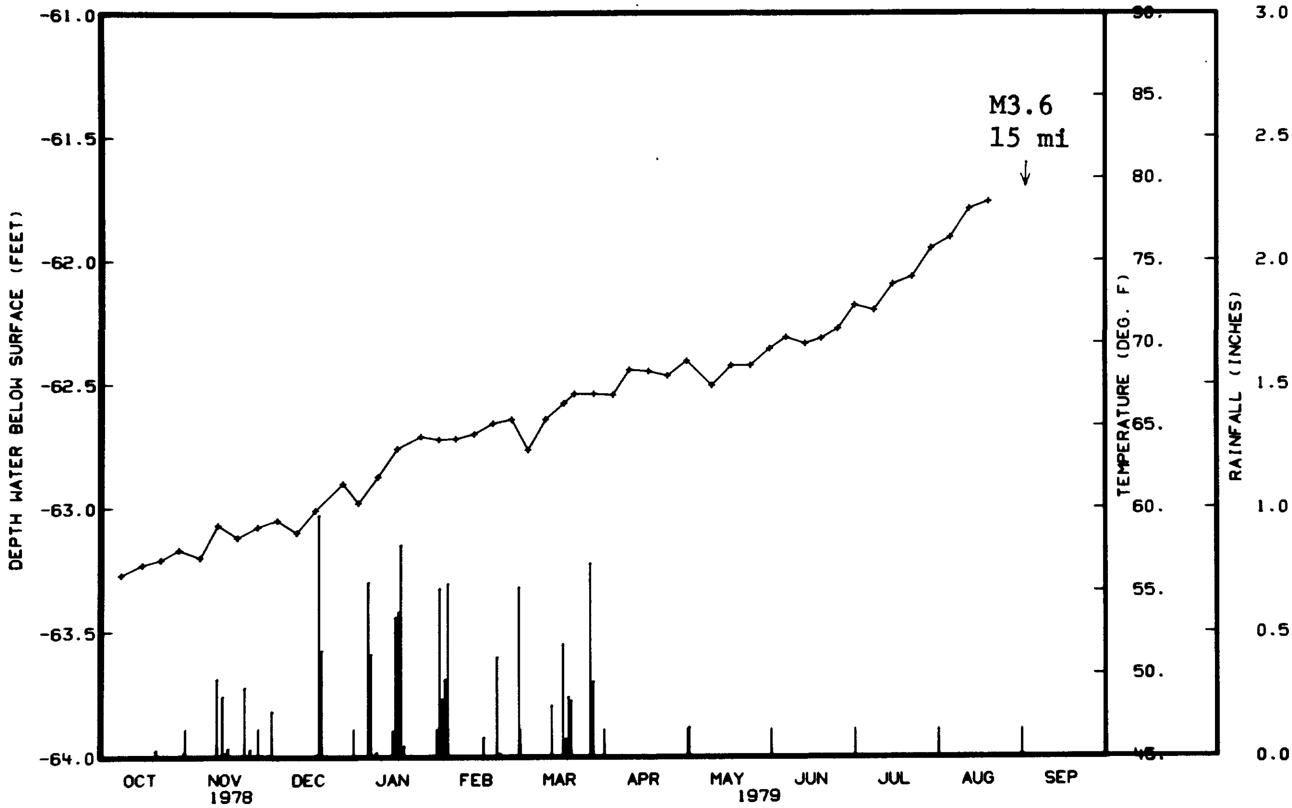

FIGURE 26-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/11W-24G01 AND RAINFALL (.) DURING 1978-1979, PALMDALE AREA

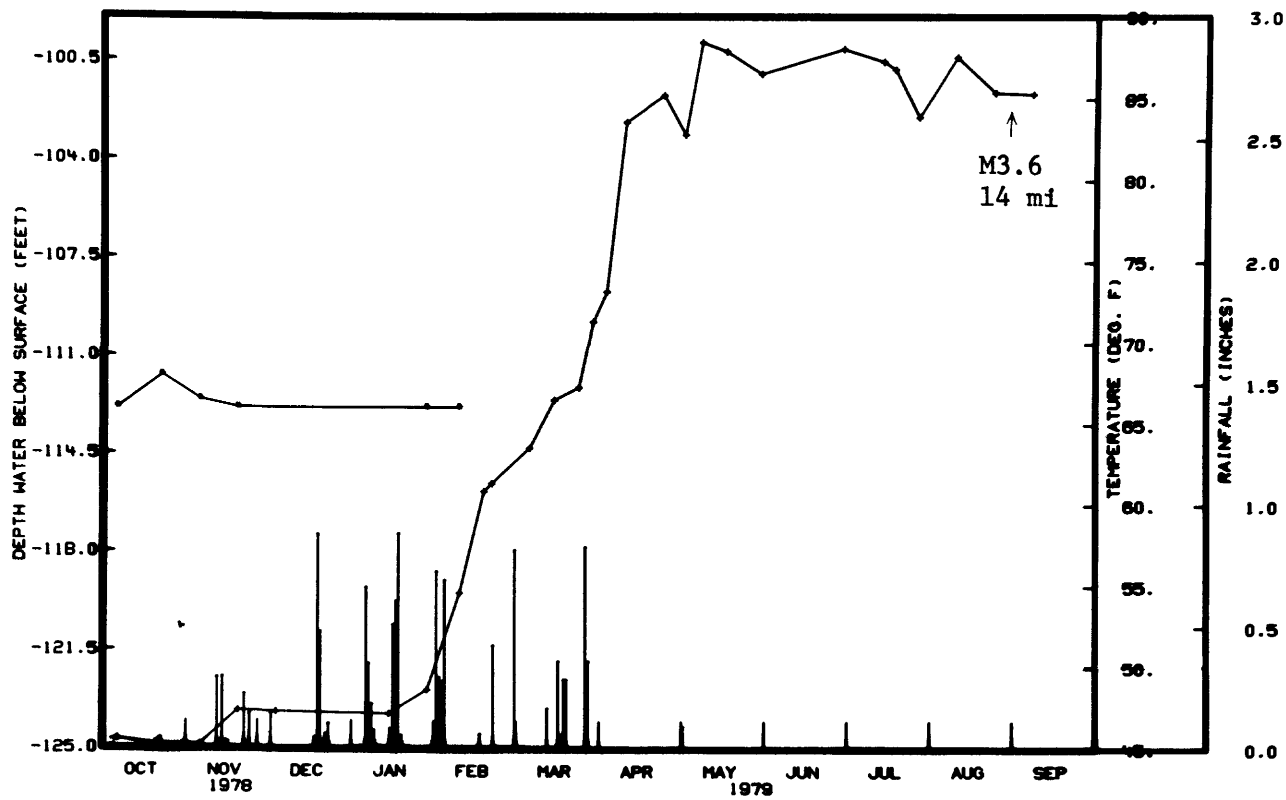

FIGURE 27-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/10W-30L01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

peaked in September 1977 (Merifield and Lamar, 1978, Fig. 43), and then dropped until February 1978 (Merifield and Lamar, 1978, Fig. 44). Water levels then rose until May 1978 and were relatively steady until February 1979, and again rose sharply until August 1979 (Fig. 19, this report).

During the first year of monitoring, water levels in wells 5N/12W-4L2, -4J4, -4J2, and -14C1 (Merifield and Lamar, 1978, Figs. 37, 39, 41 and 45) were relatively steady and showed no seasonal variations. Levels in these wells rose beginning February 1978 in response to the relatively heavy rainfall of the 1977-78 season (Merifield and Lamar, 1978, Figs. 38, 40, 42, and 46) and have shown an annual cycle for the past two seasons (Figs. 20-23, this report). Water levels were at a maximum during March-June 1978, and then gradually dropped. Levels in these wells again began to rise in February 1979 and peaked last April in wells -4L2 (Fig. 20) and -14C1 (Fig. 21); levels in well -4J4 peaked last July. In contrast, water levels in well -4J2 (Fig. 23) have continued to rise.

The behavior of well 5N/12W-4H1 has been unusual compared to the other wells in the Palmdale area described above, in that during the first two years of monitoring, water levels in this well showed no annual cycle (Merifield and Lamar, 1978, Figs. 47 and 48) and were gradually dropping. As indicated on Fig. 24 (this report), levels began to rise in February 1979 and continued to rise into September 1979. This rise in water level is believed to be a delayed response to the unusually heavy rainfall during the past two seasons.

In addition to well 5N/12W-2K5, discussed above, three wells in the Palmdale-Littlerock area (Plate 1) had Stevens Type F continous water-level recorders maintained by W. R. Moyle, Jr. of the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California. Copies of the recorder charts for these wells have been obtained from W. R. Moyle, Jr. and weekly water levels have been read and entered into computer data sets on disk, similar to our observation wells. Hydrographs for these wells are presented and discussed below. Wells 5N/11W-7G2 and -24G1 located southeast of Palmdale (Plate 1) have had Stevens recorders since October 1976. Hydrographs showing water levels for the first two years of operation were presented by Merifield and Lamar (1979, Figs. 28-33). Fig. 25, this report, shows water levels in well -7G2 through mid-August 1979. Levels in this well show a clear annual cycle, with lows for the past three years in January and high levels between April and June. In contrast, water levels in well -24G1 were relatively steady from October 1976 until June 1978, when they began to rise. An unexplained peak in water level occurred in August (Merifield and Lamar, 1979, Fig. 32) and levels have gradually risen through August 1979 (Fig. 26, this report).

William R. Moyle, Jr. of the U.S.G.S. removed the Stevens recorder from well 6N/13W-8Q1 located south of Quartz Hill (Plate 1) in March 1979, and no additional water level data beyond that shown in Merifield and Lamar (1979, Figs. 24-26) are available for this well.

Juniper Hills-Valyermo Segment of the San Andreas Fault

Water levels in selected wells have been monitored in the Juniper Hills-Valyermo area beginning in October 1977, following reports of unusual microseismic activity along that segment of the San Andreas fault (McNally et al, 1978). The wells are located within or adjacent to the rift zone (Fig. 3). Figs. 27-32 show the weekly hydrographs of water levels along the Juniper Hills-Valyermo segment of the San Andreas fault. Water levels in well 5N/10W-30L1 at the northwest end of this segment were relatively steady from December 1977 (Merifield and Lamar, 1978, Fig. 49) until January 1979 (Fig. 27, this report). Levels rose abruptly about 24 feet by April 1979 but have been fairly constant since April. This rise is believed to be a delayed response to the heavy rainfall over the past two seasons.

Two wells, 5N/10W-33K1 and -33R1, lie within the San Andreas rift in the Juniper Hills area (Fig. 3). These wells are not affected by nearby streams, lakes, or, to the best of our knowledge, nearby pumping. Throughout the 1977-78 winter rainstorms, water levels in both wells did not vary more than about 0.2 foot (Merifield and Lamar, 1978, Figs. 50 and 51). Between June 1978 and February 1979, water levels in well 5N/10W-33K1 rose about 0.6 foot (Fig. 28, this report) probably as a delayed response to the 1977-78 winter rains. An anomalous drop in water level of about 1.0 foot occurred in well -33K1 in early March 1979 and water levels have gradually risen since then. Small earthquakes were reported in the vicinity immediately before the anomalously low water level was observed (Fig. 28, this report). However, the validity of the water level low is questionable because the anomalous measurements were made by a new volunteer; measurements made before and after by Lamar-Merifield personnel are not abnormal. Water levels in well 5N/10W-33R1

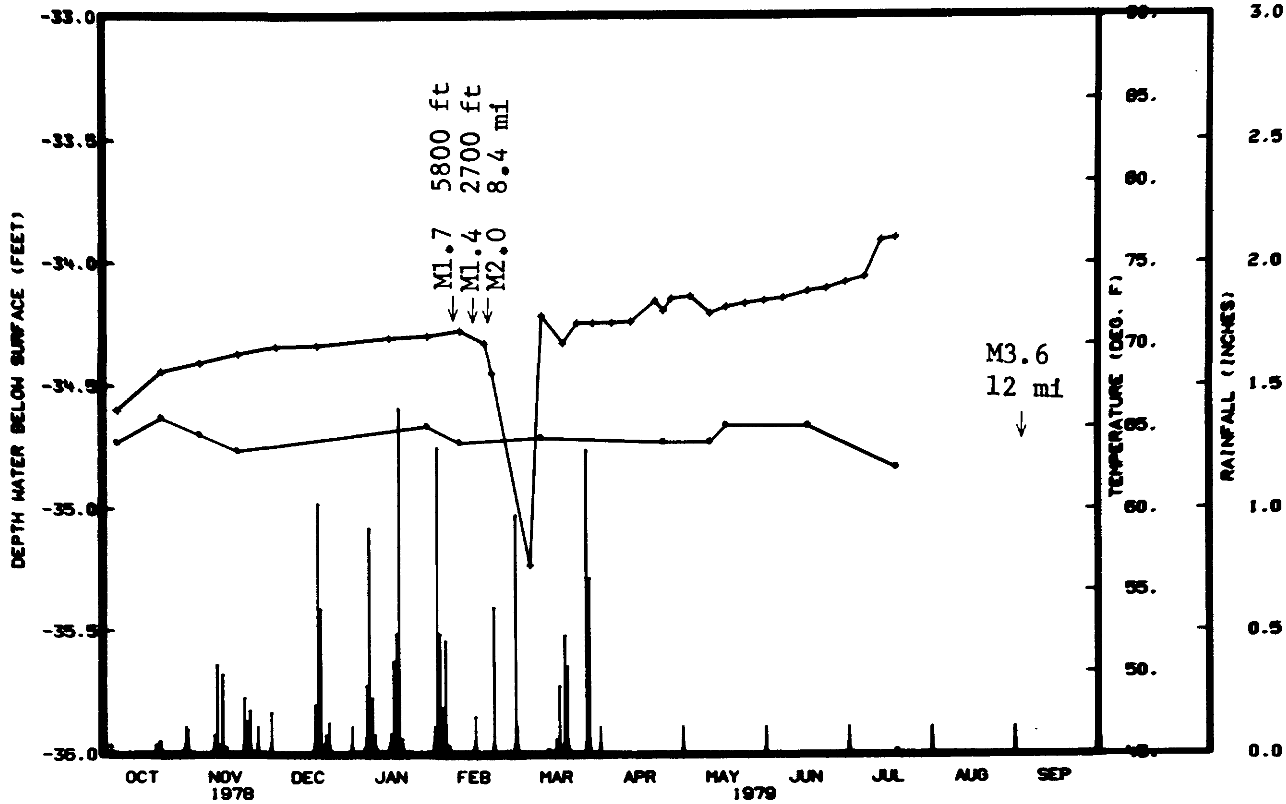

FIGURE 28 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/10W-33K01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

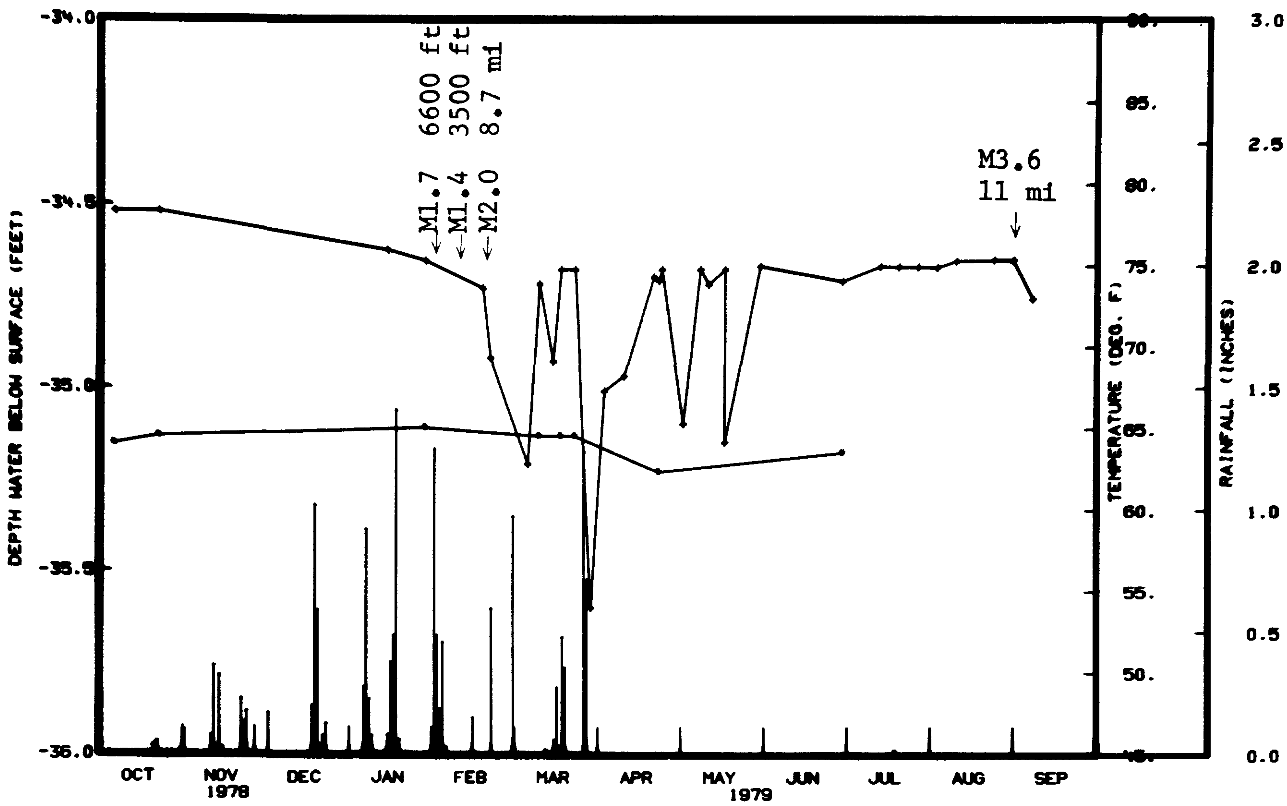

FIGURE 29 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 05N/10W-33R01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

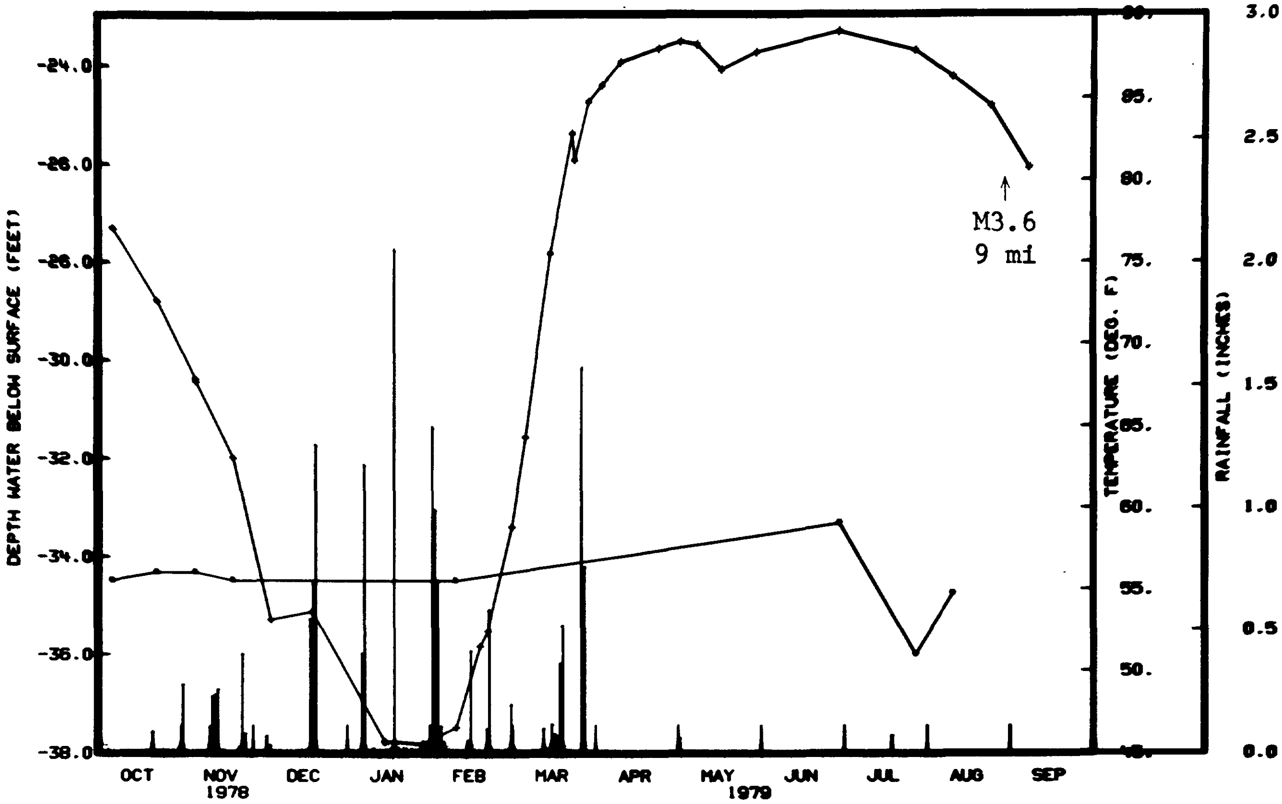

FIGURE 30 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 04N/10W-11B01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

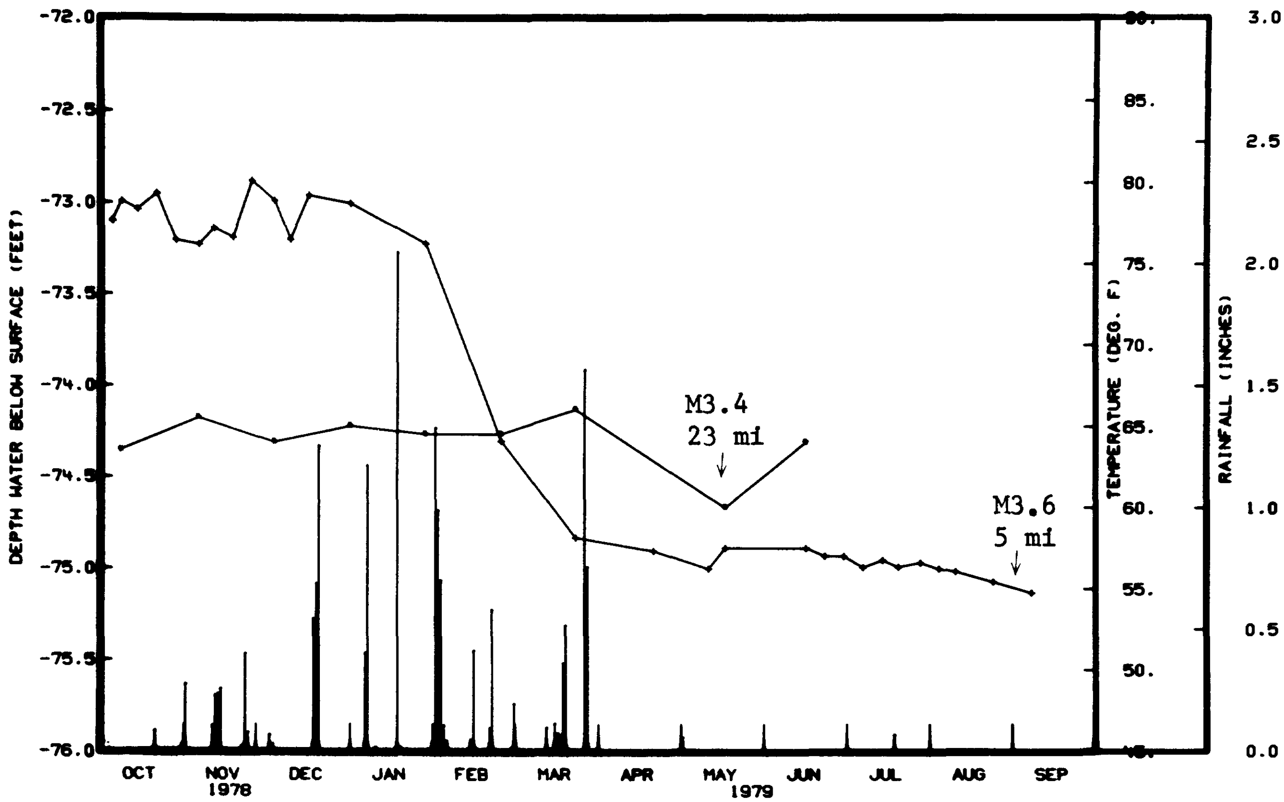

FIGURE 31 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 04N/09W-16L01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

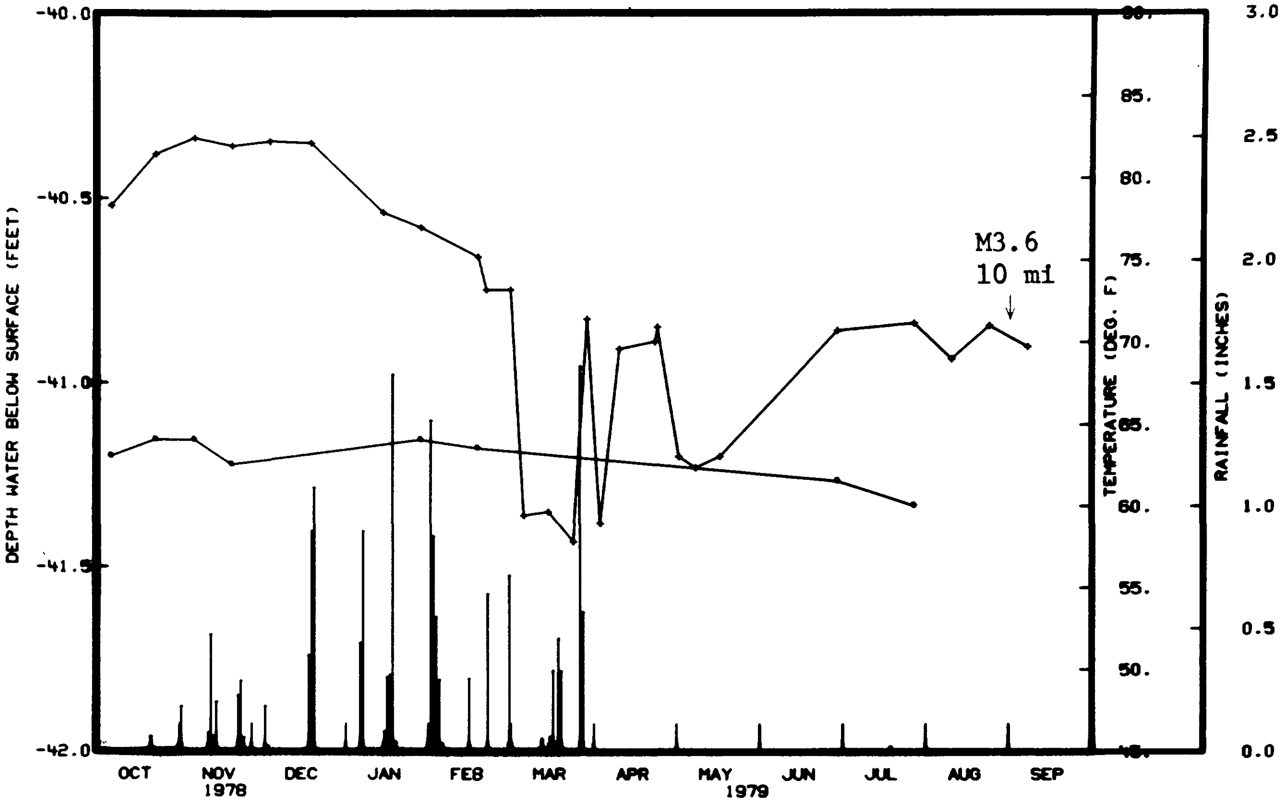

FIGURE 32 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 04N/10W-10Q01 AND RAINFALL (.) DURING 1978-1979, JUNIPER HILLS - VALYERMO AREA

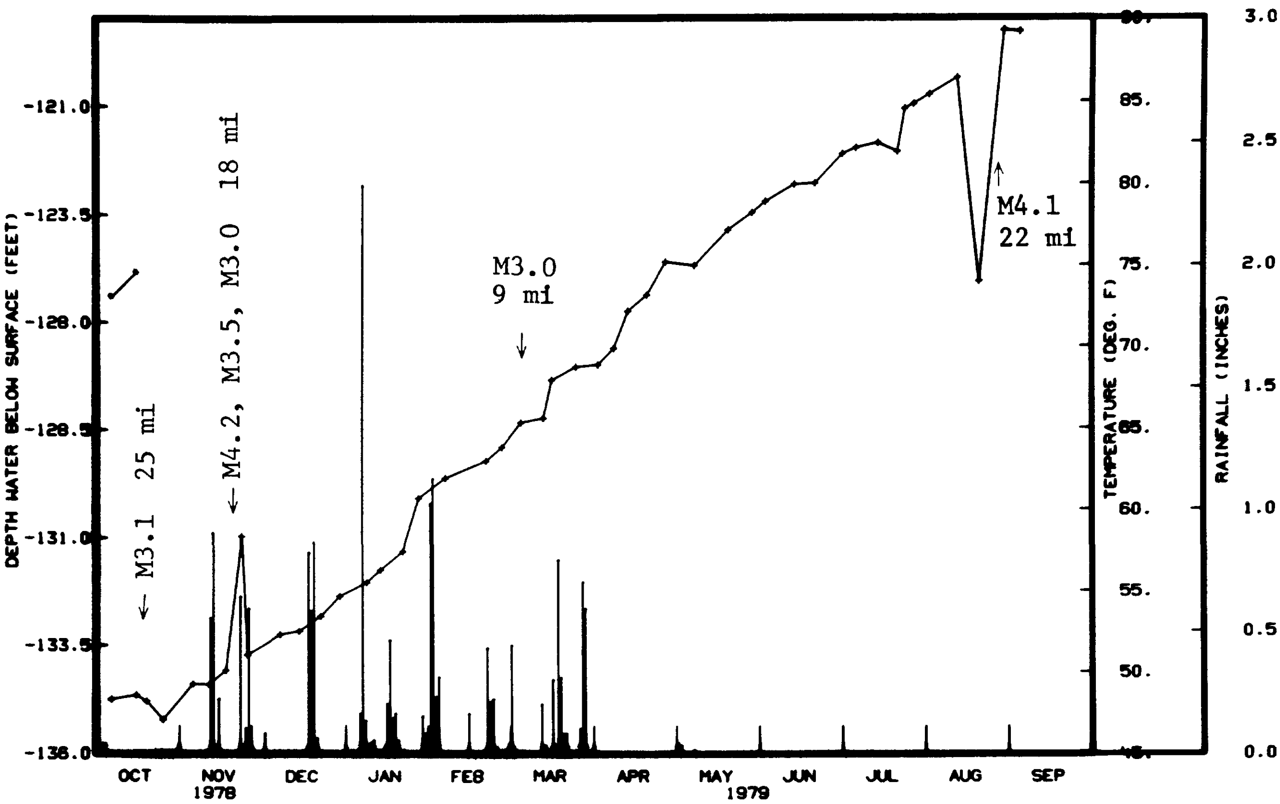

FIGURE 33 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 03S/02W-08E01 AND RAINFALL (.) DURING 1978-1979, SAN JACINTO VALLEY

fluctuated over a range of only about 0.15 foot between November 1977 and May 1978 and reached their lowest level in March 1978; water levels rose about 0.4 foot in June 1978 and dropped to previous levels in August 1978 (Merifield and Lamar, 1978, Fig. 51). Since October 1978, levels in -33R1 (Fig. 29, this report) have fluctuated over a range of 1.1 foot, with the lowest level in March. The irregular levels between February and May 1979 were measured by a volunteer and must be considered questionable. The relatively uniform water levels since June 1979 are based on measurements made by personnel from our office and points read from charts from a Stevens recorder which has been in operation since mid-July, 1979.

Well 4N/10W-11B1 has shown a clear annual cycle with lows in January 1978 (Merifield and Lamar, 1978, Fig. 52) and January 1979 (Fig. 30, this report). Levels have been gradually dropping during the dry period since June 1979. Well 4N/10W-16L1 dropped steadily 1.6 foot in February and March 1979 in spite of heavy precipitation during that period (Fig. 31, this report). This behavior is curious because this well rose steadily about 8 feet from November 1977 to May 1978 (Merifield and Lamar, 1978, Fig. 55). A Stevens recorder has operated on this well since July 1978. The recorder charts show diurnal fluctuations in water level of up to 0.13 foot and unexplained 0.2-0.3 foot variations with a 10-15 day period. Water levels since March 1979 have been fairly steady. Water levels in well 4N/10W-10Q1 have been monitored since late March 1978 and show an annual cycle with lows in April 1978 (Merifield and Lamar, 1978, Fig. 56) and March through May 1979 (Fig. 32, this report).

San Jacinto Fault Zone

Water-level monitoring of abandoned wells along the San Jacinto fault zone began in October 1977 near Ocotillo wells and Borrego Springs. Four wells at Anza were added to the program in November 1977. Suitable wells have been more difficult to find in San Jacinto Valley (Figs. 4-6), where several wells that were monitored in early 1978 were dropped from the program, and new wells have been added.

Monitoring of water levels in well 3S/2W-8E1 in San Jacinto Valley began in February 1978; levels dropped about 3.3 feet between February and late March 1978 (Merifield and Lamar, 1978, Fig. 57). This drop was curious because it occurred during the 1978 winter rains. Water levels were fairly steady from March 1978 until October 1978 (Merifield and Lamar, 1978, Fig. 57, and Fig. 33 this report). In contrast to the drop during the 1978 winter rains, water levels have risen steadily since November 1978, in response to either the 1978-79 winter rains, or possibly in delayed response to the 1977-78 winter rains.

Water levels in well 3S/2W-15F1 have been monitored since May 1978 and show a clear annual cycle with highs in June 1978 (Merifield and Lamar, 1978, Fig. 58) and May 1979 and a low in January 1979 (Fig. 34, this report). Water levels in well 3S/2W-26R1 have been measured since March 1978 and steadily dropped from March 1978 until February 1979 (Merifield and Lamar, 1978, Fig. 60, and Fig. 35, this report). This drop during 1978 is curious because water levels over the same period in 1979 rose to a maximum in April and have since been dropping (Fig. 35, this report).

Monitoring of water levels in well 3S/2W-23J2 in San Jacinto Valley was stopped in November 1978 (Merifield and Lamar, 1979, Fig. 42). Weekly monitoring of wells 3S/2W-35R1 and 4S/2W-2D1 only began in August 1979, thus insufficient data are available to discuss in this report.

A Stevens recorder has been operating on well 7S/3E-13D5 in Anza since early December 1977. Since November 1977 water levels have shown a fairly steady rise of almost a foot, and no seasonal cycle in levels can be seen (Merifield and Lamar, 1978, Fig. 61, and Fig. 36, this report). Water levels in well 7S/3E-14A1 show a rough annual cycle with lows in November-December, 1977, and October 1978, and highs in March 1978 and February 1979 (Merifield and Lamar, 1978, Fig. 62, and Fig. 37, this report). Monitoring of well -14A1 since March 1979 has been infrequent because we have not had a volunteer in the Anza area since that time.

Water levels in well 7S/3E-23B1 have been monitored since November 1977. Between November 1977 and February 1978, levels dropped gradually about 0.7 foot and then rose steadily almost 3 feet until September 1978 (Merifield and Lamar, 1978, Fig. 64). From October 1978 to April 1979, water levels fluctuated within a range of less than 2.5 feet (Fig. 38, this report). In May 1979, water levels rose over 4 feet, then abruptly dropped 8 feet in June 1979, followed by a sharp rise of 16 feet in July 1979. Because of this strange behavior, a Stevens recorder was installed on the well in July 1979.

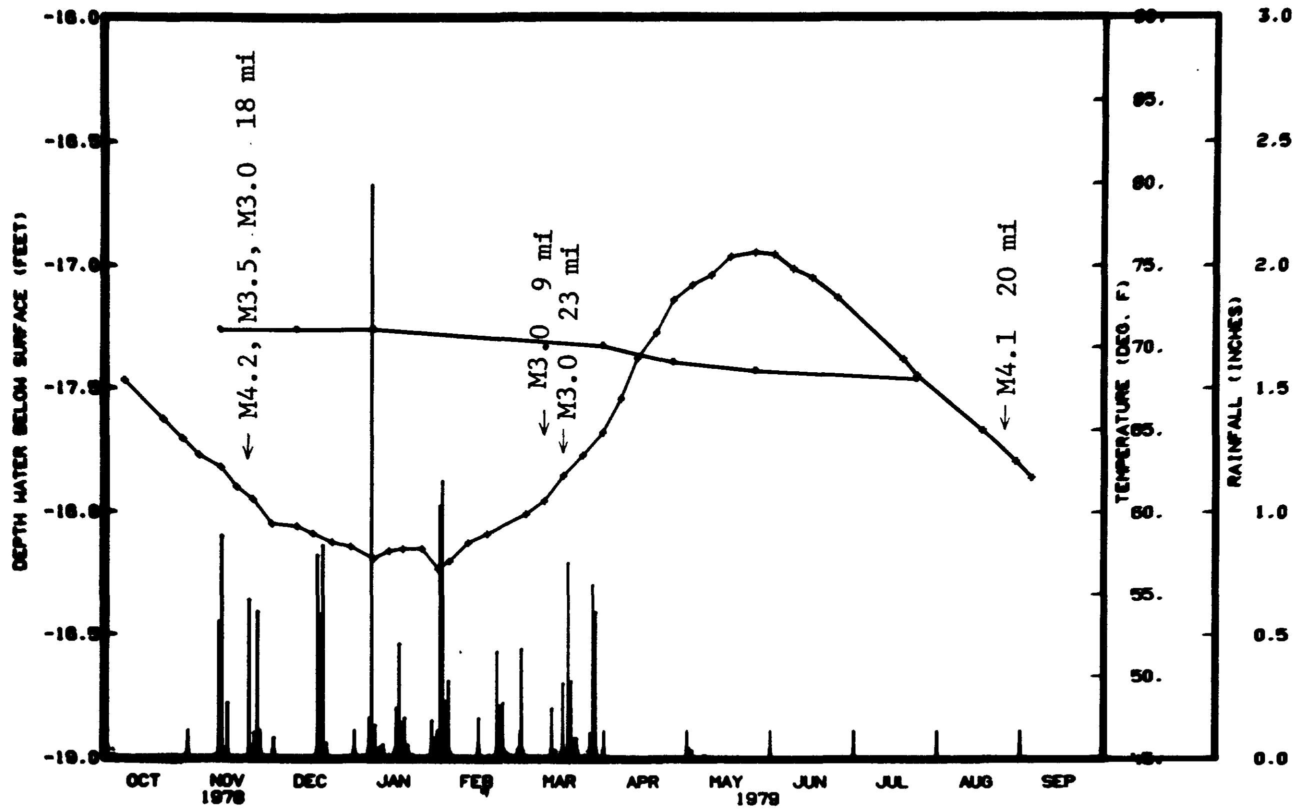

FIGURE 34-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 03S/02W-15F01 AND RAINFALL (.) DURING 1978-1979, SAN JACINTO VALLEY

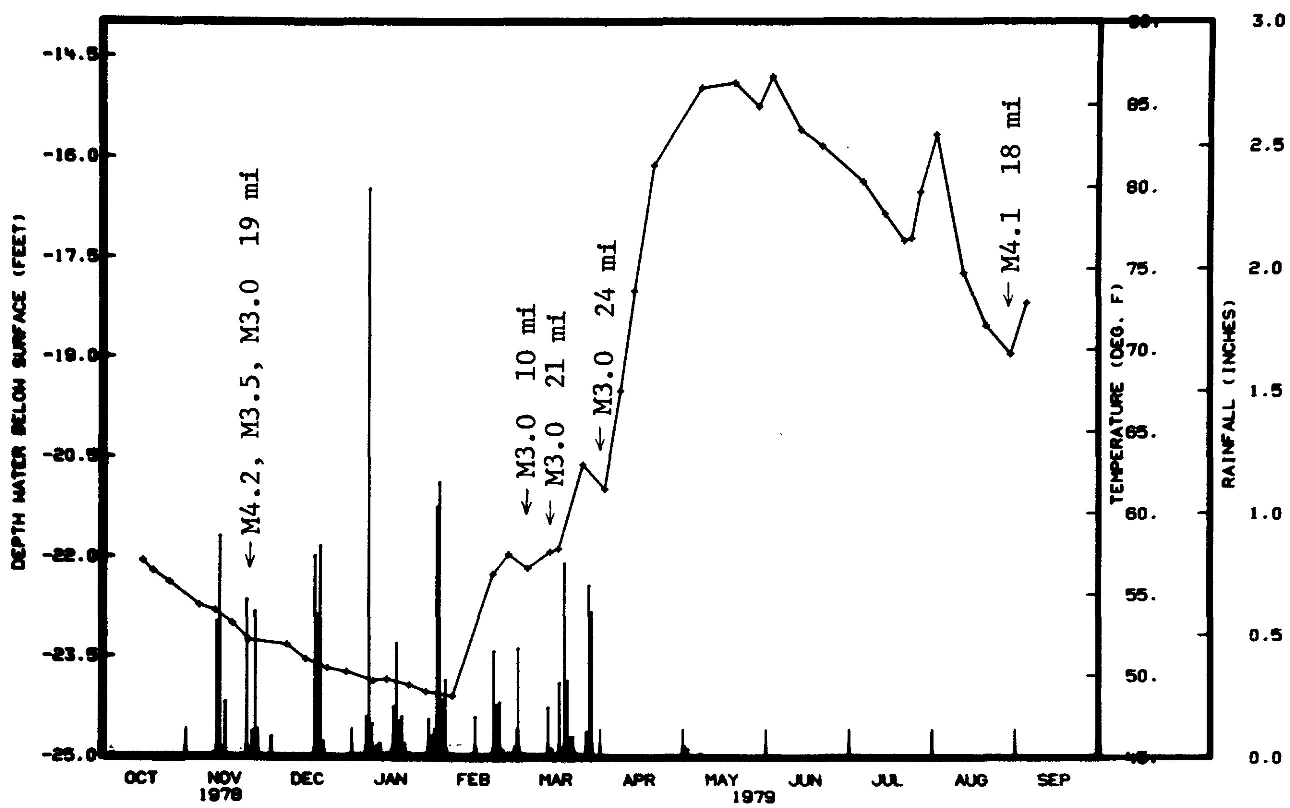

FIGURE 35-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 03S/02W-26R01 AND RAINFALL (.) DURING 1978-1979, SAN JACINTO VALLEY

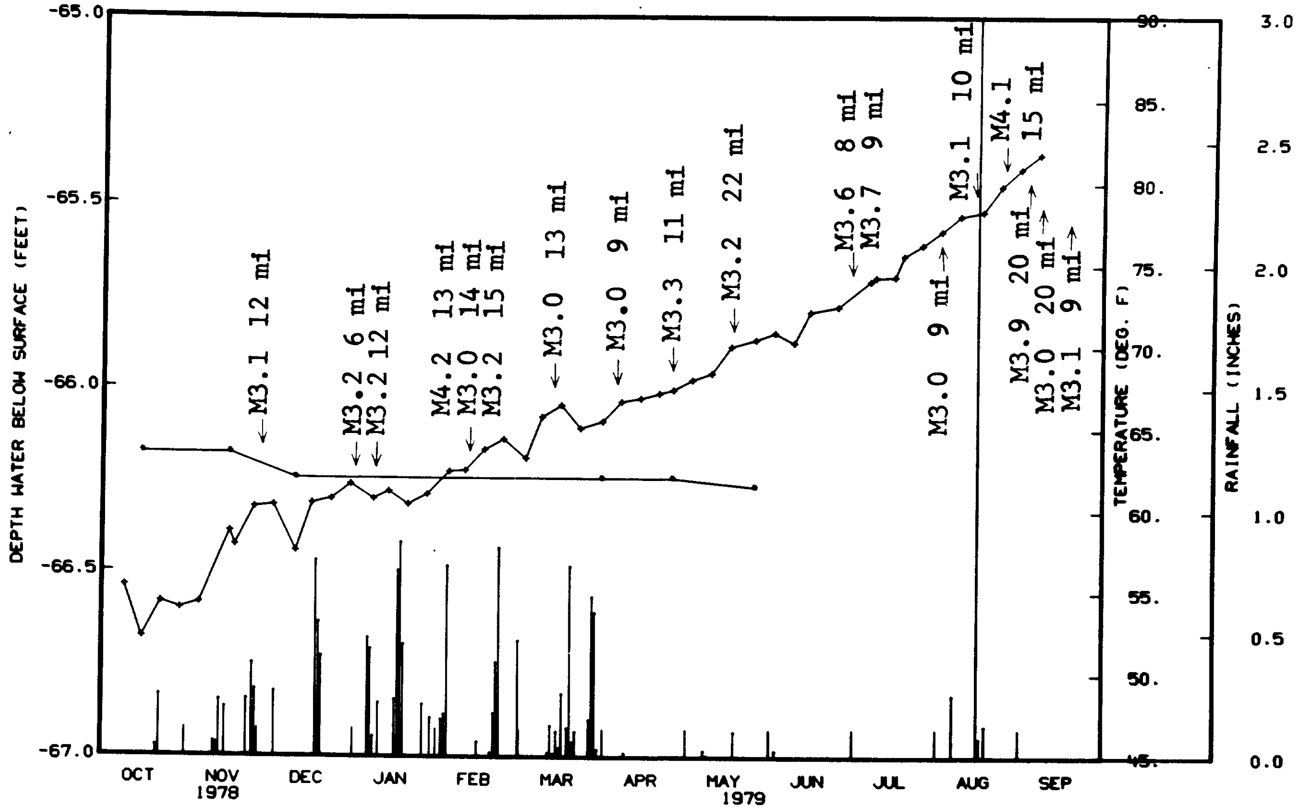

FIGURE 36.-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 07S/03E-13D05 AND RAINFALL (.) DURING 1978-1979, ANZA AREA

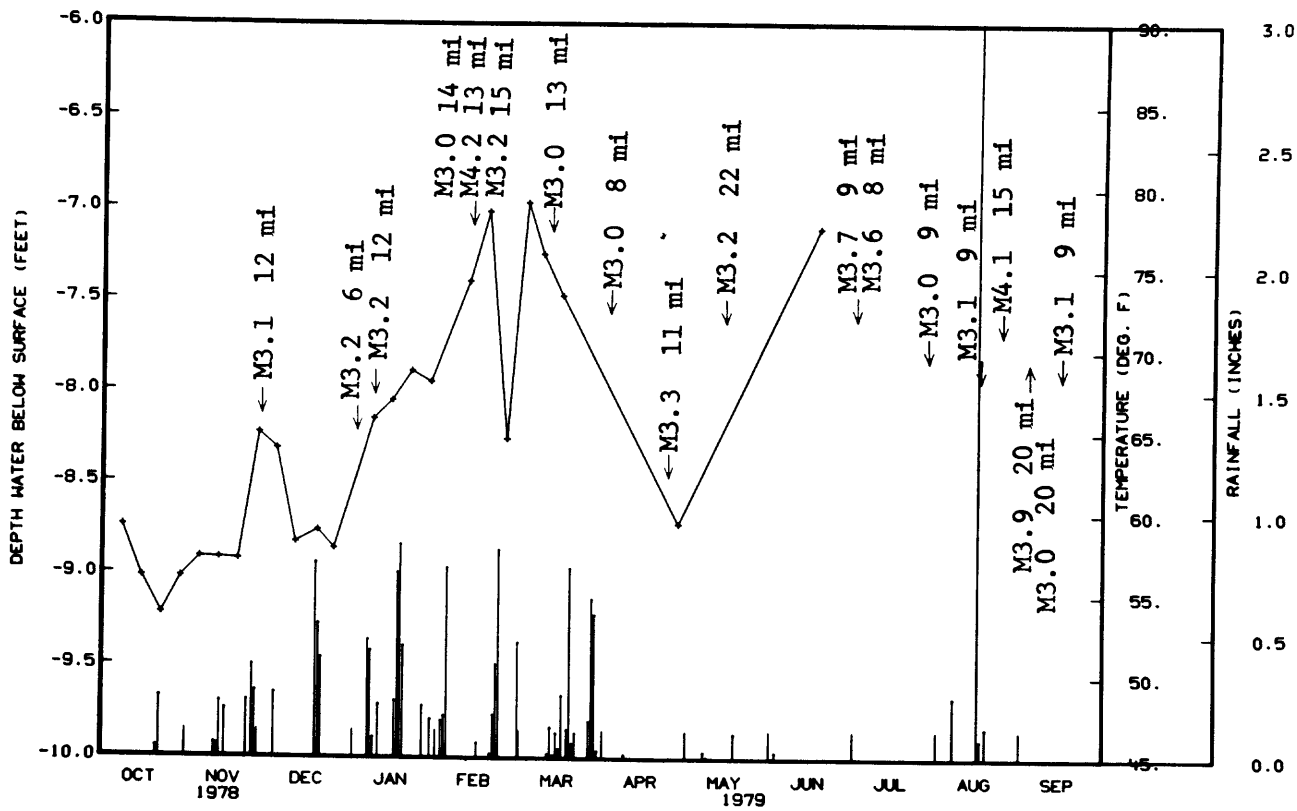

FIGURE 37 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 07S/03E-14A01 AND RAINFALL (.) DURING 1978-1979, ANZA AREA

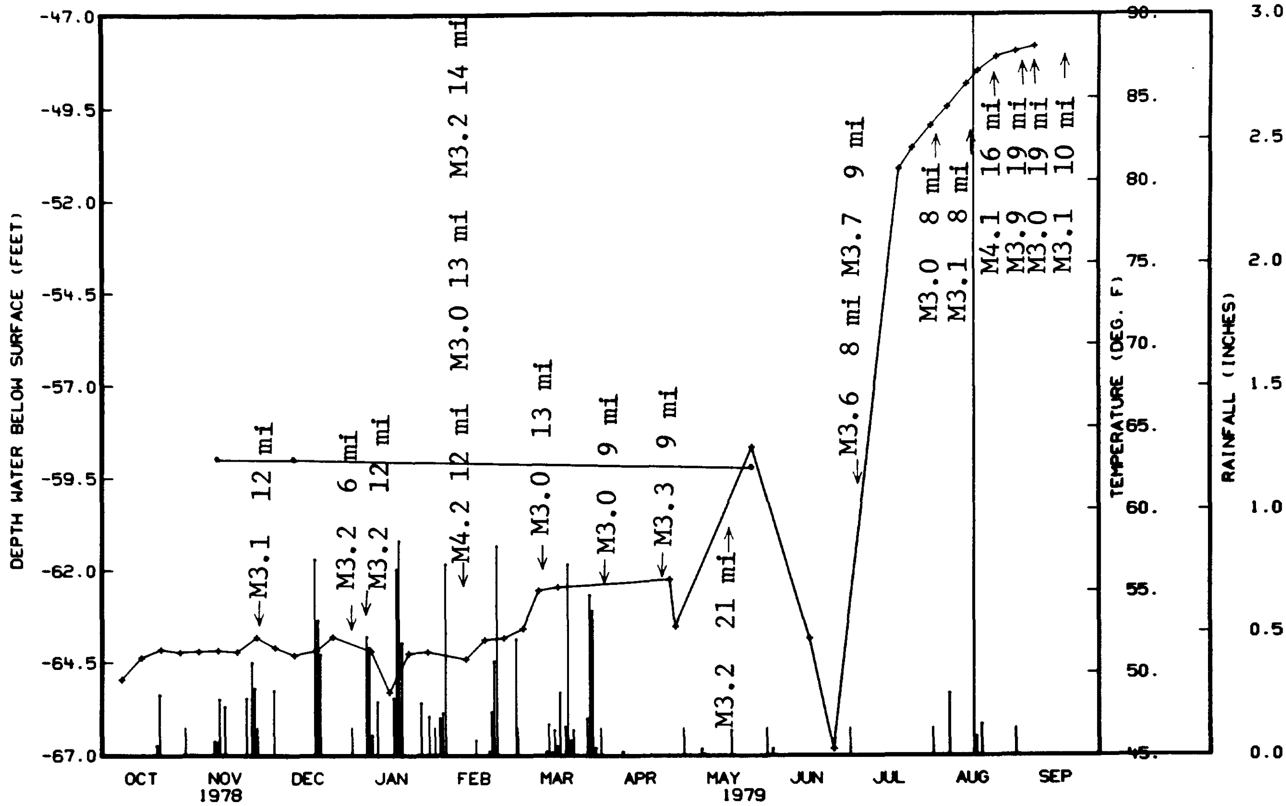

FIGURE 38 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 07S/03E-23B01 AND RAINFALL (.) DURING 1978-1979, ANZA AREA

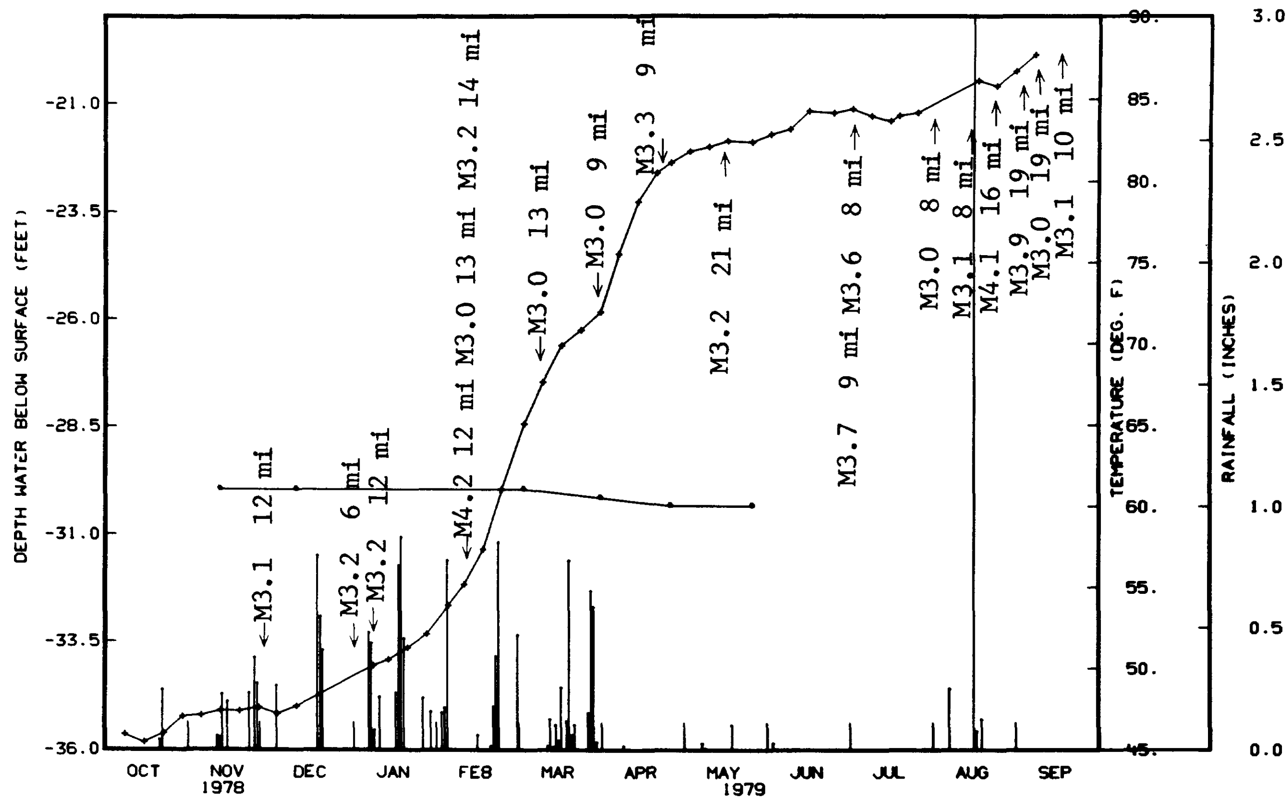

FIGURE 39 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 07S/03E-23R01 AND RAINFALL (.) DURING 1978-1979, ANZA AREA

Water levels have continued to rise but at a smaller rate since August 1979. Water levels in well 7S/3E-23R1 have been monitored since November 1977 and show remarkably similar annual changes over the past two years. Levels rose slowly during November 1977-January 1978, and November 1978-January 1979 and then rose abruptly during February-April 1978 and 1979; during May-September 1978 and 1979, the rise was less rapid (Merifield and Lamar, 1978, Fig. 63, and Fig. 39, this report).

Water levels in well 10S/6E-36Q1 in the Borrego Springs area have been monitored since November 1977 and show an irregular annual cycle over the past two years. Water levels were relatively high during January-March 1978 and December 1978-February 1979, and were generally low during the intervening periods (Merifield and Lamar, 1978, Fig. 66, and Fig. 40, this report). Water levels in well 11S/6E-1C1 have been continuously monitored since April 1978 and, although water levels are somewhat irregular, an annual cycle can also be seen with highs in April- May 1978 and January-April 1979 and relatively low levels during other periods (Merifield and Lamar, 1978, Fig. 67, and Fig. 41, this report). Levels in well 11S/6E-3N4 in Borrego Valley have steadily dropped about 1.8 feet since monitoring began in October 1977 (Merifield and Lamar, 1978, Fig. 65, and Fig. 42, this report). In contrast to the other two wells in the Borrego Springs area, this well has shown no noticeable response to the rainy seasons of the past two years. A Stevens recorder operated on this well between May 1978 and July 1979 and showed clear diurnal fluctuations, which suggests that the well should be a good strain meter. Well 10S/7E-30G1 in Borrego Valley (Fig. 8) was cleaned out and monitoring began in July 1979; because of the brief record no hydrograph is included for this well.

Water levels in well 11S/8E-33P1 in the Ocotillo Wells area have been monitored since November 1977. Water levels gradually rose about 0.2 foot between November 1977 and June 1979 (Merifield and Lamar, 1978, Fig. 68, and Fig. 43, this report). An abrupt drop in water level of 1.7 feet occurred in mid-July 1979 followed by an abrupt recovery of 2.3 feet in water level to 0.6 foot above previous levels. Based on almost two years of monitoring, we consider this abrupt change to be quite anomalous. Water levels in well 12S/8E-9Q1 in the Ocotillo Wells area have gradually dropped about 0.35 foot

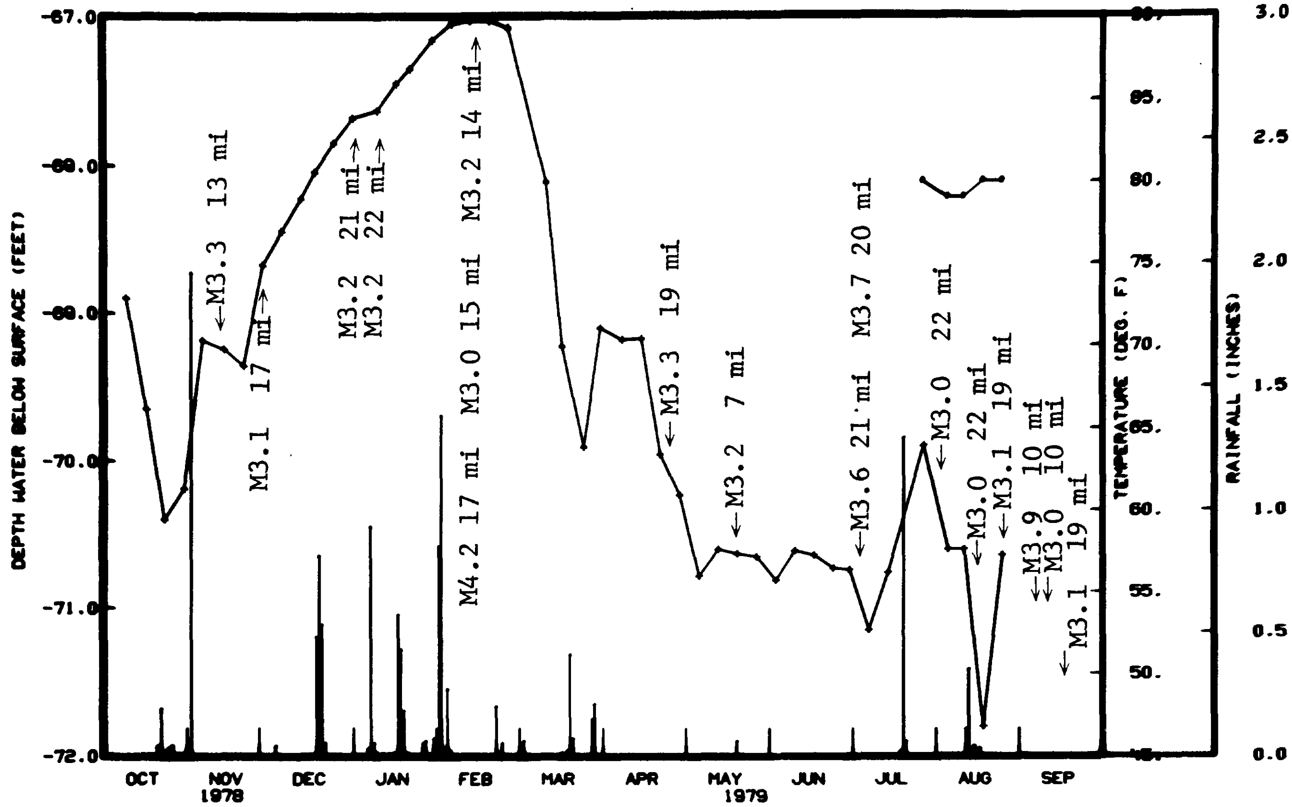

FIGURE 40-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 10S/06E-36Q01 AND RAINFALL (.) DURING 1978-1979, BORREGO SPRINGS AREA

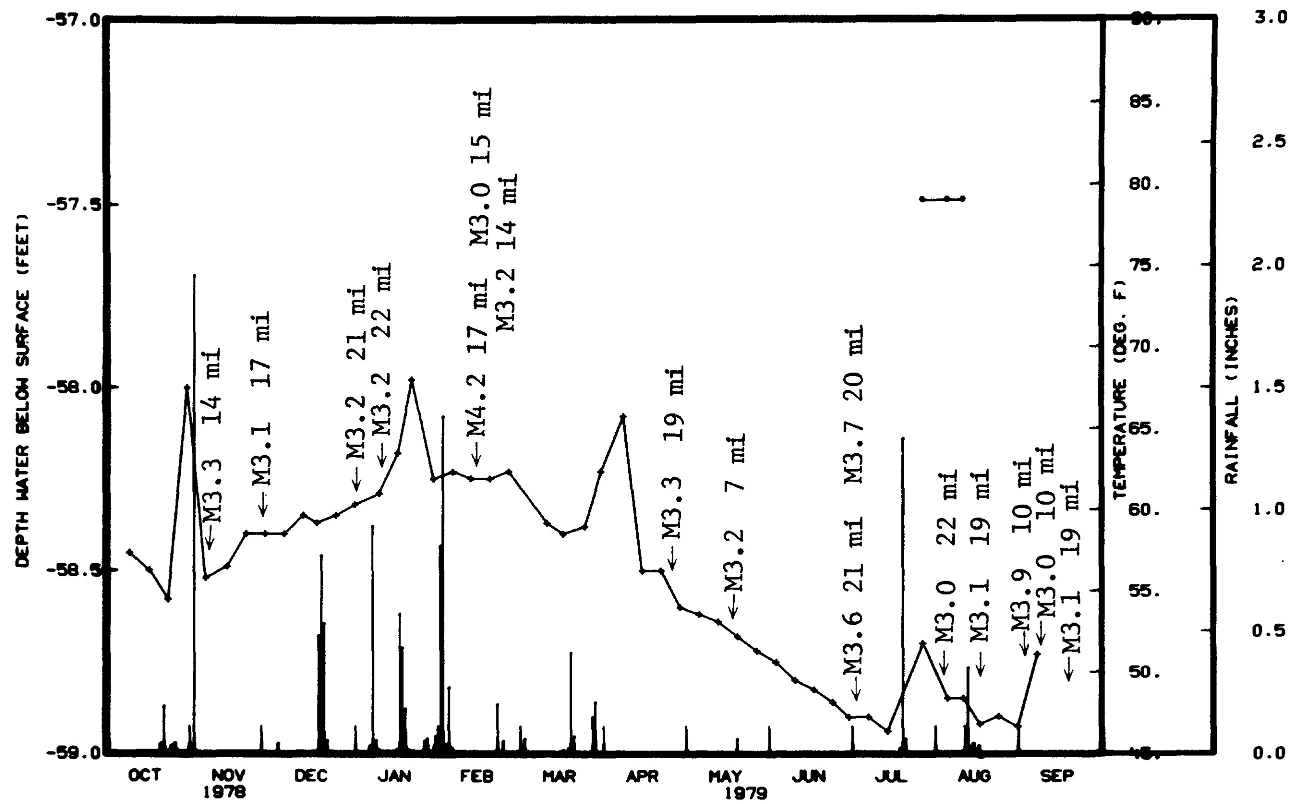

FIGURE 41-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 11S/06E-01C01 AND RAINFALL (.) DURING 1978-1979, BORREGO SPRINGS AREA

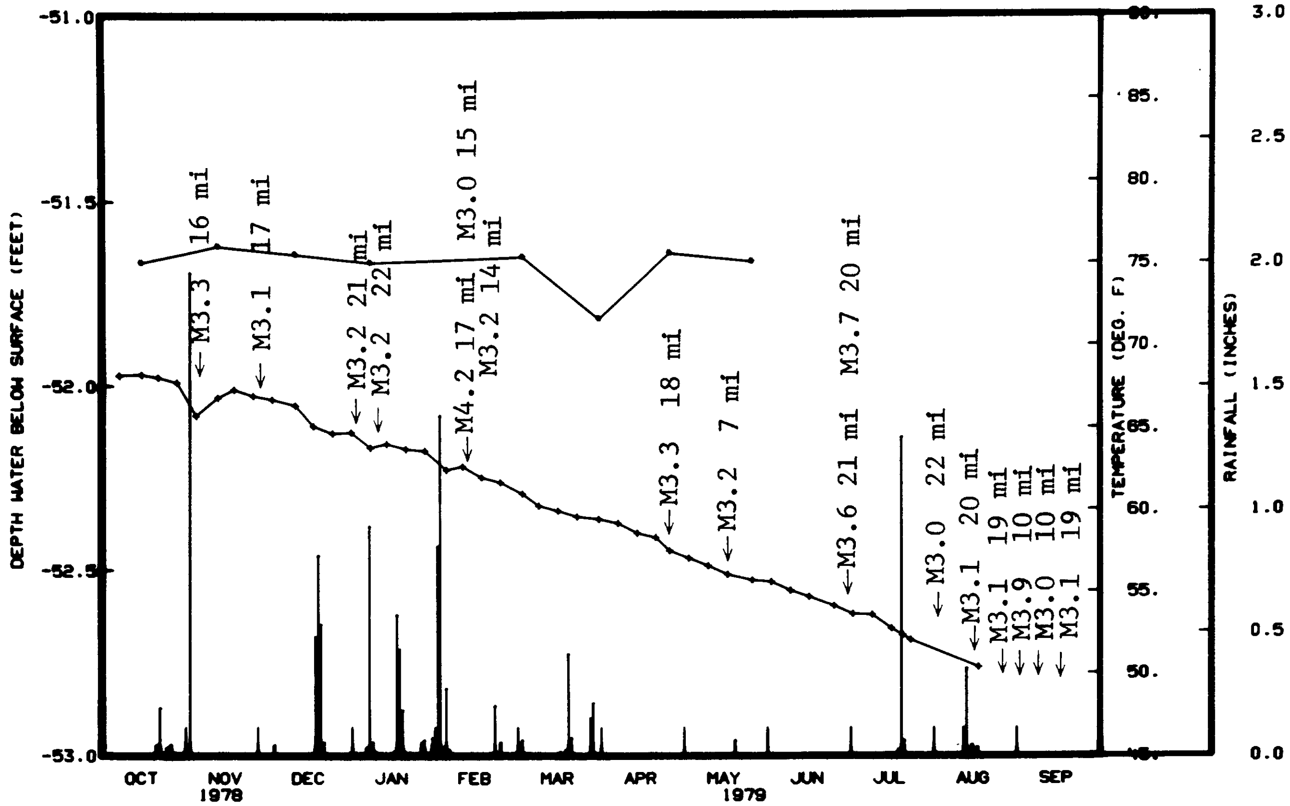

FIGURE 42 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 11S/08E-03N04 AND RAINFALL (.) DURING 1978-1979, BORREGO SPRINGS AREA

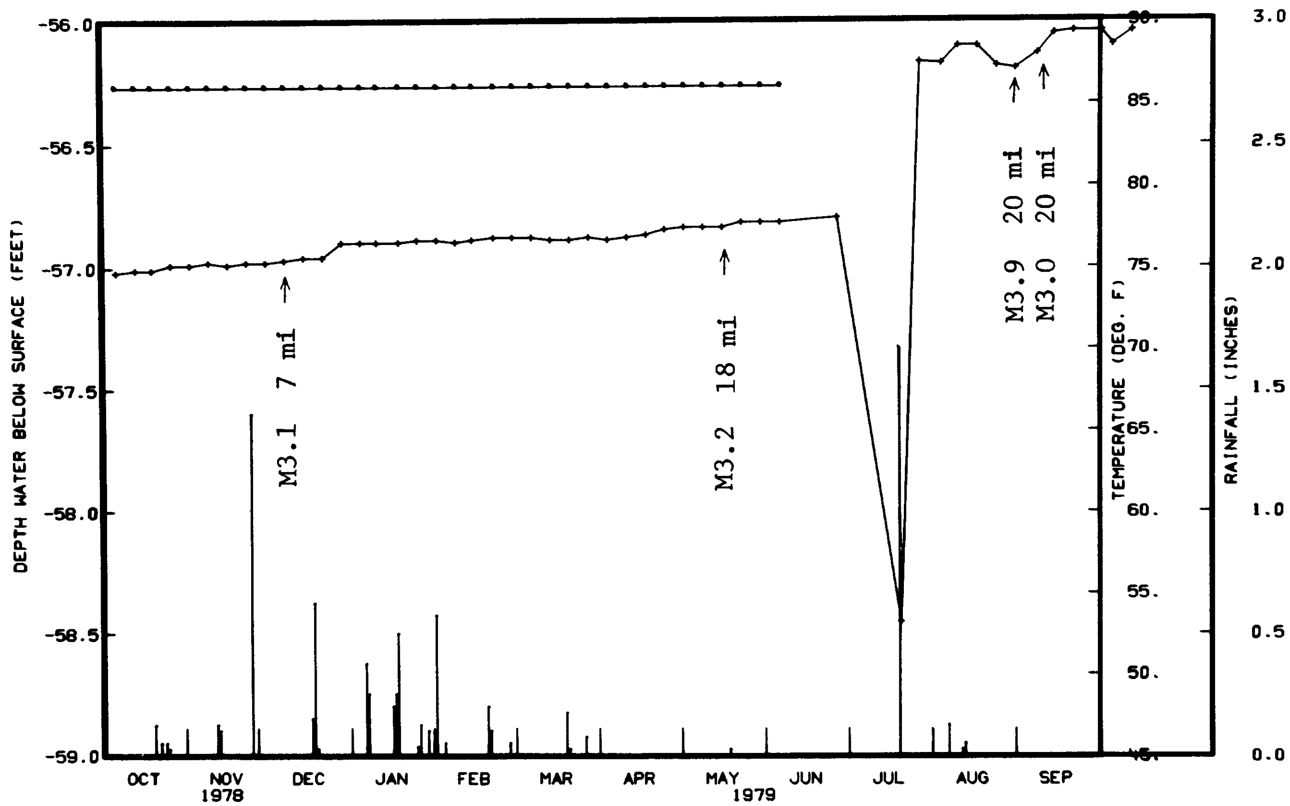

FIGURE 43 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 11S/08E-33P01 AND RAINFALL (.) DURING 1978-1979, OCOTILLO WELLS AREA

since monitoring began in May 1978 (Merifield and Lamar, 1978, Fig. 71, and Fig. 44, this report). In contrast, water levels in well 12S/8E-10E1 have gradually risen about 0.28 foot since November 1977 (Merifield and Lamar, 1978, Fig. 69, and Fig. 45, this report).

Monitoring of water levels in well 12S/8E-27A1 was stopped in January 1979 because the well went dry. No hydrograph is included for this well.

EARTHQUAKES AND THEIR RELATION TO WATER LEVELS

Data on earthquakes from October 1978 through September 1979 in the area covered by Plate 1 along the San Andreas and San Jacinto faults were obtained from the Caltech Seismological Laboratory (monthly preliminary lists of earthquakes of magnitude 3.0 or more in southern California). Data for microearthquakes shown on hydrographs of wells in the Valyermo area (Figs. 28 and 29) were obtained from K. C. McNally (personal communication, 1979). Earthquakes with magnitudes of 3.0 or greater are plotted on Plate 1, and those within 25 miles are plotted on the hydrographs for each well. Only two earthquakes of magnitude 3.0 or greater occurred within 25 miles of the observation wells in the Palmdale-Valyermo area. No water-level anomalies were observed prior to these earthquakes.

Several earthquakes of magnitude 3.0 or above occurred within 25 miles of our observation wells along the San Jacinto fault zone. Well 3S/2W-26R1 (Fig. 35) in San Jacinto Valley showed an anomalous rise of about 1.5 feet during late July and early August, three to four weeks prior to the M4.1 earthquake on 22 August 1979, which was centrally located within the San Jacinto fault zone (Plate 1). No rainfall occurred that would explain this rise, which is supported by two measurements. Fluctuations in the hydrograph for this well also occurred prior to two M3.0 earthquakes earlier in the year, but these were during the rainy season and could be accounted for by rainfall. Unfortunately, the casing on this well is too small to permit installation of a continuous recorder.

Well 3S/2W-8E1, also in San Jacinto Valley, showed an abrupt drop of about 4.5 feet and recovery beginning one to two weeks prior to the M4.1 earthquake (Fig. 33). This apparent anomaly is based on only one measurement; we tend to be suspicious of anomalies based on only one measurement, particularly

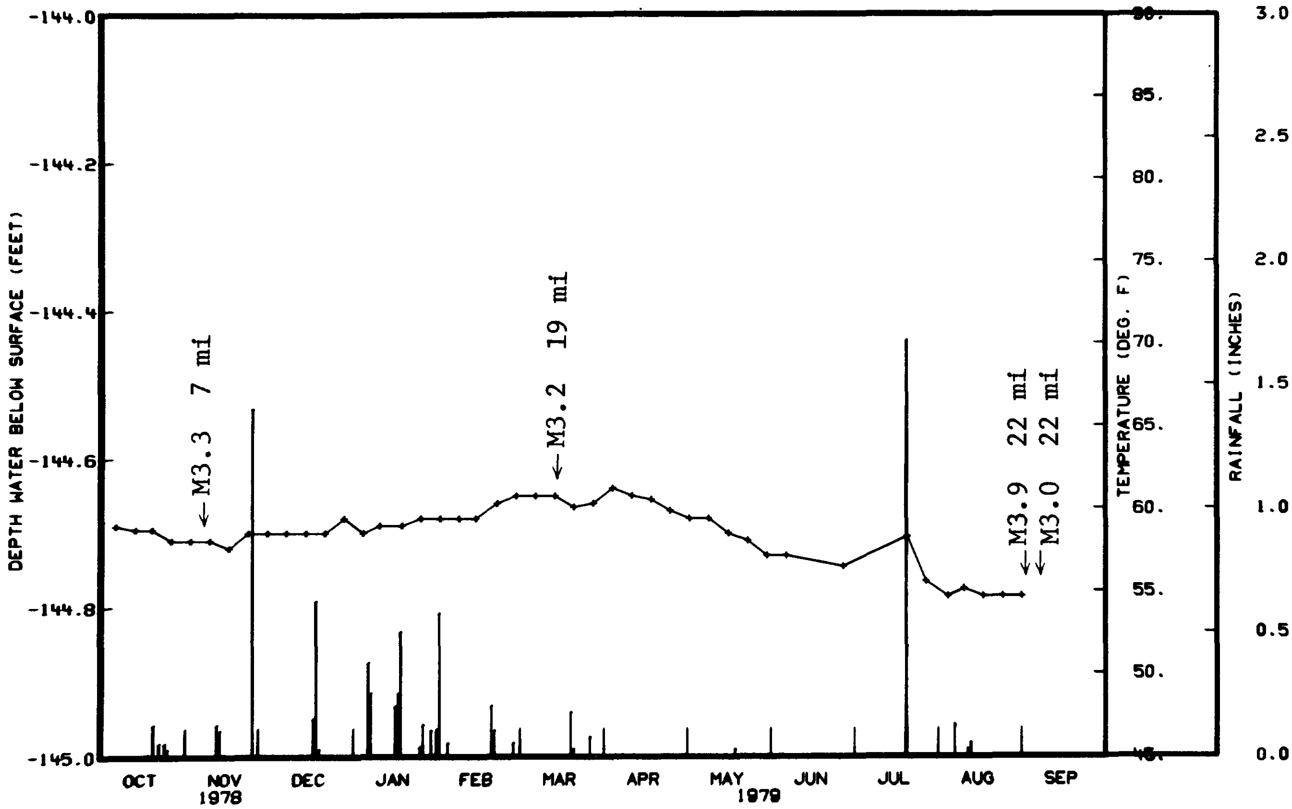

FIGURE 44-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 12S/08E-09Q01 AND RAINFALL (.) DURING 1978-1979, OCOTILLO WELLS AREA

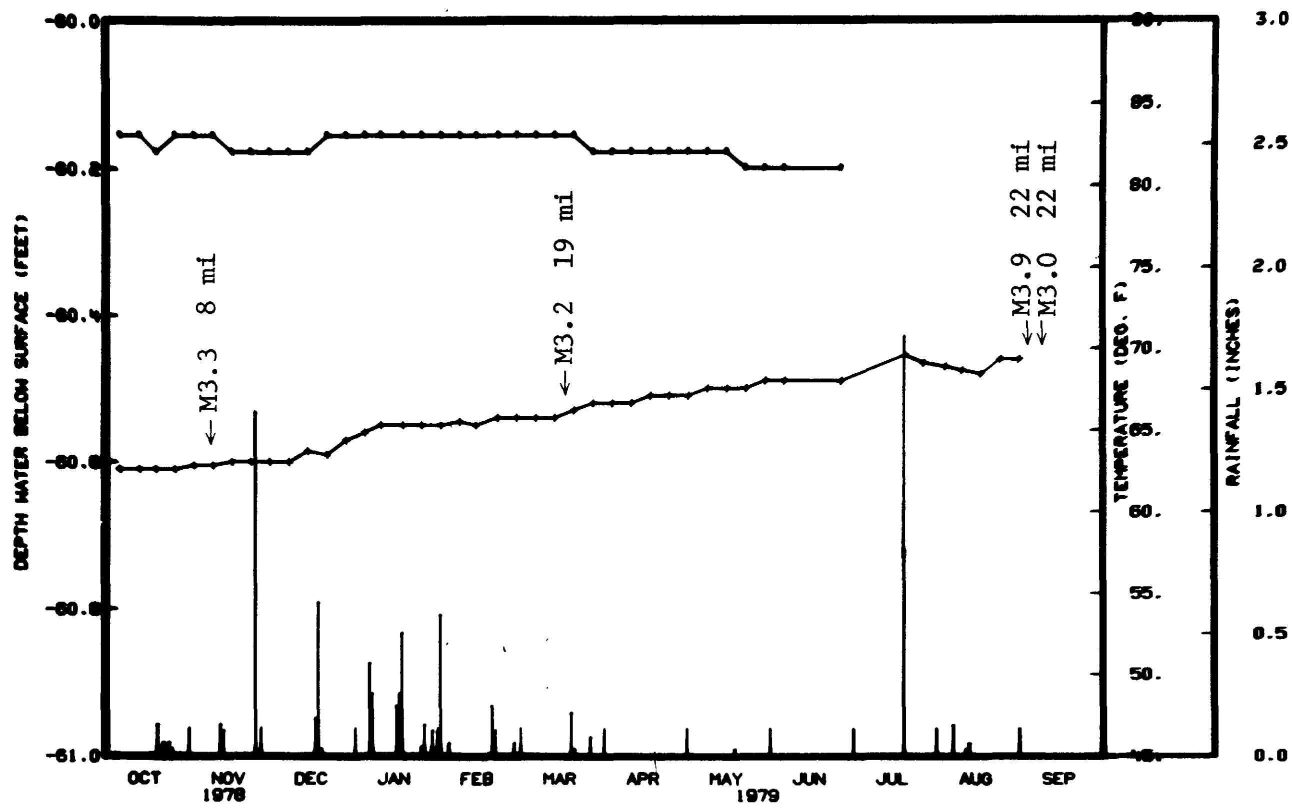

FIGURE 45-- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 12S/08E-10E01 AND RAINFALL (.) DURING 1978-1979, OCOTILLO WELLS AREA

when made by a volunteer as in this case. A third well in San Jacinto Valley, 3S/2W-15F1 (Fig. 34), showed no anomaly during the same period. The Stevens recorder that had been operating on this well was removed on 24 July 1979 after several bullet holes were found in the enclosure (fortunately, the recorder was not damaged). Up to that time, the Stevens records showed no clear anomalies.

The epicenter of the 22 August 1979 earthquake was roughly an equivalent distance between our wells in Anza and those in San Jacinto Valley. Well 7S/3E-23B1 in Anza showed large unexplained fluctuations in water level during 1979 (Fig. 38). In May, it rose over 4 feet (Fig. 38), then abruptly dropped 8 feet in June, then rose sharply 16 feet in July. Since mid-July, the rise has leveled off. A relation between this behavior and rainfall patterns is not apparent. The measurement in mid-June was made by a volunteer, but the adjacent measurements were made by an experienced employee. Two other wells in Anza, 7S/3E-23R1 and 7S/3E-13D5, both of which were monitored throughout 1979 with Stevens recorders, showed no large fluctuations during the same period. The record of a fourth well (-14A1, Fig. 37) in Anza is ignored in this discussion, because large fluctuations are typical of this well, which is only 23 feet deep. Frequent monitoring of this well has been terminated. It should be noted that -23B1 is deeper (185 feet) than the other two wells (83 and 94 feet). The anomalous drop in water level of -23B1 occurred in June 1979, about two months before the anomalies in the two San Jacinto wells occurred.

In summary, two of three wells being monitored in San Jacinto Valley and one of three wells in Anza showed abnormal behavior prior to the M4.1 earthquake of 22 August 1979. The anomalies occurred at different times, which varied from nearly three months to one-two weeks prior to the earthquake. Anomalies in three of six wells, occurring at different times, do not constitute a particularly strong case for precursor phenomena.

Well 11S/6E-1C1 in the Borrego Springs area showed four spikes (Fig. 41) which may be precursors to earthquakes which occurred within 25 miles. The significance of these spikes is questionable because several earthquakes occurred without similar spikes (Fig. 41). The largest earthquake that could be related to an anomalous rise in the water level of well 11S/6E-1C1 had a magnitude of 4.2 and occurred on February 12, 1979, approximately midway between our observation wells in Anza and Borrego Valley. No change in water level precursory to this earthquake was observed in the other two wells in Borrego Valley (Figs. 40 and 42) nor in three of the four wells being monitored in Anza (Figs. 36, 37 and 39). However, an apparently anomalous 1.2-foot drop in water level in well 7S/3E-23B1 (Fig. 38) occurred in mid-January 1979 about one month before the earthquake. A Stevens recorder was placed on well 11S/6E-1C1 in Borrego Valley within the past month to more closely monitor variations in water level. Similarly, the short-term fluctuations in water level in well 10S/6E-36Q1 in Borrego Springs (Fig. 40) could be related to earthquakes within 25 miles, but the relationship is by no means clear. This well is within 1/3 mile of well 11S/6E-1C1, which now has a continuous recorder.

An earthquake of M4.2 occurred on November 22, 1978, 18 to 19 miles north of the observation wells in San Jacinto Valley (Plate 1). No unusual water level variations on the records for the San Jacinto Valley wells or any other wells along the San Jacinto fault zone can be associated with this earthquake. However, this earthquake did not occur on the San Jacinto fault zone; it was located about 4 miles north of the San Andreas fault.

Two wells showed particularly anomalous behavior during the reporting period, 11S/8E-33P1 in Ocotillo Wells and 7S/3E-23B1 in Anza. The possible relation between these anomalies and the strong earthquake in Imperial Valley on 15 October 1979 should be considered. Preliminary reports place the earthquake near the U.S.-Mexico border on the Imperial fault, which is generally considered to be a strand in the San Jacinto fault zone. A preliminary estimate of the magnitude is MS=6.8 (K. C. McNally, Caltech, 22 October 1979). Well 11S/8E-33P1 in Ocotillo Wells is about 60 miles (100 km) northwest of the epicenter. The single anomalously low measurement (Fig. 43) in mid-July (3 months prior to the earthquake) was made under the direction of one of our experienced employees and is more likely to be accurate than not. The subsequent abrupt rise above previous levels is documented by several measurements and must be accepted. Recent measurements subsequent to those on the hydrograph (Fig. 43) indicate that the water levels in this well have returned to levels similar to those before the anomalous drop in mid-July.

In contrast, neither of the other two wells being monitored in the Ocotillo Wells area showed such an anomaly. However, water levels in well

12S/8E-9Q1 showed a rise in mid-July of about 0.06 foot, and levels in well 12S/8E-10E1 also rose about 0.03 foot at the same time. These rises would not be considered anomalous by themselves; however, it is perhaps significant that they occurred at the same time as the unusual drop and and immediate rise in water level in well 11S/8E-33P1. Water levels in well 11S/8E-33P1 could be expected to be more responsive to strain than those in the other two wells in the Ocotillo Wells area because of greater depth. As indicated on Table 1, well 11S/8E-33P1 has a depth of 374 feet, which is at least 174 feet deeper than well 12S/8E-9Q1 and 264 feet deeper than well 12S/8E-10E1.

An alternate hypothesis for the abrupt rise in water level in well 11S/8E-33P1 is based upon the rainstorm of 20 July 1979, which amounted to 1.65 inches at a station a little over a mile to the southwest. This well had not shown a significant response to prior rainstorms; for example, that of 24 November 1978 (1.35 inches). The well is in lacustrine sediments which would be expected to have impervious strata in the interval penetrated by the well. If, however, the rainfall occurred within a brief time period, resulting in flooding, surface water may have entered the gravel pack between the casing and sidewall and could account for an abrupt rise in water level. If this alternative is correct, the low reading made on 20 July 1979 is unexplained. We consider it possible, although unlikely, that this measurement was in error. The small rises in water levels in 12S/8E-9Q1 and 12S/8E-10E1 would also be related in some way to the rainstorm in this alternative. However, water levels in these wells showed less response to previous rainstorms of comparable magnitude (Figs. 44 and 45, this report).

As mentioned previously, well 7S/3E-23B1 in Anza showed large unexplained fluctuations in water level during 1979. The abrupt drop of 8 feet in June is particularly strange. If the anomalous behavior of well 11S/8E-33P1 in Ocotillo Wells in July is related to the Imperial Valley earthquake, that of -23B1 in Anza may be also.

It should also be noted that none of the wells in the Borrego Springs area, located between Anza and Ocotillo Wells, showed any anomalous water level changes which could be considered precursors to the Imperial Valley earthquake. By analogy with other wells in the San Jacinto fault zone, the absence of precursory water-level changes in wells 11S/6E-1C1 and 11S/6E-3N4 could be explained by their relatively shallow depths (116 and 71 feet, respectively); however, if the anomalies in wells 11S/8E-33P1 (Ocotillo Wells) and 7S/3E-23B1 (Anza) are both earthquake precursors, the absence of a precursory water-level change in well 10S/6E-36Q1 (Borrego Springs) is unexplained because it is 330 feet deep and located about the same distance from a strand of the San Jacinto fault zone as well 7S/3E-23B1 in Anza.

In summary, certain of the deeper wells along the San Jacinto fault zone have shown anomalous water-level changes prior to earthquakes of M4 or greater occurring along the fault zone. Although the results are encouraging, the data are not sufficiently consistent to confirm that the water-level changes represent actual earthquake precursors.

ANALYSIS OF INFLUENCE OF RAINFALL ON WELLS

By R. Robert Rapp

As discussed above, individual storms and seasonal variations in rainfall have an important influence on water levels in individual wells. However, water-level changes in wells and rainfall since October 1976 indicate large differences in the response of individual wells to rainfall. We are developing statistical techniques to forecast changes in water level as a result of these effects. If this effort is successful, we will have a method for removing the effect of rainfall on water-level variations in individual wells, so that anomalous water-level changes which may be premonitory to earthquakes will be more easily identified.

One of the factors which may influence the percolation of water to an aquifer is the amount of water which can be retained by the soil. We have chosen the period 29 April to 9 June 1977. The advantage of this choice is that a storm on 8, 9 and 10 May was preceded and followed by about a one-month dry period. The disadvantage of this choice is that the soil was dry and therefore retained much of the water. A rough soil moisture balance suggests that only about one-third of the total storm rainfall was available for runoff and percolation into the aquifer. Rain that falls on saturated soil would all be available for runoff.

In order to avoid the difficulty of estimating runoff, we have attempted to use the water levels of Lake Palmdale (location 5N/12W-3A1, Fig. 2) as a measure of available water. In order to compare Lake Palmdale level changes with the level changes of wells, water-level values were read from the Stevens recorder charts at midnight of each day from 29 April to 9 June 1977. The change in water level for each day was found by subtracting values each day from the previous day's value. These daily changes were then smoothed to eliminate very short time period fluctuations. Fig. 46 is a plot of these smoothed daily changes for Lake Palmdale and wells 5N/12W-1N1 and 5N/12W-4H1. The inset on Fig. 46 shows the reduction in amplitude of oscillations as a function of the period of the oscillations.

The root-mean-square (rms) deviation of the actual daily water-level changes from the smoothed value can be considered as a measure of the "noise" of the data. However, because the wells all have different ranges of variation, a better measure would be the ratio of the rms deviation from the smooth curve to the total variance of the observations. This ratio is 0.30 for Lake Palmdale, 0.60 for well 1N1 and 0.64 for well 4H1. Thus the well observations show much more short period variation than does Lake Palmdale; these short-term changes may be attributed largely to fluctuations in barometric pressure and tidal forces (Merifield and Lamar, 1978).

Fig. 46 shows longer period fluctuations which can be attributed to rainfall; the curves for Lake Palmdale and well 5N/12W-1N1 are similar in shape. The maxima on May 13 and May 19, 1977, for the Lake Palmdale curve are followed by maxima in the curve for well 5N/12W-1N1 on May 15 and May 21. If these events are indeed the result of the rainfall, it suggests that about two days are required for the water to infiltrate about 32 feet of earth materials to reach the aquifer tapped by well 1N1.

In order to develop a method for predicting inflow into wells from inflow to Lake Palmdale, the smoothed values of daily inflow from the lake and well 5N/12W-1N1, correlated with lag times from -9 days to +9 days, were computed. These showed, as expected, a maximum correlation between lake inflow on one day and -1N1 inflow two to three days later. The correlation between the lake inflow and the inflow to -1N1 three days later explains 72.6% of the observed variance of well -1N1. Use of additional lag correlations might explain more of the variation in well -1N1 but, because of the high day to day correlations in both the lake and the well inflow, very little additional information is added. In order to extract the maximum information, the cross spectral approach following Liu (1974) must be used.

An understanding of the response of our wells to rainfall would permit much more reliable identification of earthquake precursors, and research in this area should be encouraged. However, present funding does not provide for additional work in this area during FY 1980.

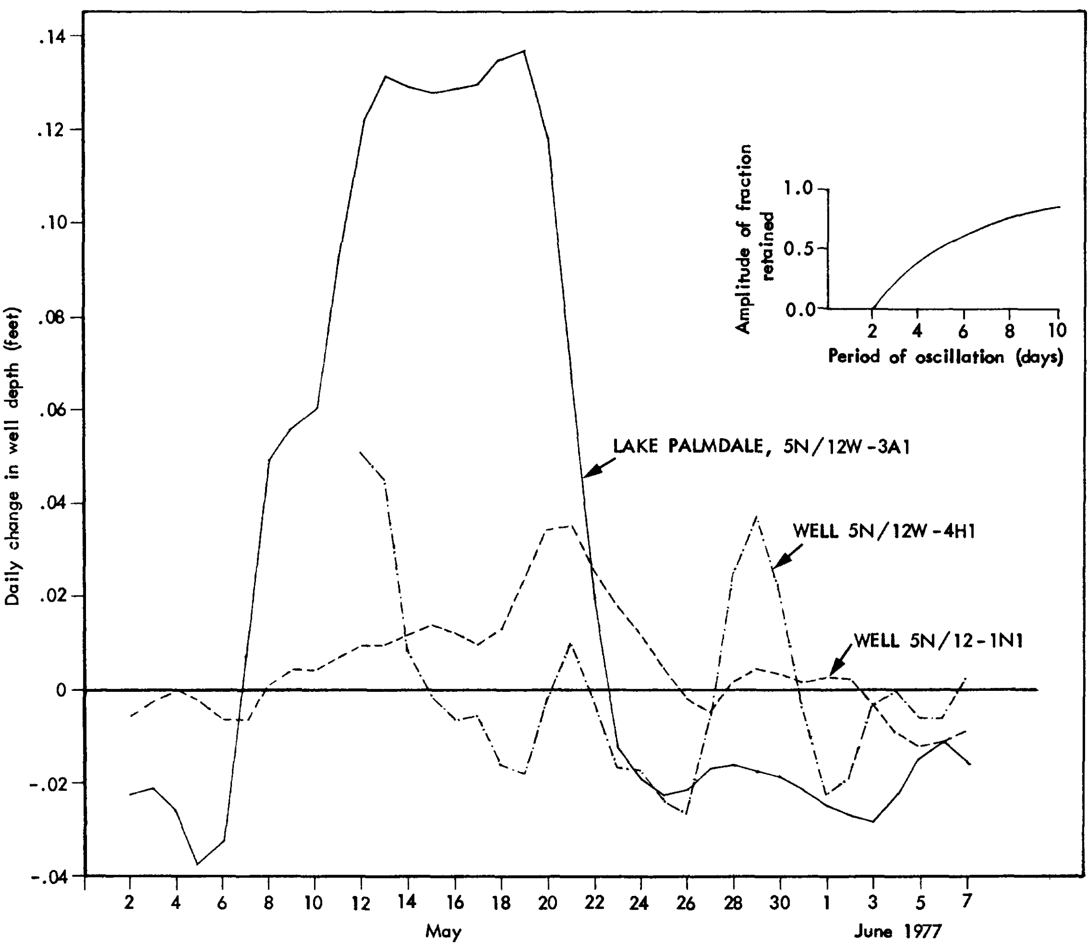

Fig. 46 - Smoothed 24-hour water-level differences for Lake Palmdale and wells 5N/12W-1N1 and -4H1

CURRENT ACTIVITIES AND FUTURE PLANS

The pulley and shaft from a Stevens recorder have been modified to drive a potentiometer mounted on well 5N/10W-33K1 in the Valyermo area. The potentiometer provides a variable voltage to a Caltech Remote Observatory Support System (TIMS). When difficulties with the telephone line are corrected, this device will telemeter water-level and other data from the observation well to Caltech. Permission for installation of a similar device on a well in the Anza area has been obtained. Valyermo and Anza are comparatively remote, so it has been difficult to obtain continuous and reliable volunteer assistance. Use of the TIMS should significantly improve the frequency and reliability of our monitoring program.

As a result of communications with Dr. Yasue Oki of the Hot Spring Research Institute, Hakone, Kanagawa, Japan, we have obtained a digital water-level gauge. This gauge is float actuated and gives a direct readout in mm of water depth on a counter mounted on the well. Dr. Oki designed this device for use by volunteers in his successful program of earthquake prediction by water-level monitoring (Oki and Hiraga, 1978, 1979). The gauge has been loaned to Ms. Marilyn MacCabe of the U.S. Geological Survey for the purpose of fabricating several for her program in the San Francisco area and for use on our program. We have had difficulty obtaining reliable weekly observations from some of our volunteers; installation of these digital gauges will greatly simplify the measurement of water levels in wells. It will also be much easier for volunteers to make more frequent observations. With some wells it should be possible to have daily, rather than weekly, observations.

When the TIMS and digital gauges are operational, we plan to search for additional wells along segments of the San Andreas and San Jacinto faults where coverage is sparse or lacking, such as San Bernardino and San Jacinto and Borrego Valleys. Depending on access to phone lines and the availability of volunteers, water levels will be sent by the TIMS system or will be monitored by volunteers using digital gauges. Additional rainfall stations will be added to provide coverage in areas where new wells are added to the program.

ACKNOWLEDGMENTS

David Douglass and Erdem Idiz assisted in making the observations. The enthusiastic aid of the following volunteers in the acquisition of water-level, temperature and rainfall observations is also gratefully acknowledged: Mary Lou MacKenzie, Quartz Hill; Robert Wilson, Palmdale; Richard Dahl, Borrego Springs; Bud Good, Ocotillo Wells; Kathy Ridge, Anza; Sarah Kermott, Banning; William Sutton, Quartz Hill; Arthur Patnode, Lancaster; and Robert Turner, Ocotillo Wells.

Tammy Muir has managed the data from the volunteers and placed data in computer storage; Jeannine V. Lamar accomplished the computer programming required to generate the hydrographs and display the rainfall data. The program would not be possible without the cooperation of the landowners listed in Table 1. William R. Moyle, Jr., of the U.S. Geological Survey has provided monthly charts from Stevens Type F water-level recorders on four wells in the Palmdale area. The manuscript was typed and reviewed by Velma Furchner and Ruth Merifield, and the illustrations were drafted by David Douglass.

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APPENDIX A: PROGRAM TO GENERATE HYDROGRAPHS OF WEEKLY WATER LEVEL AND TEMPERATURE IN WELLS AND DAILY RAINFALL FOR PALMDALE AREA

```
//X0253#PS JOB (8508,350,121),'PALMDALE',CLASS=N
// EXEC IGSIM1P,REGG=230K
//FORT.SYSIN DD *
C
      DIMENSION RT(3,2),PASTA(2),PASTB(2),PASTC(2),RTEST(2),TIT(4)
      DIMENSION Z(200)
      DIMENSION X1(2),Y1(2),X2(2),Y2(2),X3(2),Y3(2),X4(2),Y4(2),X5(2),
     * Y5(2),X6(2),Y6(2),X7(2),Y7(2),X8(2),Y8(2),X9(2),Y9(2),X10(2),
     * Y10(2),X11(2),Y11(2)
      DIMENSION RAININ(3,2000),TMDP(200),DEPTH(200),TMTM(200),
     * TEMP(200),TOTRA(200),TMRA(200)
      DATA RT(1,1)/' PSP'/,RT(1,2)/'A19N'/,RT(2,1)/' PSP'/,RT(2,2)/
     * 'M24L'/,RT(3,1)/' NOT'/,RT(3,2)/'HING'/
      REAL MIN
      CALL MODESG(Z,0)
      ID=7
   10 CONTINUE
      DO 20 I=1,150
      TMDP(I)=0.
      DEPTH(I)=0.
      TMTM(I)=0.
      TEMP(I)=0.
      TOTRA(I)=0.
      TMRA(I)=0.
   20 CONTINUE
      DO 30 IJ=1,3
      DO 30 I=1,2000
      RAININ(IJ,I)=0.
   30 CONTINUE
      ID=ID+1
      READ (ID,40) (TIT(I),I=1,4)
   40 FORMAT(12X,4A4)
      READ (ID,50)
   50 FORMAT(2X,/,2X,/,2X,/,2X,/)
      READ (ID,60) CONA,(PASTA(I),I=1,2),CONB,(PASTB(I),I=1,2),
     * CONC,(PASTC(I),I=1,2)
   60 FORMAT(17X,F4.2,2A4,3X,F4.2,2A4,3X,F4.2,2A4)
      READ (ID,70)
   70 FORMAT(1H ,/,/,/,/,/,/,/,/,/,/)
      K=0
      J=0
      KINDA=0
      KINDB=0
      KDEXA=0
      KDEXB=0
      KPLOTA=0
      KPLOTB=0
      KPLOTC=0
      NOK1=0
      NOK2=0
      NOK3=0
      JDEXA=0
      JDEXB=0
      JPLOTA=0
      JPLOTB=0
      JPLOTC=0
      NOJ1=0
      NOJ2=0
      NOJ3=0
      LDEXA=0
```

```
      LDEXB=0
      LPLOTA=0
      LPLOTB=0
      LPLOTC=0
      NOL1=0
      NOL2=0
      NOL3=0
   80 READ (ID,90) YR,DAY,HR,MIN,TEM,DEP
   90 FORMAT(6X,F2.0,3X,F3.0,6X,F2.0,1X,F2.C,2X,F4.1,15X,F7.3)
      IF (DAY.EQ.0.) GO TO 140
      IF (HR.EQ.0.) GO TO 80
      IF (DEP.EQ.0.) GO TO 80
      IF (YR.EQ.76..AND.DAY.LT.274.) GO TO 80
      DAY=DAY+HR/24.+MIN/1440.
      IF((YR.EQ.76..AND.DAY.GE.274.).OR.(YR.EQ.77..AND.DAY.LE.273.))
     * KPLOTA=1
      IF((YR.EQ.77..AND.DAY.GT.273.).OR.(YR.EQ.78..AND.DAY.LE.273.))
     * KPLOTB=1
      IF((YR.EQ.78..AND.DAY.GT.273.).OR.(YR.EQ.79.))
     * KPLOTC=1
      IF (YR.EQ.77..AND.DAY.GT.273.) KINDA=1
      IF (YR.EQ.77..AND.DAY.LE.273.) DAY=DAY+366.
      IF (YR.EQ.78..AND.DAY.GT.273.) KINDB=1
      IF (YR.EQ.78..AND.DAY.LE.273.) DAY=DAY+365.
      IF (YR.EQ.79.) DAY=DAY+365.
      K=K+1
      IF (KDEXA.GT.0) GO TO 100
      IF (KINDA.EQ.1) KDEXA=K-1
      GO TO 110
  100 IF (KDEXB.GT.0) GO TO 110
      IF (KINDB.EQ.1) KDEXB=K-1
  110 CONTINUE
      TMDP(K)=DAY
      DEPTH(K)=DEP
      IF (TEM.EQ.0.) GO TO 80
      IF((YR.EQ.76..AND.DAY.GE.274.).OR.((YR.EQ.77..AND.DAY.GE.367.).
     * AND.(YR.EQ.77..AND.DAY.LE.639.))) JPLOTA=1
      IF(((YR.EQ.77..AND.DAY.GE.273.).AND.(YR.EQ.77..AND.DAY.LT.366.)).
     * OR.((YR.EQ.78.AND.DAY.GE.367).AND.(YR.EQ.78..AND.DAY.LE.638.)))
     * JPLOTB=1
      IF(((YR.EQ.78..AND.DAY.GT.273.).AND.(YR.EQ.78..AND.DAY.LT.366)).
     * OR.(YR.EQ.79)) JPLOTC=1
      J=J+1
      IF (JDEXA.GT.0) GO TO 120
      IF (KINDA.EQ.1) JDEXA=J-1
      GO TO 130
  120 IF (JDEXB.GT.0) GO TO 130
      IF (KINDB.EQ.1) JDEXB=J-1
  130 CONTINUE
      TEMP(J)=TEM
      TMTM(J)=DAY
      GO TO 80
  140 CONTINUE
      IF (KDEXA.NE.0) GO TO 150
      IF (KPLOTA.EQ.1) KDEXA=K
      IF (KPLOTA.EQ.0) NOK1=1
  150 IF (KDEXB.NE.0) GO TO 160
      IF (KPLOTB.EQ.1) KDEXB=K
      IF (KPLOTB.EQ.0) NOK2=1
  160 IF (KPLOTC.EQ.0) NOK3=1
      IF (JDEXA.NE.0) GO TO 170
```

```
      IF (JPLOTA.EQ.1) JDEXA=J
      IF (JPLOTA.EQ.0) NOJ1=1
170   IF (JDEXB.NE.0) GO TO 180
      IF (JPLOTB.EQ.1) JDEXB=J
      IF (JPLOTB.EQ.0) NOJ2=1
180   IF (JPLOTC.EQ.0) NOJ3=1
      YMAX=0.
      YMIN=200.
      DO 190 I=1,K
      IF (DEPTH(I).LT.YMIN) YMIN=DEPTH(I)
      IF (DEPTH(I).GT.YMAX) YMAX=DEPTH(I)
190   CONTINUE
      IMAX=YMAX
      IMIN=YMIN
      TMAX=YMAX-FLOAT(IMAX)
      TMIN=YMIN-FLOAT(IMIN)
      IF (TMAX.GE..5) YMAX=-(FLOAT(IMAX)+1.)
      IF (TMAX.LT..5) YMAX=-(FLOAT(IMAX)+1.)
      IF (TMIN.GE..5) YMIN=-FLOAT(IMIN)
      IF (TMIN.LT..5) YMIN=-FLOAT(IMIN)
      IXY=ABS(YMAX-YMIN)
      IF (IXY.EQ.1) YLABL=.2
      IF (IXY.GE.2.AND.XY.LE.4) YLABL=.5
      IF (IXY.GE.5.AND.XY.LE.8) YLABL=1.
      IF (IXY.GE.9.AND.XY.LE.12) YLABL=1.5
      IF (IXY.GE.13.AND.XY.LE.16) YLABL=2.
      IF (IXY.GE.17.AND.XY.LE.20) YLABL=2.5
      IF (IXY.GE.21.AND.XY.LE.24) YLABL=3.
      IF (IXY.GE.25.AND.XY.LE.28) YLABL=3.5
      IF (IXY.GE.29.AND.XY.LE.32) YLABL=4.
      IF (IXY.GE.33.) YLABL=5.
      DO 200 I=1,K
      DEPTH(I)=-DEPTH(I)
200   CONTINUE
      IDA=0
      IDB=0
      IDC=0
      IONE=10
      ITWO=10
      ITHRE=10
      DO 210 I=1,3
      RTEST(1)=RT(I,1)
      RTEST(2)=RT(I,2)
      IF (IONE.EQ.0) GO TO 210
      IONE=NCOMP(PASTA,1,8,RTEST,1)
      IF (IONE.EQ.0) IDA=I+30
210   CONTINUE
      DO 220 I=1,3
      RTEST(1)=RT(I,1)
      RTEST(2)=RT(I,2)
      IF (ITWO.EQ.0) GO TO 220
      ITWO=NCOMP(PASTB,1,8,RTEST,1)
      IF (ITWO.EQ.0) IDB=I+30
220   CONTINUE
      DO 230 I=1,3
      RTEST(1)=RT(I,1)
      RTEST(2)=RT(I,2)
      IF (ITHRE.EQ.0) GO TO 230
      ITHRE=NCOMP(PASTC,1,8,RTEST,1)
      IF (ITHRE.EQ.0) IDC=I+30
230   CONTINUE
```

```
      IF (IDA.EQ.0) GO TO 390
      INC=IDA
      ILM=1
      CON=CONA
  240 CONTINUE
      READ (INC,250)
  250 FORMAT(1H ,/,/,/,/,/,/,/,/,/)
  260 READ (INC,270) IDAY,IYR,RAIN
  270 FORMAT(11X,I3,1X,I2,21X,F5.2)
      IF (IDAY.EQ.0.AND.INC.EQ.31) GO TO 280
      IF (IDAY.EQ.0.AND.INC.EQ.32) GO TO 290
      IF (IDAY.EQ.0.AND.INC.EQ.33) GO TO 300
      IF (IYR.EQ.75) GO TO 260
      IF (IYR.EQ.76..AND.IDAY.LT.274) GO TO 260
      IF (IYR.EQ.77) IDAY=IDAY+366
      IF (IYR.EQ.78) IDAY=IDAY+731
      IF (IYR.EQ.79) IDAY=IDAY+1096
      RAININ(ILM,IDAY)=RAIN*CON
      GO TO 260
  280 IF (IDB.EQ.0) GO TO 300
      INC=IDB
      CON=CONB
      ILM=2
      GO TO 240
  290 IF (IDC.EQ.0) GO TO 300
      INC=IDC
      CON=CONC
      ILM=3
      GO TO 240
  300 L=0
      DO 320 I=1,2000
      IF(RAININ(1,I).NE.0..OR.RAININ(2,I).NE.0..OR.RAININ(3,I).
     * NE.0.) GO TO 310
      GO TO 320
  310 L=L+1
      TOTRA(L)=RAININ(1,I)+RAININ(2,I)+RAININ(3,I)
      TMRA(L)=FLOAT(I)
  320 CONTINUE
      LNDEX=0
      DO 360 I=1,L
      IF (TMRA(I).GE.274..AND.TMRA(I).LE.639.) LPLOTA=1
      IF (TMRA(I).GT.639..AND.TMRA(I).LE.1004.) LPLOTB=1
      IF (TMRA(I).GT.1004) LPLOTC=1
      IF (LDEXA.GT.0) GO TO 330
      IF (TMRA(I).GT.639) LDEXA=I-1
      IF (LDEXA.GT.0) GO TO 330
         GO TO 360
 330  IF (TMRA(I).GT.1004) GO TO 340
      TMRA(I)=TMRA(I)-366.
      GO TO 360
  340 IF (LDEXB.GT.0) GO TO 350
      LDEXB=I-1
  350 TMRA(I)=TMRA(I)-731.
  360 CONTINUE
      IF (LDEXA.NE.0) GO TO 370
      IF (LPLOTA.EQ.1) LDEXA=L
      IF (LPLOTA.EQ.0) NOL1=1
  370 IF (LDEXB.NE.0) GO TO 380
      IF (LPLOTB.EQ.1) LDEXB=L
      IF (LPLOTB.EQ.0) NOL2=1
  380 IF (LPLOTC.EQ.0) NOL3=1
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```
      GO TO 410
  390 WRITE(6,400)
  400 FORMAT(1H ,'NO RAIN DATA')
      STOP
  410 CONTINUE
C
C  HYDROGPAPHIC PLOTS
C
      X1(1)=.175
      Y1(1)=.240
      X1(2)=.175
      Y1(2)=.265
      X2(1)=.240
      Y2(1)=.240
      X2(2)=.240
      Y2(2)=.265
      X3(1)=.325
      Y3(1)=.240
      X3(2)=.325
      Y3(2)=.265
      X4(1)=.400
      Y4(1)=.240
      X4(2)=.400
      Y4(2)=.265
      X5(1)=.475
      Y5(1)=.240
      X5(2)=.475
      Y5(2)=.265
      X6(1)=.550
      Y6(1)=.240
      X6(2)=.550
      Y6(2)=.265
      X7(1)=.625
      Y7(1)=.240
      X7(2)=.625
      Y7(2)=.265
      X8(1)=.700
      Y8(1)=.240
      X8(2)=.700
      Y8(2)=.265
      X9(1)=.775
      Y9(1)=.240
      X9(2)=.775
      Y9(2)=.265
      X10(1)=.850
      Y10(1)=.240
      X10(2)=.850
      Y10(2)=.265
      X11(1)=.925
      Y11(1)=.240
      X11(2)=.925
      Y11(2)=.265
      KNTP=1
      LNDEX=LDEXA
      KNDEX=KDEXA
      JNDEX=JDEXA
      NOJ=NOJ1
      NOK=NOK1
      NOL=NOL1
  420 CONTINUE
      CALL OBJCTG(Z,.1,.24,1.0,.9)
```

```
      CALL SUBJEG(Z,273.,0.,639.,3.0)
      CALL SETSMG(Z,55,2.)
      CALL SETSMG(Z,84,'2')
      CALL SETSMG(Z,53,.75)
      IF (NOL.EQ.1) GO TO 440
      DO 430 I=1,LNDEX
      CALL POINTG(Z,1,TMRA(I),TOTRA(I))
      Y=0.
      CALL LINESG(Z,1,TMRA(I),Y)
  430 CONTINUE
  440 CONTINUE
      CALL SETSMG(Z,55,0.)
      CALL SUBJEG(Z,273.,45.,639.,80.)
      CALL SETSMG(Z,100,3.0)
      CALL GRIDG(Z,0,0,0,0)
      CALL SETSMG(Z,84,'*')
      IF (NOJ.EQ.1) GO TO 450
      CALL POINTG(Z,JNDEX,TMTM,TEMP)
      CALL LINESG(Z,JNDEX,TMTM,TEMP)
  450 CONTINUE
      CALL SETSMG(Z,105,1.)
      CALL TITLEG(Z,0,'DUMMY',20,'TEMPERATUPE (DEG. F)',0,'DUM')
      CALL SETSMG(Z,103,.01)
      CALL LABELG(Z,1,5.,0,5.0)
      CALL SUBJEG(Z,273.,YMAX,639.,YMIN)
      CALL SETSMG(Z,84,'+')
      IF (NOK.EQ.1) GO TO 460
      CALL POINTG(Z,KNDEX,TMDP,DEPTH)
      CALL LINESG(Z,KNDEX,TMDP,DEPTH)
  460 CONTINUE
      CALL SETSMG(Z,105,-1.)
      CALL SETSMG(Z,102,.01)
      CALL LABELG(Z,1,YLABL,0,6.1)
      CALL TITLEG(Z,0,'DUMMY',32,'DEPTH WATER BELOW SURFACE (FEET)',
     1 0,'DUMMY')
      CALL SETSMG(Z,14,3.0)
      CALL LEGNDG(Z,.125,.22,3,'OCT')
      CALL LEGNDG(Z,.200,.22,3,'NOV')
      CALL LEGNDG(Z,.275,.22,3,'DEC')
      CALL LEGNDG(Z,.350,.22,3,'JAN')
      CALL LEGNDG(Z,.425,.22,3,'FEB')
      CALL LEGNDG(Z,.500,.22,3,'MAR')
      CALL LEGNDG(Z,.575,.22,3,'APR')
      CALL LEGNDG(Z,.650,.22,3,'MAY')
      CALL LEGNDG(Z,.725,.22,3,'JUN')
      CALL LEGNDG(Z,.800,.22,3,'JUL')
      CALL LEGNDG(Z,.875,.22,3,'AUG')
      CALL LEGNDG(Z,.950,.22,3,'SEP')
      IF (KNTR.EQ.2) GO TO 470
      IF (KNTR.EQ.3) GO TO 480
      CALL LEGNDG(Z,.1,.205,93,'          1976
     1          1977                                  ')
      CALL LEGNDG(Z,.125,.155,86,'FIGURE    -- WEEKLY OBSERVATIONS OF WA
     1TER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER')
      CALL LEGNDG(Z,.405,.14,49,' AND RAINFALL (.) DURING 1976-1977, PAL
     *MDALE AREA')
      GO TO 490
  470 CONTINUE
      CALL LEGNDG(Z,.1,.205,93,'          1977
     1          1978                                  ')
      CALL LEGNDG(Z,.125,.155,86,'FIGURE    -- WEEKLY OBSERVATIONS OF WA
```

```
     1TER LEVEL (+) AND TEMPERATURE (*) IN WEIL NUMBER')
      CALL LEGNDG(Z,.405,.14,49,' AND RAINFALL (.) DURING 1977-1978, PAL
     *MDALE AREA')
      GO TO 490
  480 CONTINUE
      CALL LEGNDG(Z,.1,.205,93,'          1978
     1                1979                              ')
      CALL LEGNDG(Z,.125,.155,86,'FIGURE    -- WEEKLY OBSERVATIONS OF WA
     1TER LEVEL (+) AND TEMPERATURE (*) IN WEIL NUMBER')
      CALL LEGNDG(Z,.405,.14,49,' AND RAINFALL (.) DURING 1978-1979, PAL
     *MDALE AREA')
  490 CONTINUE
      CALL LEGNDG(Z,.26,.14,16,TIT)
      CALL LINESG(Z,2,X1,Y1)
      CALL LINESG(Z,2,X2,Y2)
      CALL LINESG(Z,2,X3,Y3)
      CALL LINESG(Z,2,X4,Y4)
      CALL LINESG(Z,2,X5,Y5)
      CALL LINESG(Z,2,X6,Y6)
      CALL LINESG(Z,2,X7,Y7)
      CALL LINESG(Z,2,X8,Y8)
      CALL LINESG(Z,2,X9,Y9)
      CALL LINESG(Z,2,X10,Y10)
      CALL LINESG(Z,2,X11,Y11)
      CALL SETSMG(Z,14,0.)
      CALL OBJCTG(Z,.1,.24,1.1,.9)
      CALL SUBJEG(Z,273.,0.,639.,3.0)
      CALL SETSMG(Z,100,3.0)
      CALL GRIDG(Z,0,0,0,0)
      CALL SETSMG(Z,105,1.)
      CALL TITLEG(Z,0,'DUMMY',17,'RAINFALL (INCHES)',0,'DUM')
      CALL LABELG(Z,1,.5,0,6.1)
      CALL PAGEG(Z,0,1,1)
      CALL RSETMG(Z)
      KNTR=KNTR+1
      IF (KNTR.EQ.2.OR.KNTR.EQ.3) GO TO 500
      IF (KNTR.EQ.4.AND.ID.LT.10) GO TO 10
      CALL EXITG(Z)
      STOP
  500 CONTINUE
      IF (KNTR.EQ.2) GO TO 510
      KNDEX=KDEXB
      JNDEX=JDEXB
      KA=K
      JA=J
      LA=L
      LNDEX=LDEXB
      NOK=NOK3
      NOL=NOL3
      NOJ=NOJ3
      GO TO 520
  510 KNDEX=KDEXA
      KA=KDEXB
      JNDEX=JDEXA
      JA=JDEXB
      LNDEX=LDEXA
      LA=LDEXB
      NOK=NOK2
      NOL=NOL2
      NOJ=NOJ2
  520 CONTINUE
```

```
      KND=KNDEX+1
      DO 530 IJK=KND,KA
      TMDP(IJK-KNDEX)=TMDP(IJK)
      DEPTH(IJK-KNDEX)=DEPTH(IJK)
  530 CONTINUE
      KNDEX=KA-KNDEX
      JND=JNDEX+1
      DO 540 IJK=JND,JA
      TMTM(IJK-JNDEX)=TMTM(IJK)
      TEMP(IJK-JNDEX)=TEMP(IJK)
  540 CONTINUE
      JNDEX=JA-JNDEX
      LND=LNDEX+1
      DO 550 IJK=LND,LA
      TMRA(IJK-LNDEX)=TMRA(IJK)
      TOTRA(IJK-LNDEX)=TOTRA(IJK)
  550 CONTINUE
      LNDEX=LA-LNDEX
      REWIND 31
      REWIND 32
      REWIND 33
      GO TO 420
      END
/*
//GO.FT31F001 DD DSN=X.X0253.A8508.PSPA19N,UNIT=USER,
//    VOL=SER=USER50,DISP=OLD
//GO.FT32F001 DD DSN=X.X0253.A8508.PSPM24L,UNIT=USER,
//    VOL=SER=USER50,DISP=OLD
//GO.FT33F001 DD DSN=X.X0253.A8508.DDUMMYY,UNIT=USER,
//    VOL=SER=USER50,DISP=OLD
//GO.FT08F001 DD DSN=X.X0253.A8508.PA01N01,UNIT=USER,
//    VOL=SER=USER50,DISP=OLD
//GO.FT09F001 DD DSN=X.X0253.A8508.PA01N02,UNIT=USER,
//    VOL=SER=USER50,DISP=OLD
//GO.FT10F001 DD DSN=X.X0253.A8508.PA02J01,UNIT=USER,
//    VOL=SER=USER80,DISP=OLD
//
```