WATER-LEVEL MONITORING ALONG SAN ANDREAS AND SAN JACINTO FAULTS, SOUTHERN CALIFORNIA, DURING FIRST HALF OF FISCAL YEAR 1980

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LAMAR-MERIFIELD

TECHNICAL REPORT 80-1

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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 reported in Merifield and Lamar (1978) and Lamar and Merifield (1978). Work during Fiscal Year 1979 was accomplished under Contract No. 14-08-0001-17680 and was described in Lamar and Merifield (1979). To avoid repetition, much of the background and other data included in the final reports for Contract Nos. 14-08-0001-15881 (Merifield and Lamar, 1978) and 14-08-0001-17680 (Lamar and Merifield, 1979) 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.

ABSTRACT

Beginning in October 1976, a program of water-level monitoring of abandoned water wells was initiated in the Palmdale area with the purpose of identifying possible water-level changes premonitory to a major earthquake on the San Andreas fault. In October 1977, the program was extended southeastward along the rift zone to the Valyermo area. In November 1977, the monitoring of water wells along the San Jacinto fault was initiated with the expectation of experiencing a moderate size earthquake while monitoring was in progress. Currently about 35 wells are being monitored. Eight wells are monitored continuously with Stevens Type F recorders. The remaining wells are probed weekly, or in some cases semi-weekly or daily, by volunteers. We are endeavoring to improve the volunteer program by increasing the frequency of measurements and simplifying the procedure to minimize measurement errors.

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. The hydrographs are updated and reviewed weekly. Weekly hydrographs are also prepared from recorder charts on two wells maintained by W. R. Moyle, Jr., of the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California.

Remote Observatory Support Systems (TIMS) constructed by the Caltech Seismological Laboratory have been installed at wells in Juniper Hills and Anza to telemeter water-level data to Caltech. Because of noisy phone lines, neither system is operational at present.

A M5.3 earthquake occurred on 25 February 1980, between the Buck Ridge and San Jacinto strands of the San Jacinto fault zone, about 8 miles east-southeast of Anza. This is the largest earthquake which has occurred on the faults within our monitoring network. The Stevens recorder chart for well number 11S/6E-3N4 located in Borrego Valley about 22 miles southeast of the epicenter indicates that, during a period of about four hours on 21 February, the water level rose 1.5 to 1.6 feet and returned to its prior level. This is one of the most remarkable short-term water-level fluctuations observed during our monitoring program; it occurred about 88 hours prior to the earthquake. This well has been monitored since October 1977 and has had a Stevens recorder since October 1978. Long-term

water levels have been remarkably steady compared to those in other wells we are monitoring. Since October 1977, the water level has gradually and steadily dropped about two feet and has shown no seasonal variation and no identifiable response to rainfall. This well shows a strong response to earth tides. The Stevens record on a second well in Borrego Valley (11S/6E-1C1) showed a much smaller (0.1 foot) spike in water level at the same time as the spike in well number 11S/6E-3N4. Other continuously recording wells in Anza and Ocotillo Wells showed no identifiable water-level anomalies. The two wells in Borrego Valley which showed possible strain-induced water-level spikes appear to be more sensitive to earth tides than wells in the same area which did not show spikes in water level. We cannot conceive of any nontectonic cause for the spike on the Stevens record of well 11S/6E-3N4. A creep event on the Coyote Creek fault about 4 miles from the well is one possibility. Because the spikes in the two wells in Borrego Valley are unique for the long-term record of these wells, they may represent precursors to the 25 February earthquake.

Several wells in the Palmdale-Valyermo area have shown peculiar changes in water level within the past year or so. The long-term hydrograph of well number 5N/12W-4H1 shows the most unusual behavior. The well showed no response to the 1977 and very heavy 1978 rainstorms, yet began to rise in early 1979 and continued to rise through the dry season of 1979. By comparison, most wells show a more normal seasonal response to rainfall. Eight wells in the Palmdale-Valyermo area have shown water-level changes which are different than would have been predicted from the previous history of water-level changes and seasonal rainfall. A longer period of observation is required to determine whether the changes are anomalous. Changes in the strain pattern and other geophysical phenomena have also been observed in southern California during the same period as the water-level changes. If the water-level changes are the result of tectonic strain, the mechanism and significance are unknown. However, it is interesting that five of the eight wells with possibly anomalous water-level changes have been identified as good strain meters based on their response to earth tides. Six wells showing an unexpected rise in water level are located west of the earthquake swarm which occurred in 1976-1977 (McNally et al, 1978), whereas those which show water levels lower than would have been predicted are located east of the earthquake swarm.

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INTRODUCTION

Observations and theory indicate that anomalous water-level changes in wells precede earthquakes (Merifield and Lamar, 1978; Lamar and Merifield, 1979). 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 begun. The present program includes about 35 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 AND PRECIPITATION STATIONS

The wells being monitored are shown on Plate 1 and Figures 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.

To evaluate the effect of rainfall on water levels, daily precipitation data from adjacent rainfall stations are plotted on the hydrographs for each well. Table 2 summarizes data on the precipitation stations now being used, and Plate 1 shows their locations. Figure 10 is an example rainfall data set. Computer programs have been written which will plot daily rainfall on individual well hydrographs from the closest precipitation station; if the well is located between stations, the daily rainfall at the well is derived from a combination of adjacent stations. Figure 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 and notations on individual hydrographs indicate the most recent month for which rainfall data were available at each station.

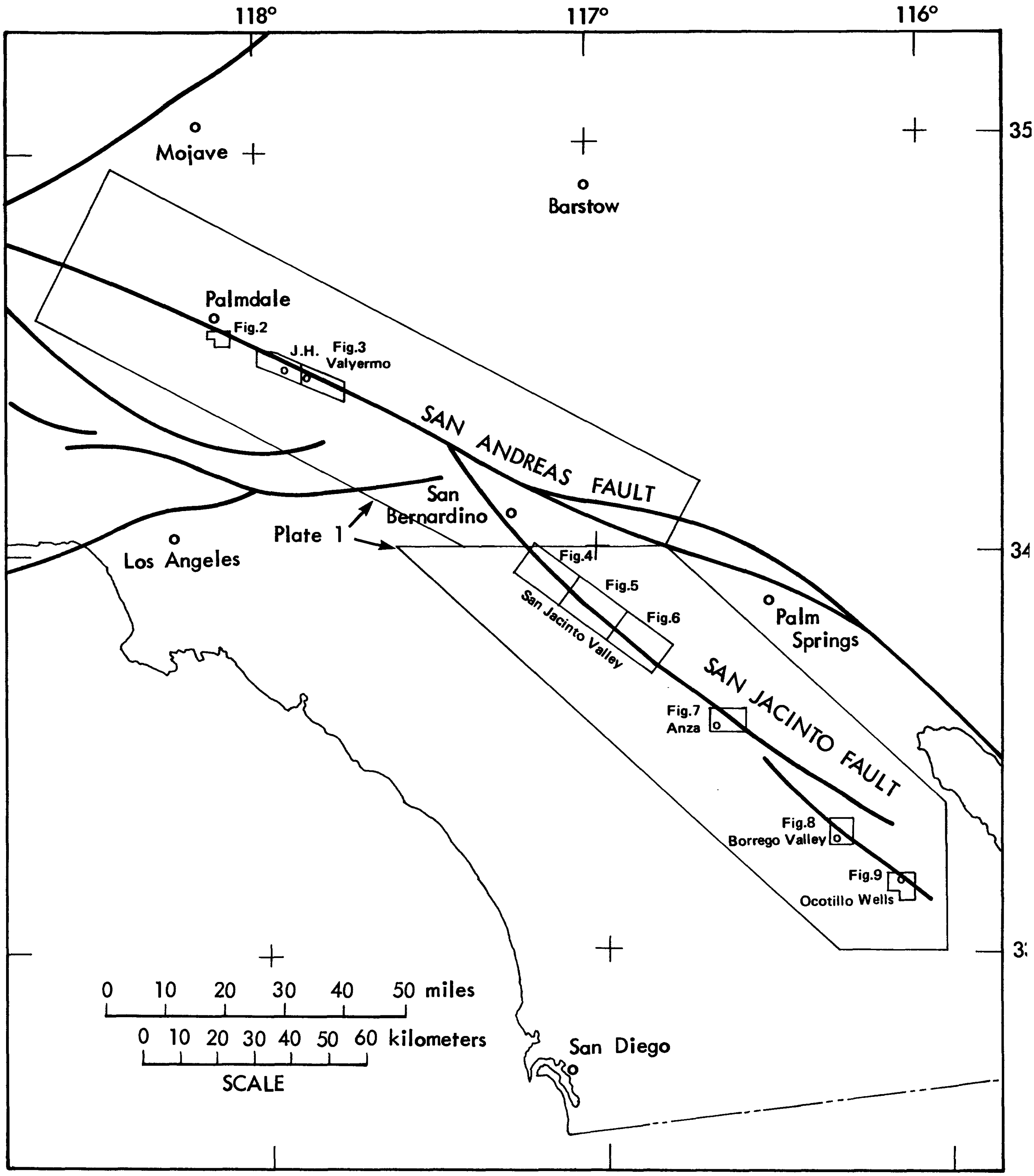

Fig. 1 - Index map showing locations of detailed maps (Figs. 2-9) of observation wells along San Andreas and San Jacinto faults and area of earthquake coverage (Plate 1).

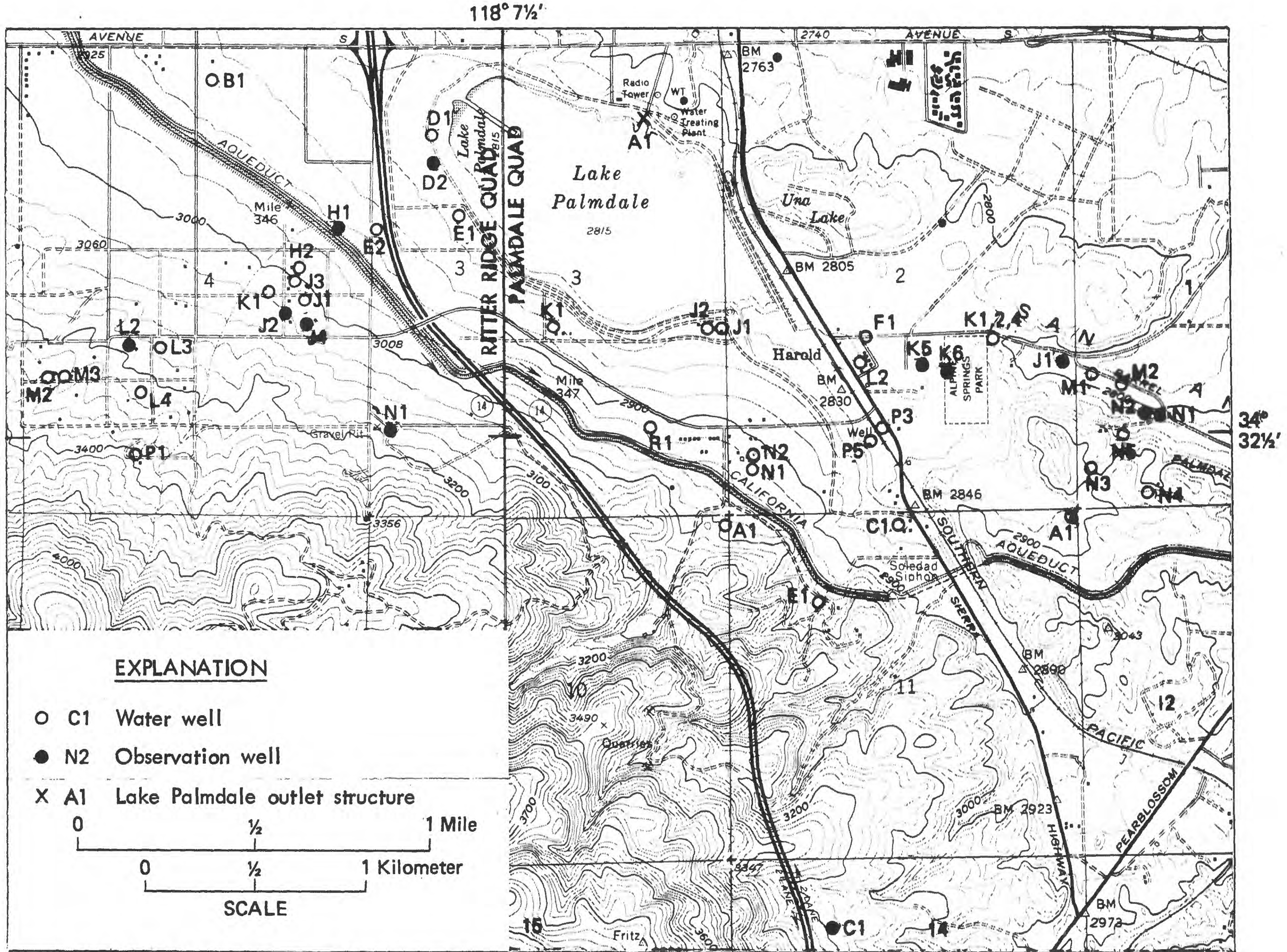

Fig. 2 - Map showing location of water and observation wells along San Andreas fault zone directly south of Palmdale. Topography from U.S. Geological Survey, Palmdale and Ritter Ridge quadrangles. All wells are located in Township 5 North, Range 12 West.

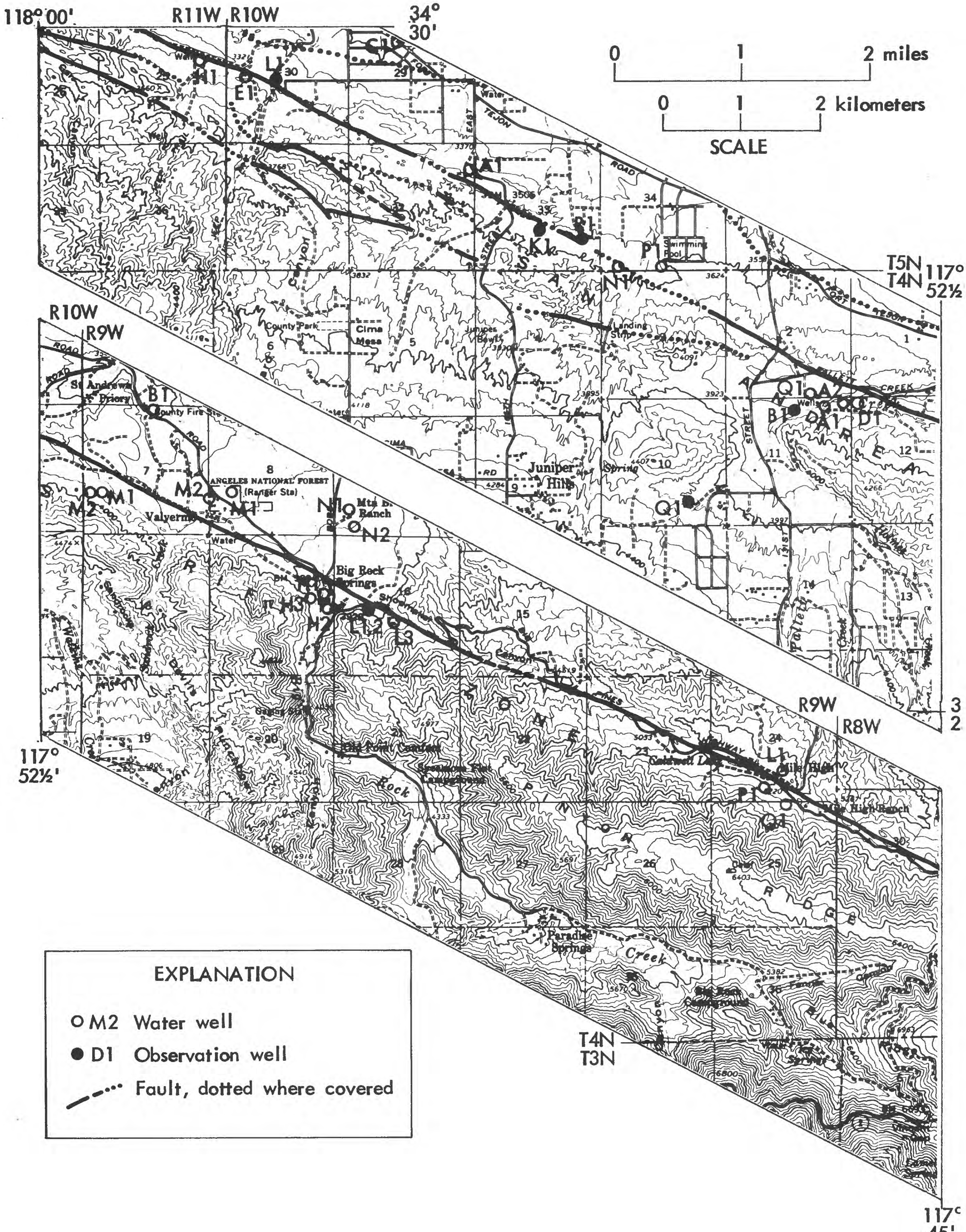

Fig. 3 - Map showing location of water and observation wells along San Andreas fault in Valyermo area. Topography from U.S. Geological Survey, 1 inch = 1 mile, Valyermo Quadrangle. Fault locations from Koehler (1966).

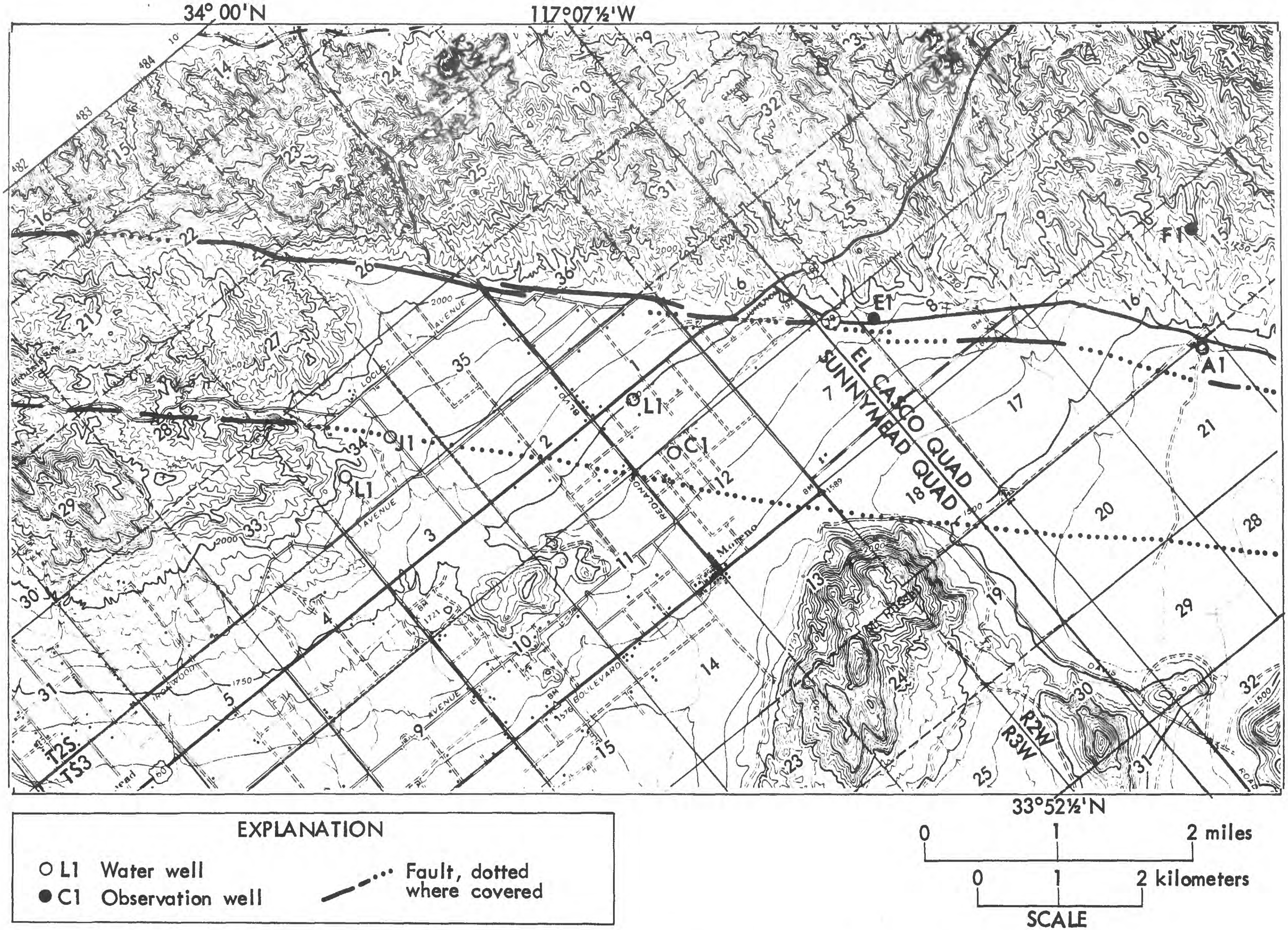

Fig. 4 - Map showing location of water and observation wells along San Jacinto fault zone at north end of San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Perris Quadrangle. Faults from Sharp (1972) and Rogers (1965).

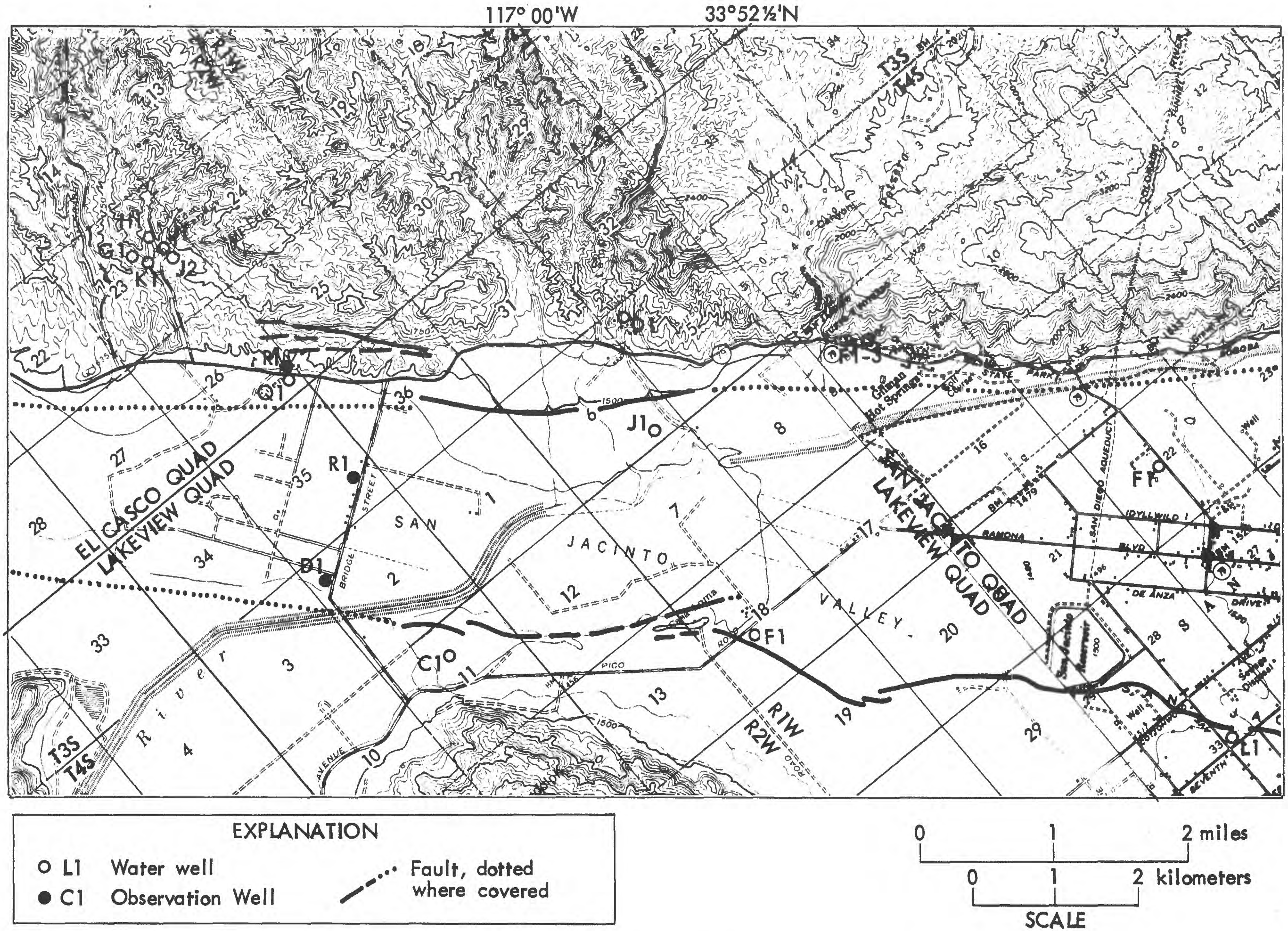

Fig. 5 - Map showing location of water and observation wells along San Jacinto fault zone in central San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Perris and Banning Quadrangles. Faults from Sharp (1972) and Rogers (1965).

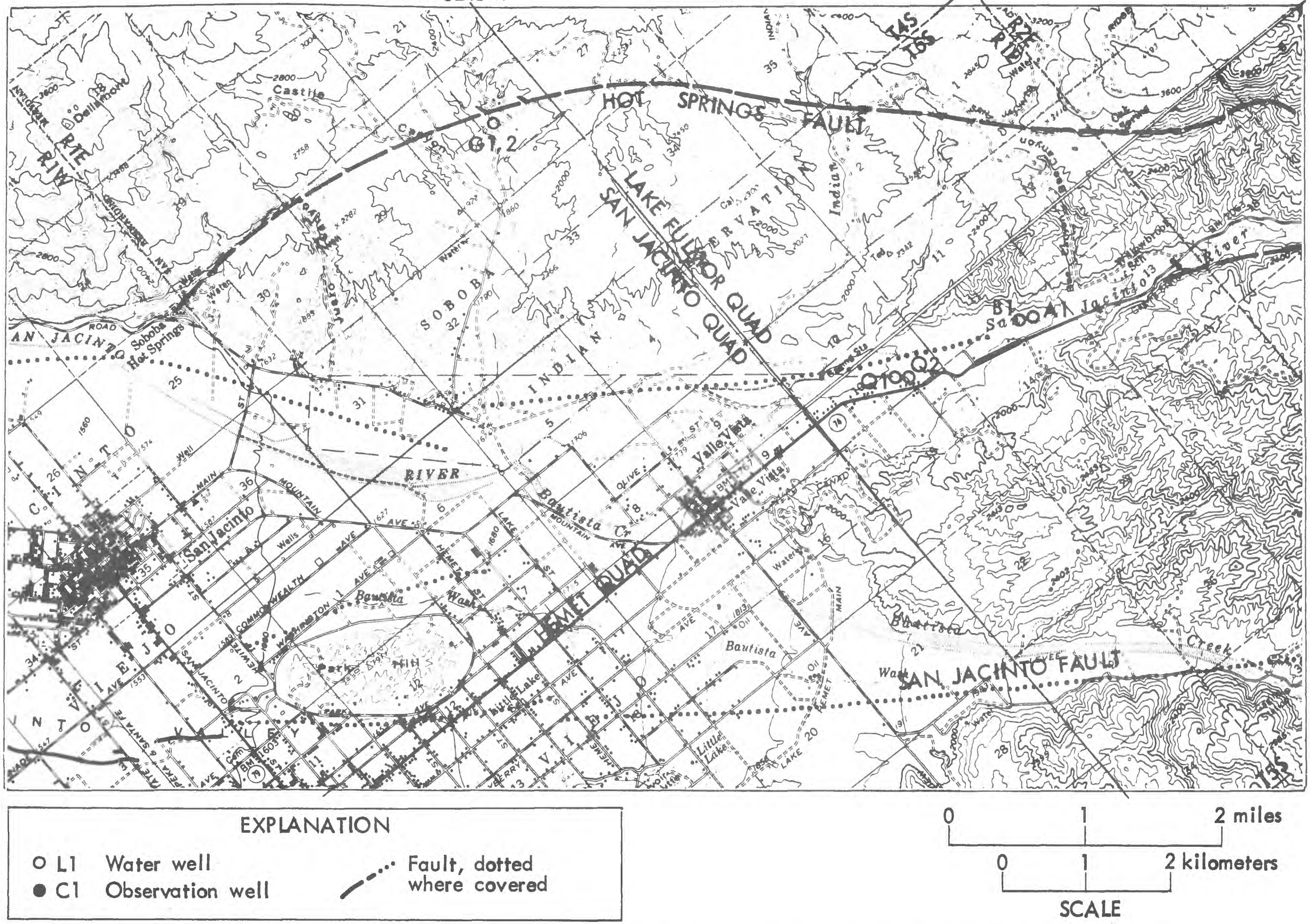

Fig. 6 - Map showing location of water and observation wells along San Jacinto fault zone at south end of San Jacinto Valley. Topography from U.S. Geological Survey, 1 inch = 1 mile, Banning and Hemet Quadrangles. Faults from Sharp (1972) and Rogers (1965).

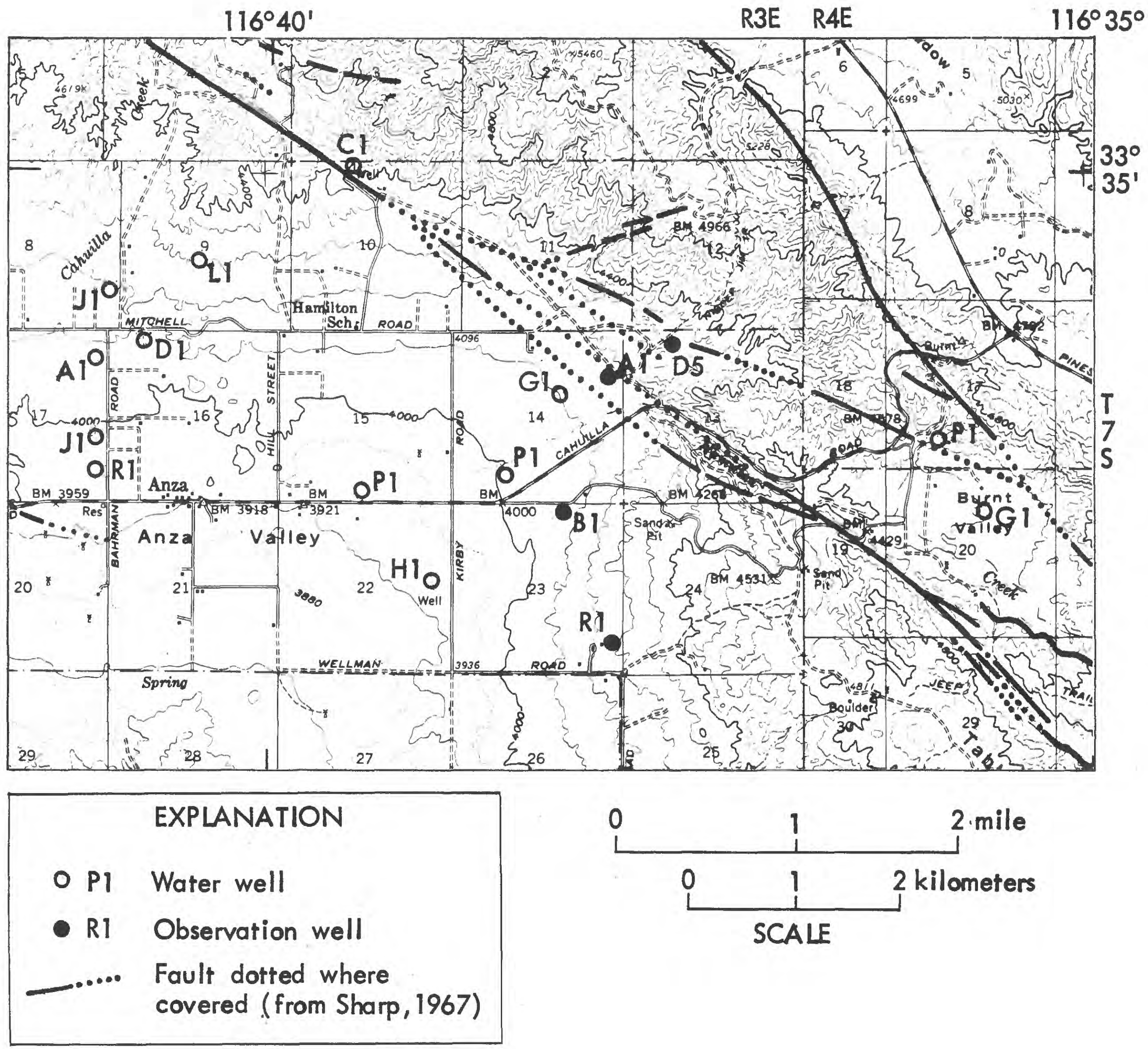

Fig. 7 - Map showing location of water and observation wells along San Jacinto fault zone in Anza area. Topography from U.S. Geological Survey, 1 inch = 1 mile, Idyllwild Quadrangle.

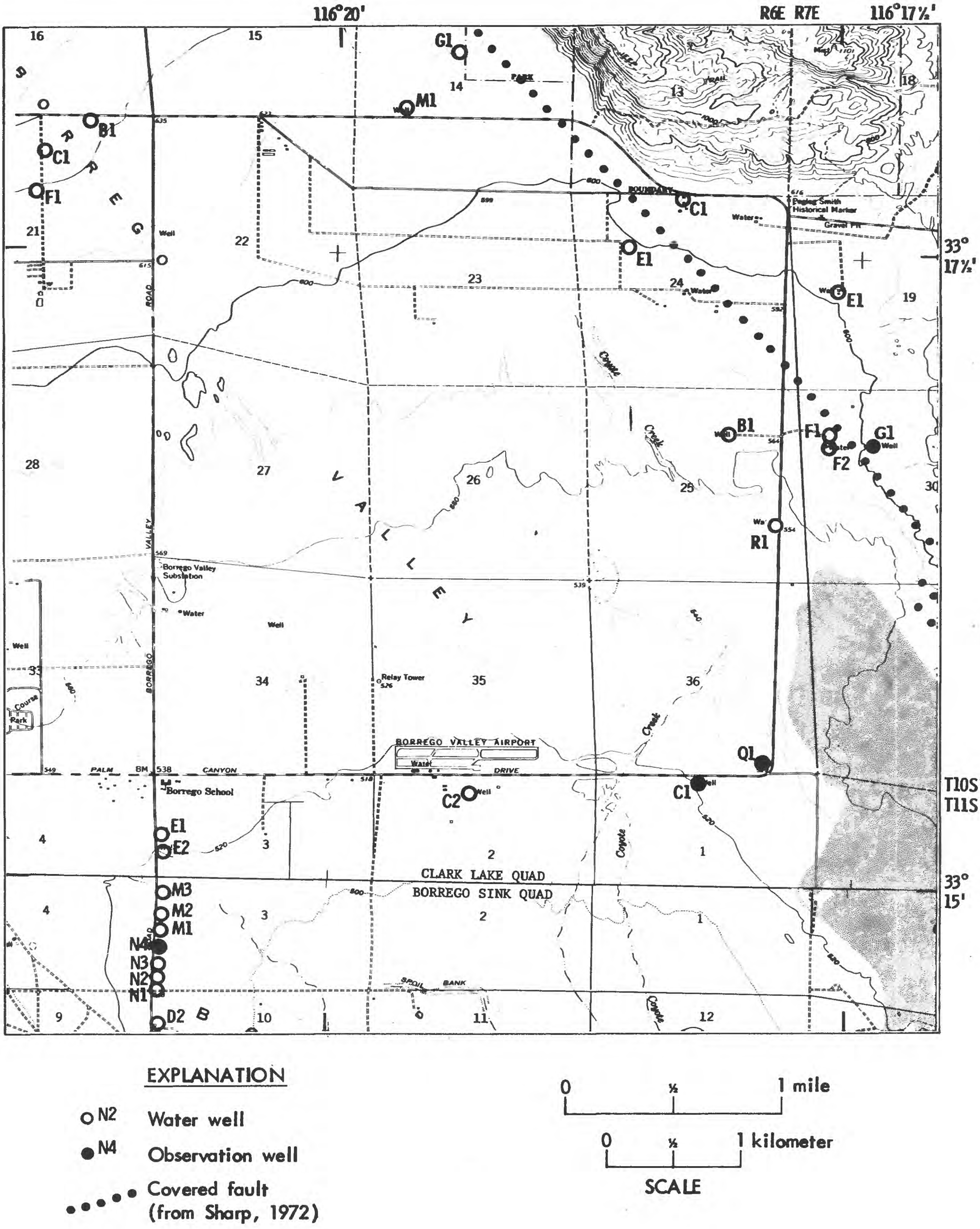

Fig. 8 - Map showing location of water and observation wells along Coyote Creek fault in Borrego Valley. Topography from U.S. Geological Survey, 1 inch = 2000 feet, Clark Lake and Borrego Sink Quadrangles.

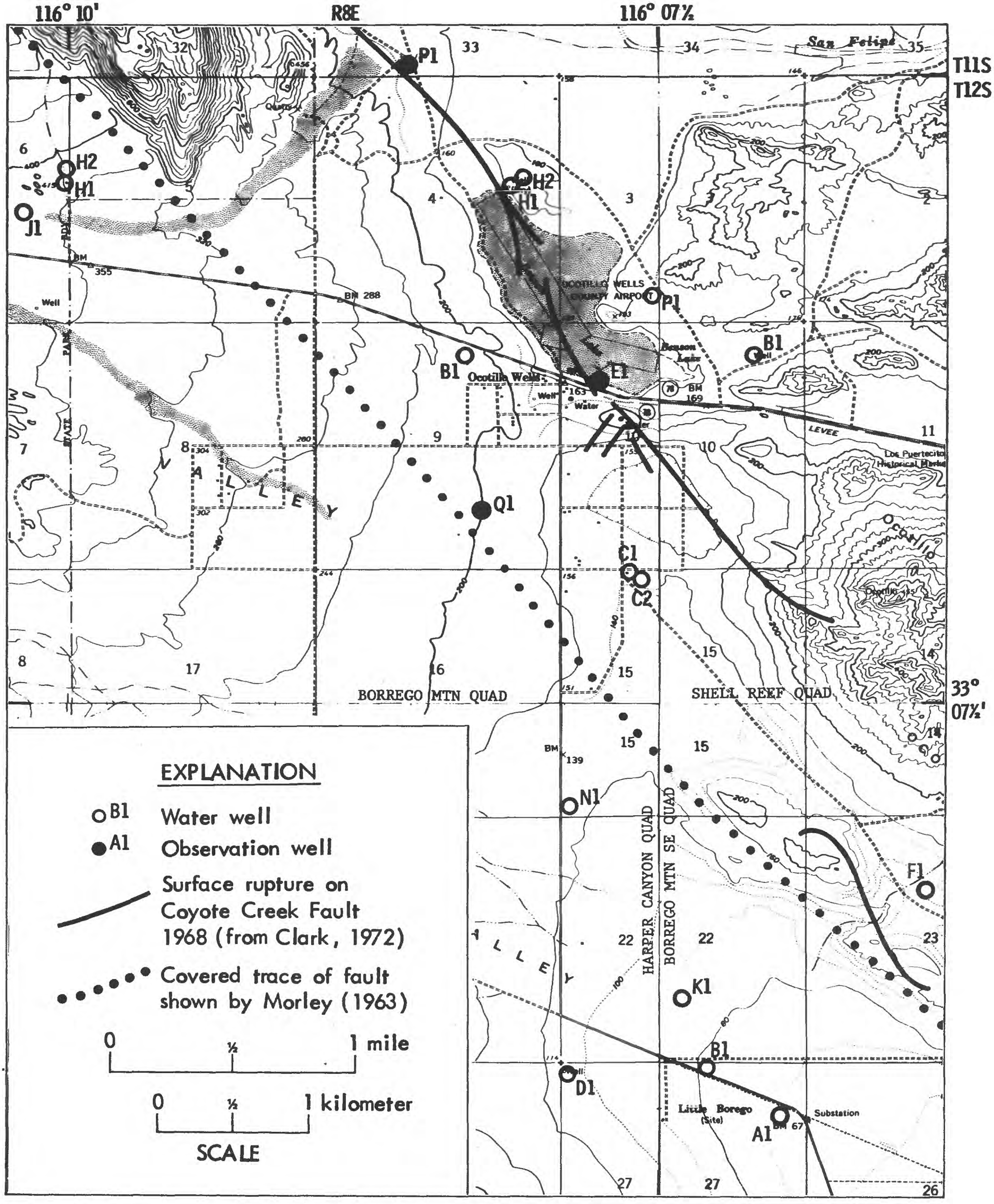

Fig. 9 - Map showing location of water and observation wells along San Jacinto fault zone in Ocotillo Wells area. Topography from U.S. Geological Survey, 1 inch = 2000 feet, Borrego Mountain, Shell Reef, Harper Canyon and Borrego Mountain SE Quadrangles.

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

State Well Number: See Merifield and Lamar (1978) for data on all water wells described on this project (locations shown on Figs. 2-9). 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). An asterisk following well number indicates well being monitored by continuous recorders maintained by W. R. Moyle, Jr., U.S. Geological Survey.

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 "±" 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 PSJH04L

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	"
<u>Anza Area</u>								
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	"
<u>Borrego Valley Area</u>								
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/7E-								
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	1.0 PSPM06H
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 currently obtained directly from individual at station; B: data obtained from LACFCD; C: NOAA, Climatological Data. The most recent month 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/Jan'80
PSRR11M	T6N,R13W	34°37.38'	118°13.91'	2880	LACFCD No. 722C, Belleview	B/Dec'79
PSPA19N	T6N,R12W	34°35.28'	118°5.58'	2598	LACFCD No. 1058B-E, Palmdale Ir.Dist.Hq.	B/Feb'80
PSPM24L	T5N,R12W	34°29.53'	118°5.47'	3520	LACFCD No. 1063, Soledad Pass	B/Feb'80
PSLR12G	T5N,R11W	34°32.20'	117°58.72'	2800	LACFCD No. 299F, Little Rock-Schwab	B/Nov'79
PSJH04L	T4N,R10W	34°27.67'	117°55.85'	3960	LACFCD No. 460C, Pleasant View Mesa	B/Sept'79
PSJH19E	T4N,R10W	34°25.03'	117°58.22'	4000	LACFCD No. 1060B, Little Rock-Sycamore Camp	B/April'79

Table 2 (continued)

Number	Township	Latitude(N)	Longitude(W)	Elevation (ft.)	Description	Notes
PSJH24E	T4N,R10W	$34^{\circ}25.20'$	$117^{\circ}53.18'$	4615	LACFCD No. 517B, Lewis Ranch	B/Dec'79
PSVY19K	T4N,R10W	$34^{\circ}24.80'$	$117^{\circ}51.42'$	4760	LACFCD No. 1111C, Devil's Punch Bowl	B/Jan'80
PSVY28M	T5N,R9W	$34^{\circ}29.22'$	$117^{\circ}50.03'$	3390	LACFCD No. 564C, Llano	B/Feb'80
San Jacinto Fault, San Jacinto Valley, Anza, Borrego Springs, Ocotillo Wells Area						
PSSJ35D	T4S,R1W	$33^{\circ}47.20'$	$116^{\circ}57.50'$	1560	California Division of Forestry Fire Station, San Jacinto	C/Nov'79
PSID16Q	T7S,R3E	$33^{\circ}33.30'$	$116^{\circ}40.48'$	3920	California Division of Forestry Fire Station, Anza	A/Feb'80
PSID23R	T7S,R3E	$33^{\circ}32.59'$	$116^{\circ}37.85'$	4200	Jack McGehee, 39775 Terwilleger Road, Star Route, Anza	A/Mar'80
PSBP01A	T10S,R5E	$33^{\circ}15.36'$	$116^{\circ}24.12'$	810	California State Park Headquarters, Borrego Springs	A/Feb'80
PSBM06H	T12S,R8E	$33^{\circ}9.35'$	$116^{\circ}10.04'$	390	California State Park Ranger Residence, Ocotillo Wells	A/Feb 14'80

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.

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 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 understood. The duration of such changes may be proportional to the magnitude of the earthquakes (Scholz *et al*, 1973). Thus, it is essential to our research to have records of both short-term and long-term variations.

Continuous recorders which measure short-term fluctuations have been installed on most of the suitable wells to determine their response to atmospheric pressure and tidal forces and, therefore, their sensitivity as strain meters (Bredehoeft, 1967; Bodvarsson, 1970). Those wells identified as good strain meters and which have not shown large response from rainfall or local pumping are most likely to detect tectonic strain or earthquake precursors. Thus, in the future the available continuous recorders will be operated almost exclusively on such wells. A computer program generates long-term hydrographs for each well from the data set on disk. Data for most of the wells are obtained on a weekly basis, either by probing or by reading average values from the continuous recorder charts. For the past few months, depths have been obtained almost every day from the new digital gauge mounted on well No. 5N/12W-4J2 (described below), and water depth for some other wells is only probed once or twice a month. Rainfall data are also plotted on the same computer-generated figures for direct comparison with water levels.

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

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

wide geographic area. Each volunteer probes the depth in one 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). However, we believe that the effectiveness of the volunteers will be improved by use of the new gauge described below.

Digital Water-Level Gauge

We have obtained a digital water-level gauge from Dr. Yasue Oki of the Hot Spring Research Institute, Hakone, Kanagawa, Japan. 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 extensive program of earthquake prediction by water-level monitoring (Oki and Hiraga, 1978, 1979). The disadvantage of this device is that a gear train is present between the pulley and counter so that a fairly large torque is required for operation. To overcome this difficulty and to simplify construction, we have designed and built a digital counter without gears (Fig. 12). Similar to the gauge designed by Oki and the Stevens water-level recorder, our device is activated by a cable attached to a float and counterweight which passes over a pulley. The circumference of the pulley is exactly 1 foot; thus each revolution of the pulley changes the reading on the digital counter by 1 foot. Fractions of a foot are read opposite a pointer to 0.01 foot on a circular scale mounted directly on the pulley. A prototype of this device has been operating satisfactorily on well 5N/12W-4J2 in Palmdale since December 28, 1979. The property owner has been taking readings almost every day and the gauge has greatly simplified the measurement of water level. Because of difficulties in obtaining frequent and reliable observations from some observers, it is planned to build and install more of these gauges on appropriate water wells conveniently located to volunteers. The other methods and equipment used for water-level measurement have been described previously (Merifield and Lamar, 1978).

LONG-TERM WATER-LEVEL CHANGES

Previous reports have presented hydrographs which show water-level

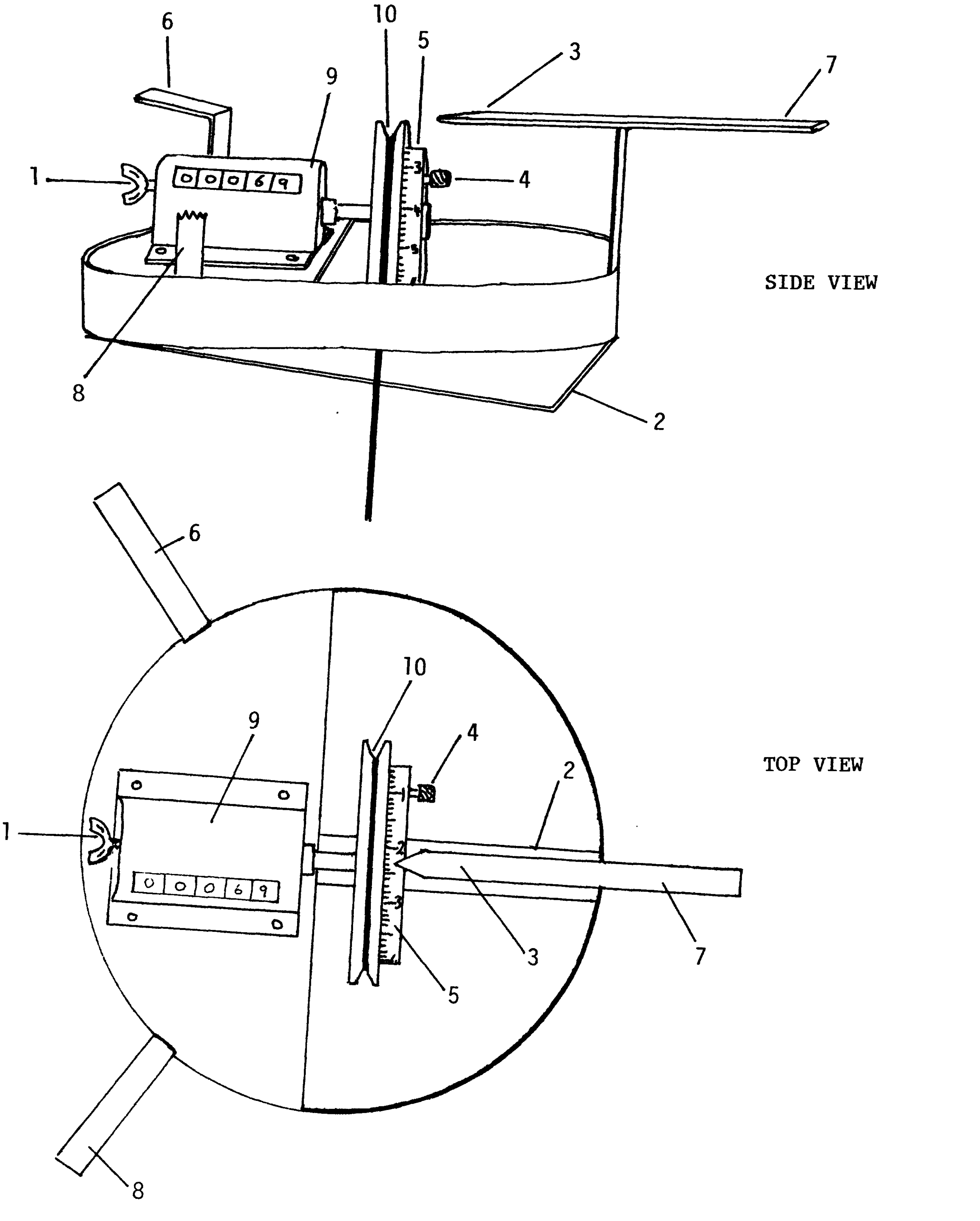

Fig. 12 - Experimental digital water-level probe.

Explanation; 1. Reset screw for digital counter; 2. Bar to prevent losing cable, float and counterweight down well; 3. Pointer for reading circular scale; 4. Adjustment screw, locks circular scale to pulley; 5. Circular scale in tenths and hundredths of foot; 6, 7, 8. Brackets to support device on well casing; 9. Digital counter, 1 digit or 1 foot per revolution; 10. Pulley with cable attached to float and counterweight.

changes for one year on a single hydrograph. Because interpretation of the relationship between seasonal water-level changes and rainfall and recognition of possible anomalies requires consideration of the changes over as many seasons as possible, the format of the hydrographs has been modified to show water-level changes and rainfall since our monitoring began.

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. Figures 13 and 14 show that water levels at Lake Palmdale (Location 5N/12W-3A1) and well 5N/12W-3D2 have fluctuated in unison in response to rainfall. 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.

Wells 5N/12W-1N1 (Fig. 15), -1N2 (Fig. 16), -2K6 (Fig. 17) and -2J1 (Fig. 18) are located in the San Andreas fault zone east of Lake Palmdale. Levels in these wells show a distinct annual cycle which appears to be related to the level of Lake Palmdale (Fig. 13) and seasonal rainfall. 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. 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, Water Resources Division Office, Laguna Niguel, California. This well was not monitored from October 1977 until July 25, 1979, when Lamar-Merifield personnel and volunteers began weekly monitoring. As indicated in Figure 19, for the period during which data are available, water levels in -2K5 have shown an annual cycle similar to adjacent wells (Figs. 15-18).

The other Lamar-Merifield observation wells in the Palmdale area are located southwest of Lake Palmdale. During the first year of monitoring, water levels in wells 5N/12W-4L2 (Fig. 20) and -14C1 (Fig. 21) were relatively steady and showed no seasonal variations. Levels began to rise in January 1978 and have shown a clear annual cycle related to rainfall since that time. Levels in well 5N/12W-3N1 (Fig. 22) also show an annual cycle superimposed on a gradual rise in water level. The rise in water

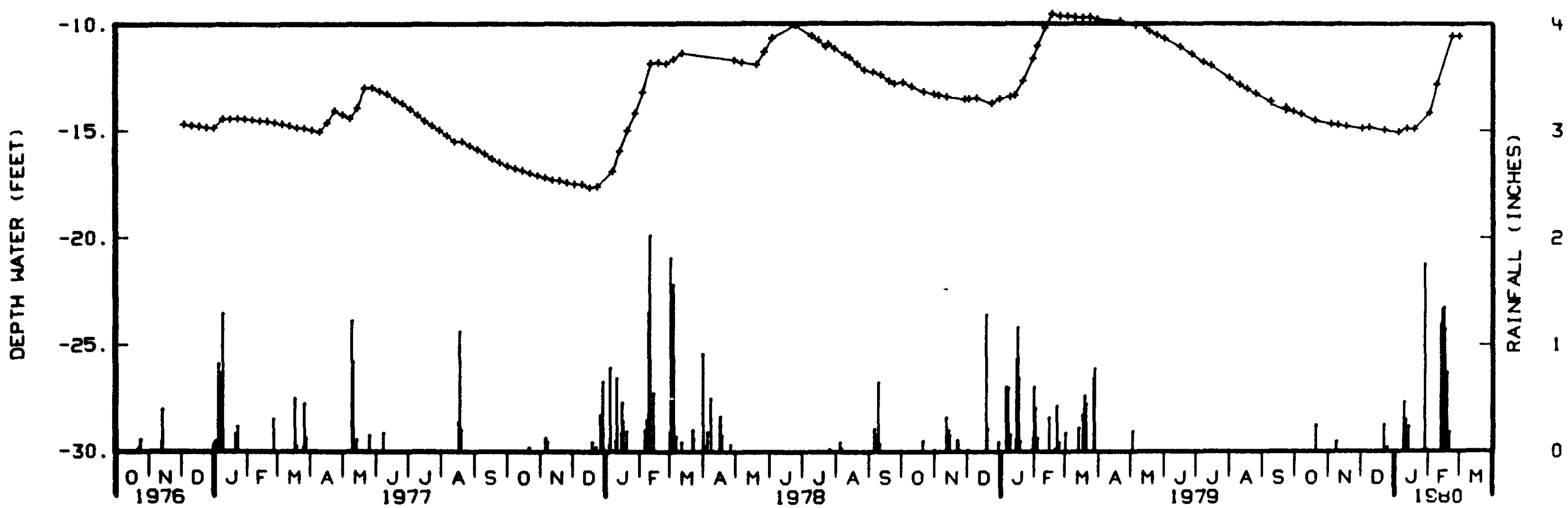

FIGURE 13 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) LAKE PALMDALE, LOCATION: 05N/12W-03A01 DURING 1976-1980, PALMDALE AREA

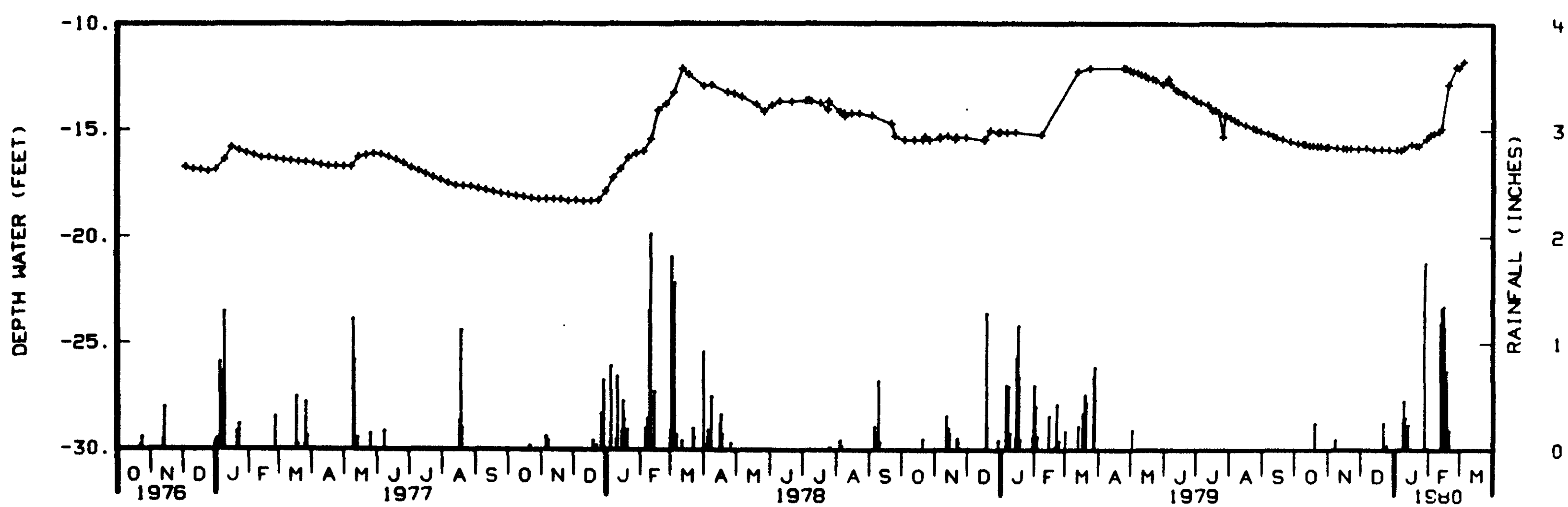

FIGURE 14 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-03D02 DURING 1976-1980, PALMDALE AREA

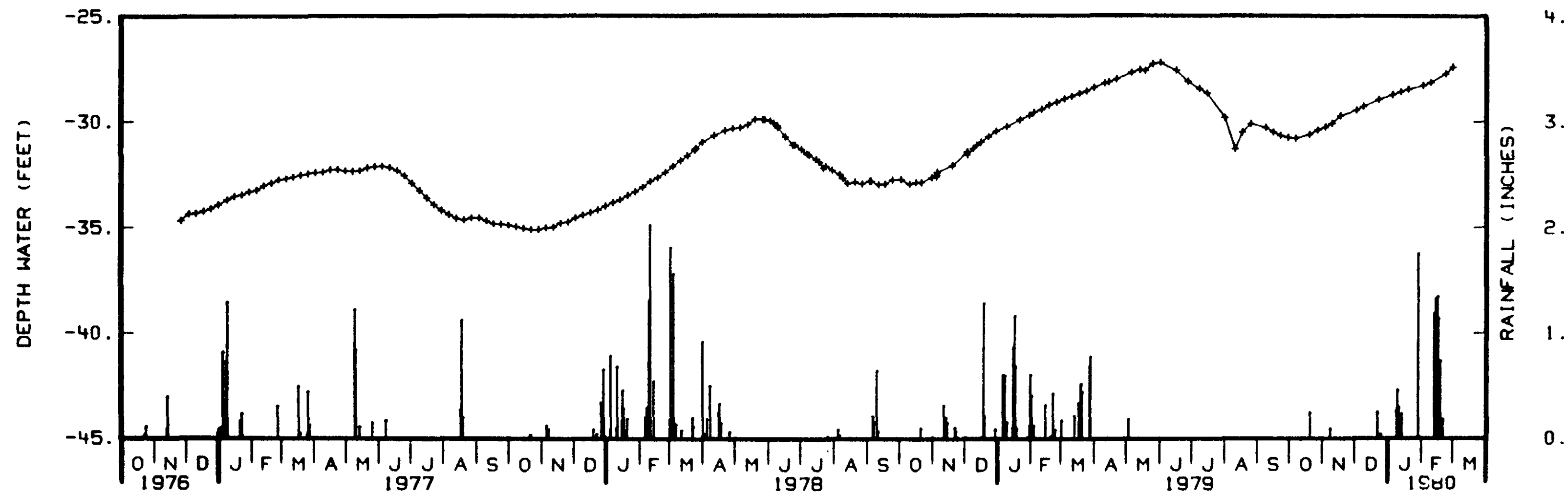

FIGURE 15 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-01N01 DURING 1976-1980, PALMDALE AREA

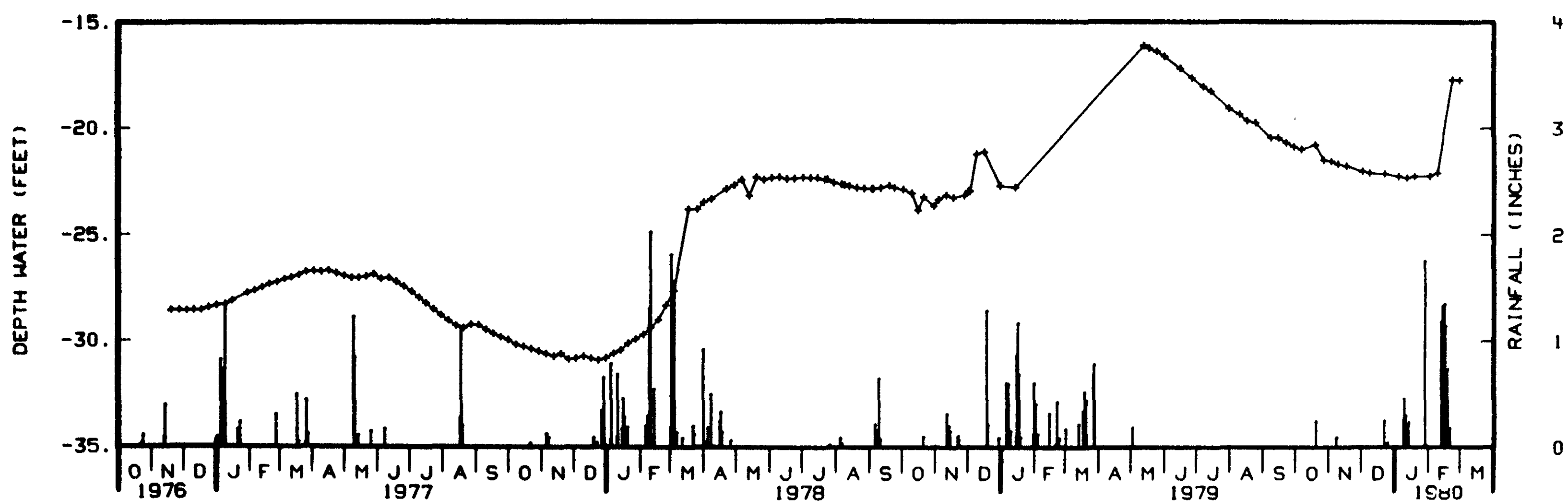

FIGURE 16 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-01N02 DURING 1976-1980, PALMDALE AREA

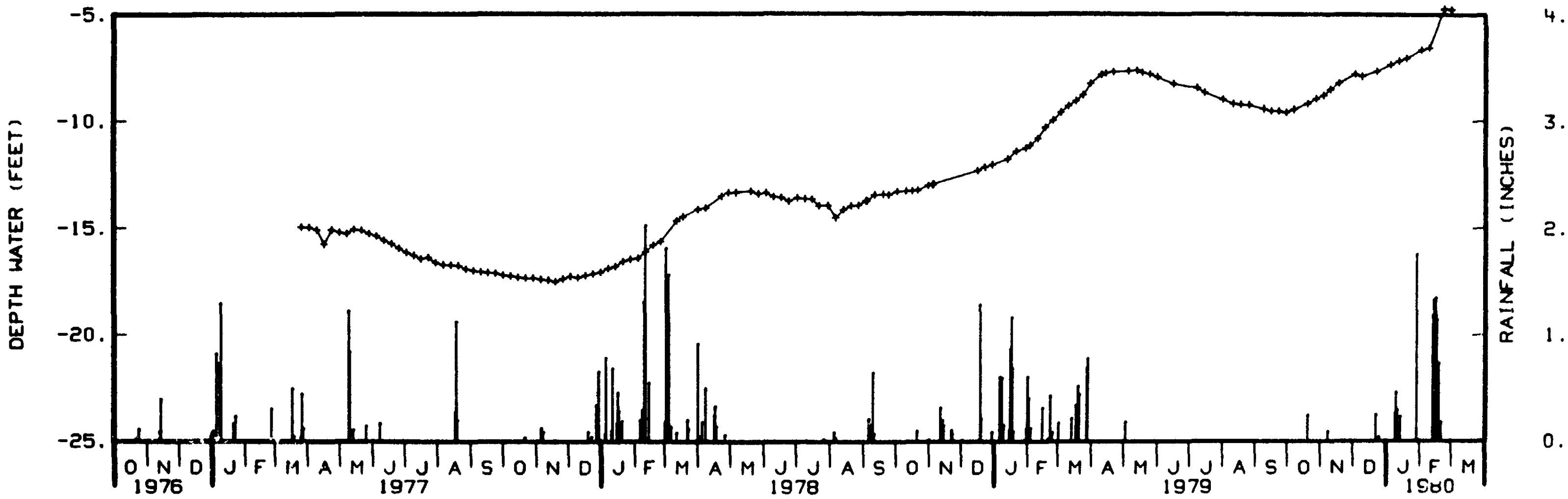

FIGURE 17 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-02K06 DURING 1976-1980, PALMDALE AREA

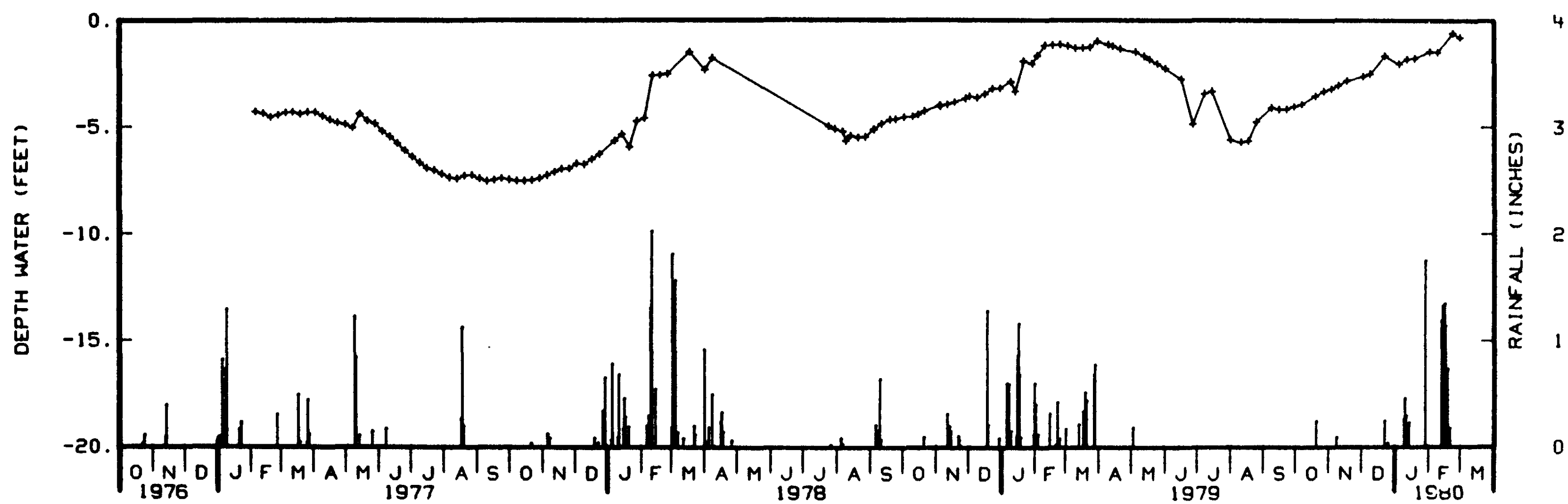

FIGURE 18 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-02J01 DURING 1976-1980, PALMDALE AREA

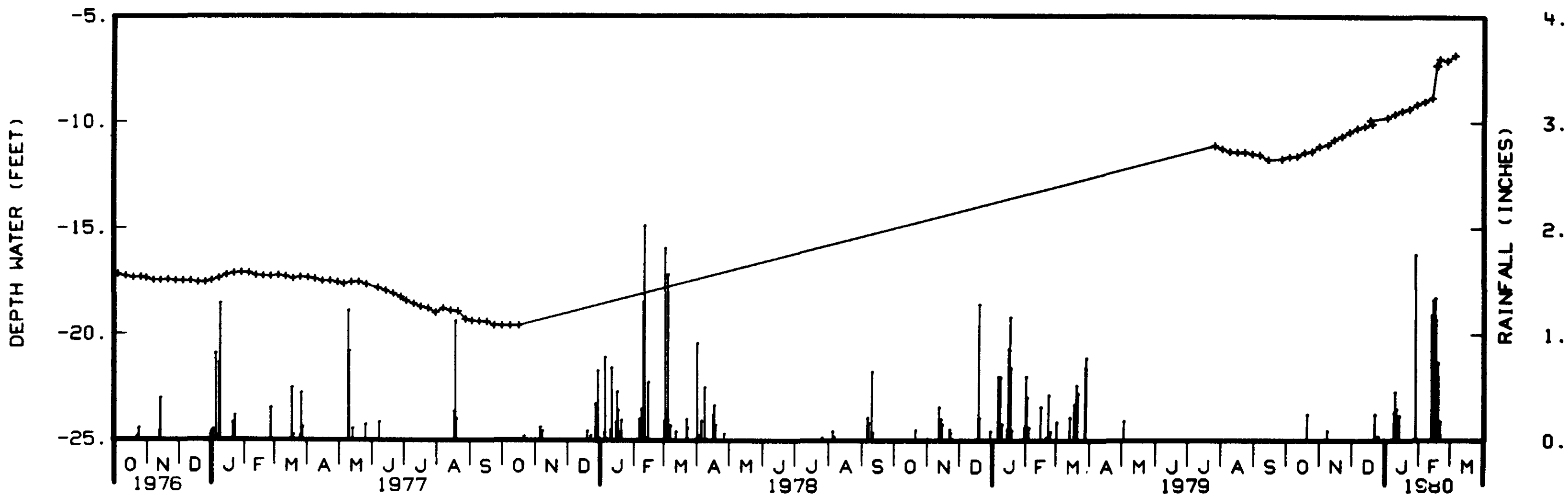

FIGURE 19 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-02K05 DURING 1976-1980, PALMDALE AREA

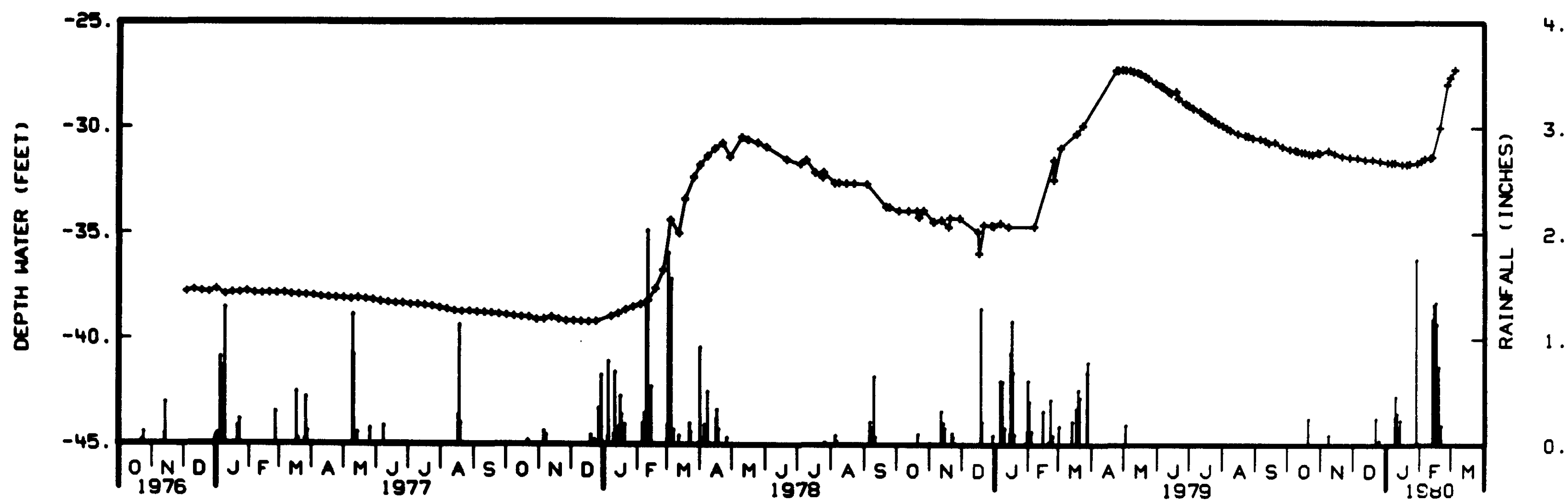

FIGURE 20 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-04L02 DURING 1976-1980, PALMDALE AREA

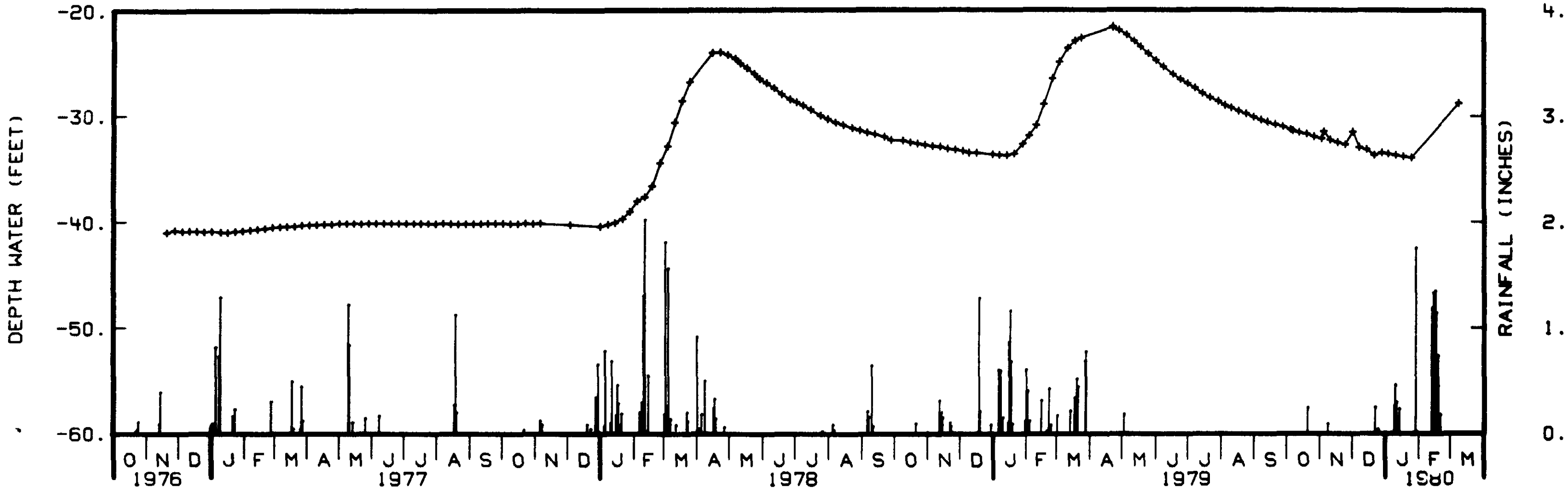

FIGURE 21 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-14C01 DURING 1976-1980, PALMDALE AREA

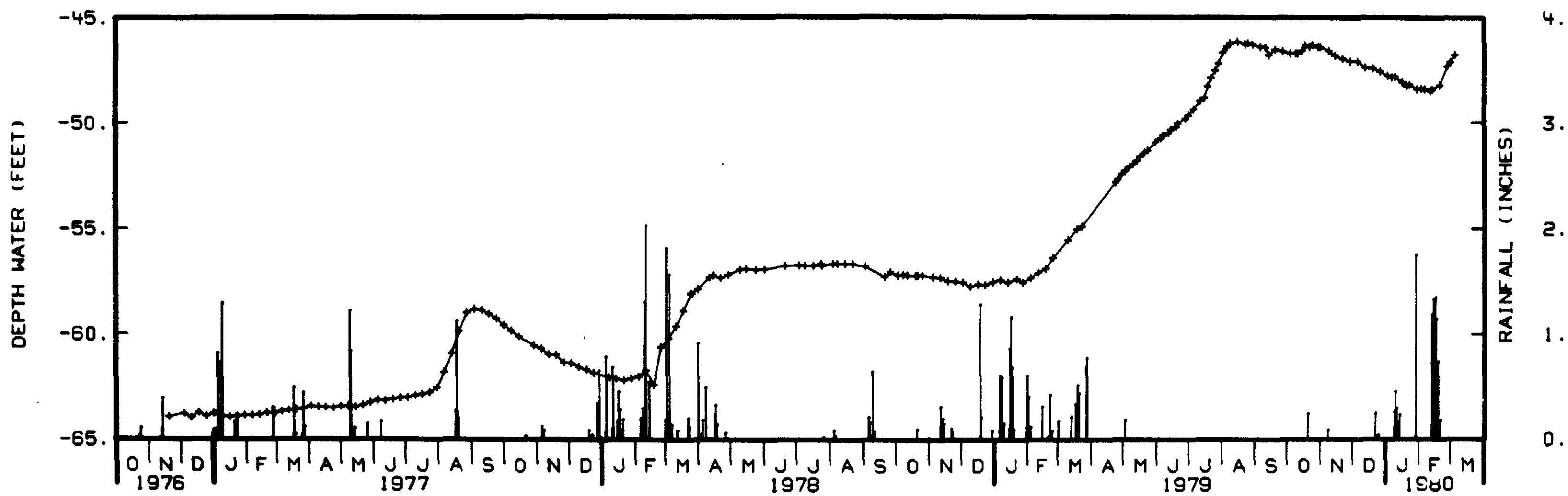

FIGURE 22 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-03N01 DURING 1976-1980, PALMDALE AREA

level between February and July 1979 is considered anomalous as compared to the much smaller rise following the 1977-78 rain season because more rain fell during the 1977-78 season than during the 1978-79 season. Based on the previous history of this well we would have expected water levels to flatten out in April 1979. Water-level variations in wells 5N/12W-4J4 (Fig. 23) and -4J2 (Fig. 24) in the past year could also be considered anomalous. Levels in both wells were fairly steady and showed no response to rainfall during the first year of monitoring; levels rose in response to rainfall during February-March 1978 and were again steady until February 1979, when levels again rose following a period of rainfall. Compared to the previous two years of record, the rises in water level from February to July 1979 in well -4J4 and from February to October 1979 in well -4J2 are larger than expected in view of the higher rainfall in 1978 compared to 1979.

The rise in the levels in well 5N/12W-4H1 (Fig. 25) during the past year is even more puzzling. During the first two years of monitoring, water levels in this well showed no annual cycle and were gradually dropping. However, water levels rose about 18 feet between January 1979 and January 1980; since then they have leveled out.

Two wells in the Palmdale-Littlerock area southeast of Palmdale (Plate 1) currently have Stevens Type F continuous water-level recorders maintained by W. R. Moyle, Jr., of the U.S. Geological Survey. Copies of the recorder charts for these wells have been obtained and average weekly water levels have been read and entered into computer data sets on disk in a procedure similar to that used for our observation wells. Water levels in well 5N/11W-7G2 (Fig. 26) show a remarkably smooth annual cycle with the height of the winter rise proportional to the cumulative seasonal rainfall. In contrast, water levels in well 5N/11W-24G1 (Fig. 27) were relatively steady from October 1976 until June 1978, when they began to rise; the rate of rise increased in March 1979. This rise in water level is unaccountable when compared to the first 1½ years of record for this well.

<u>Juniper Hills-Valyermo Segment of the San Andreas Fault</u>

Water levels in selected wells have been monitored in the Juniper Hills-Valyermo area beginning in October 1977, following reports of

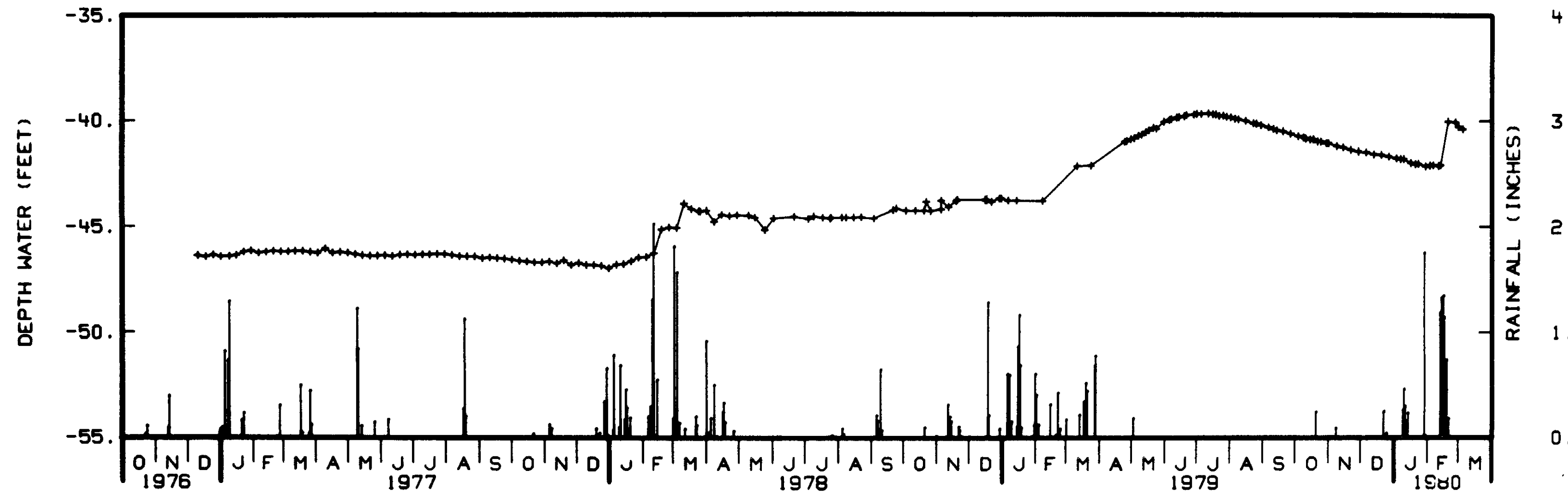

FIGURE 23 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-04J04 DURING 1976-1980, PALMDALE AREA

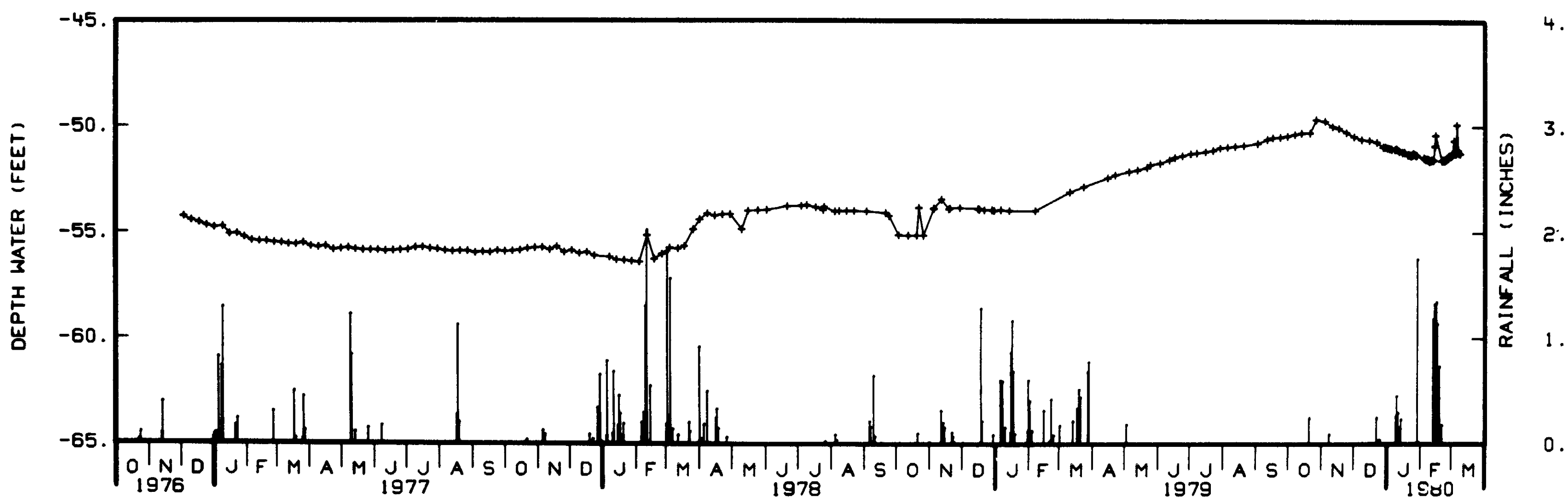

FIGURE 24 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-04J02 DURING 1976-1980, PALMDALE AREA

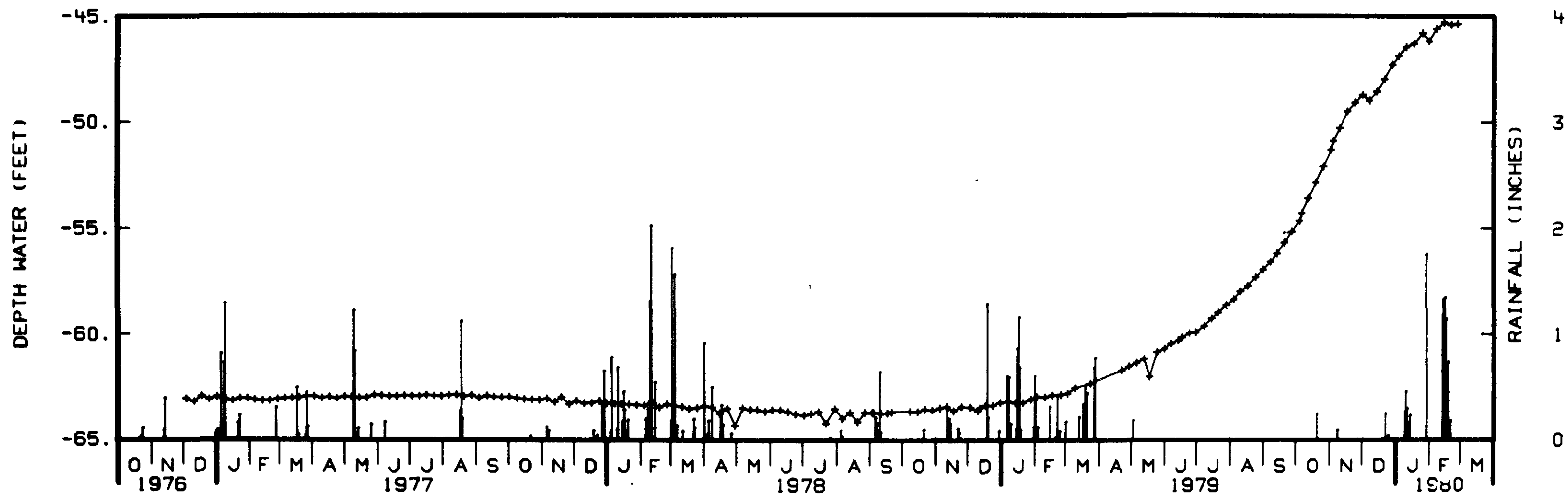

FIGURE 25 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-04H01 DURING 1976-1980, PALMDALE AREA

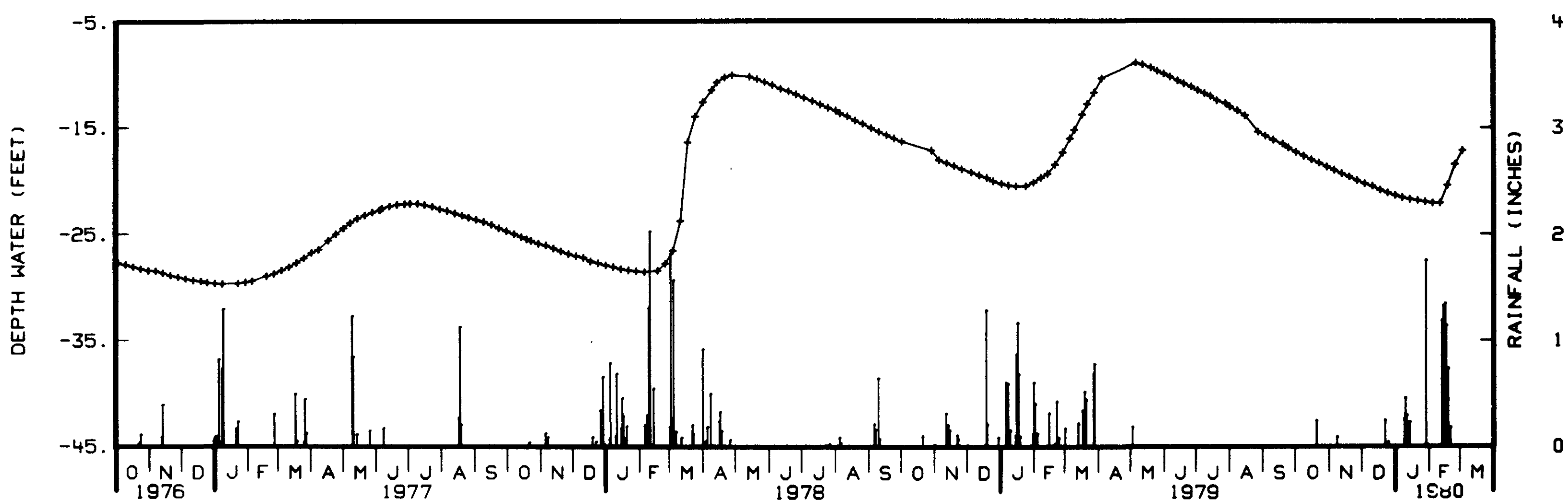

FIGURE 26 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/11W-07G02 DURING 1976-1980, PALMDALE AREA

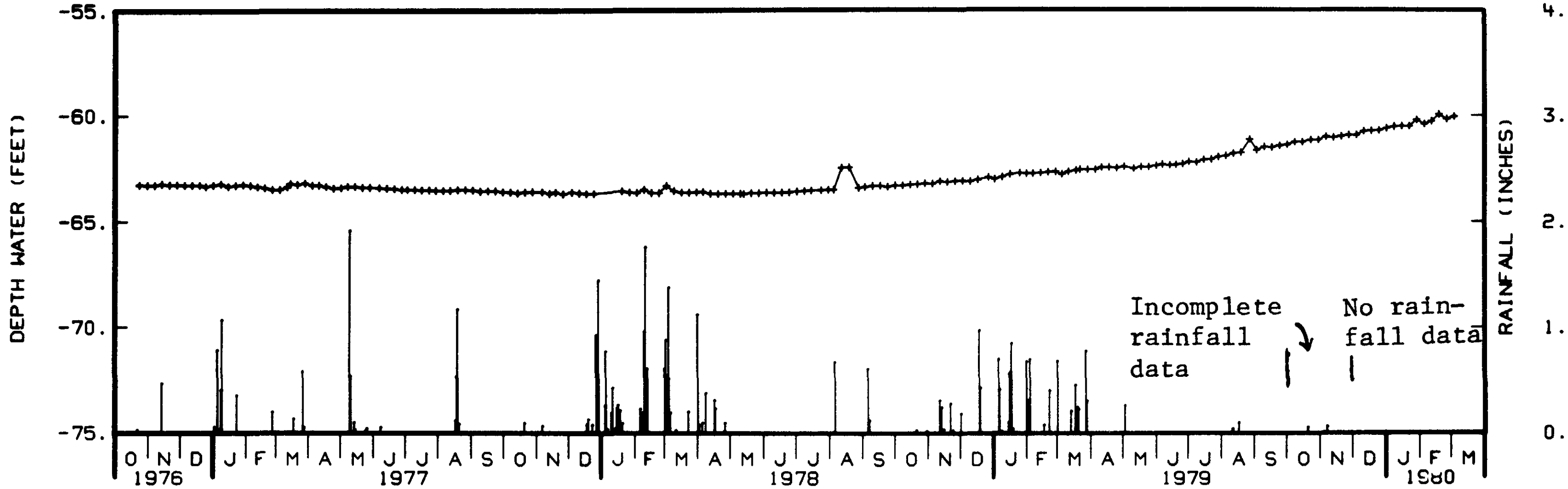

FIGURE 27 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/11W-24G01 DURING 1976-1980, PALMDALE AREA

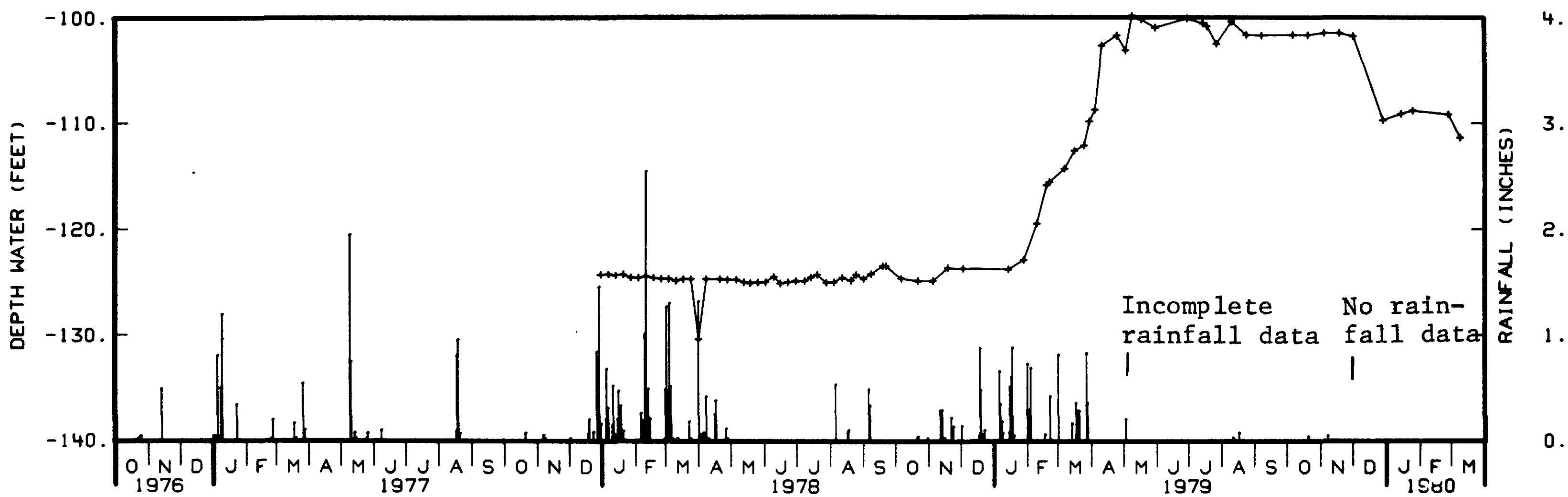

FIGURE 28 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/10W-30L01 DURING 1976-1980, VALYERMO AREA

unusual seismic 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). Figures 28 to 33 show the hydrographs of these wells.

Water levels in well 5N/12W-30L1 (Fig. 28) at the northwest end of the Juniper Hills-Valyermo segment of the San Andreas fault were relatively steady from December 1977 until January 1979. The water rose abruptly about 24 feet by April 1979 and remained at about that level until December 1979, at which time it dropped abruptly to a new level about 10 feet lower. The rise in January 1979 may have been a one-year delayed response to the 1978 rains. If so, a similar abrupt rise in response to the 1979 rains would be expected beginning in about January 1980, but such is not the case. Based on the two-year hydrograph, therefore, a clear causal relation between rainfall and water level cannot be established for this well.

Two wells, 5N/10W-33K1 and -33R1, lie within the San Andreas rift zone in the Juniper Hills area (Fig. 3). These wells have shown no clear response to rainfall and no systematic seasonal variation (Figs. 29 and 30). Apparent anomalous fluctuations of up to about 1 foot in March of 1979 were discussed in Lamar and Merifield, 1979; these are believed to be erroneous measurements made by a new volunteer. No anomalous water-level changes have occurred during the current reporting period.

Water levels in well 4N/10W-11B1 have shown an annual cycle with lows in January of 1978, 1979 and 1980 (Fig. 31). No anomalous behavior is indicated. Levels in well 4N/9W-16L1, on the other hand, have shown curious behavior (Fig. 32). The water level began rising before the rainy season in late 1977. It rose throughout 1978, then settled back to a depth of around 75 feet during most of 1979 before beginning to rise again in late December. If the rise during 1978 was in response to the rains of early 1978, there was no similar response to the rains in early 1979. Levels in well 4N/10W-10Q1 have shown similar behavior, with a sharp rise during 1978 and a relatively steady record since then (Fig. 33).

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. Wells in Anza and San Jacinto Valley were added to the program a few months later. The water level in well 3S/2W-8E1 has risen steadily since mid-1978 (Fig. 34)

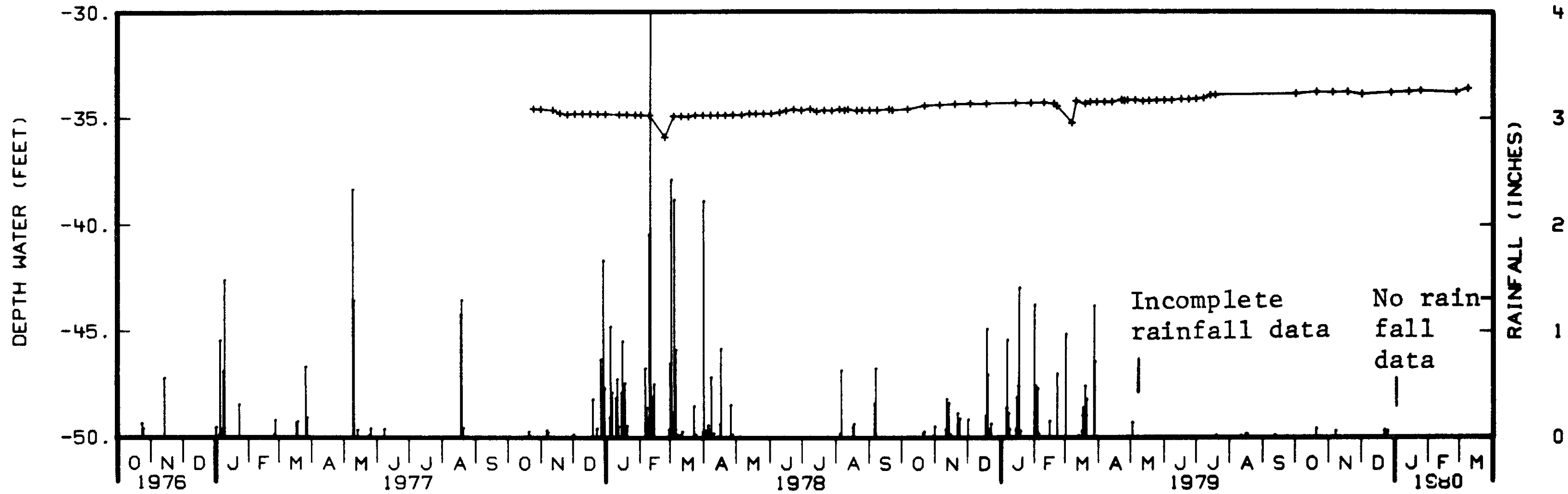

FIGURE 29 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/10W-33K01 DURING 1976-1980, VALYERMO AREA

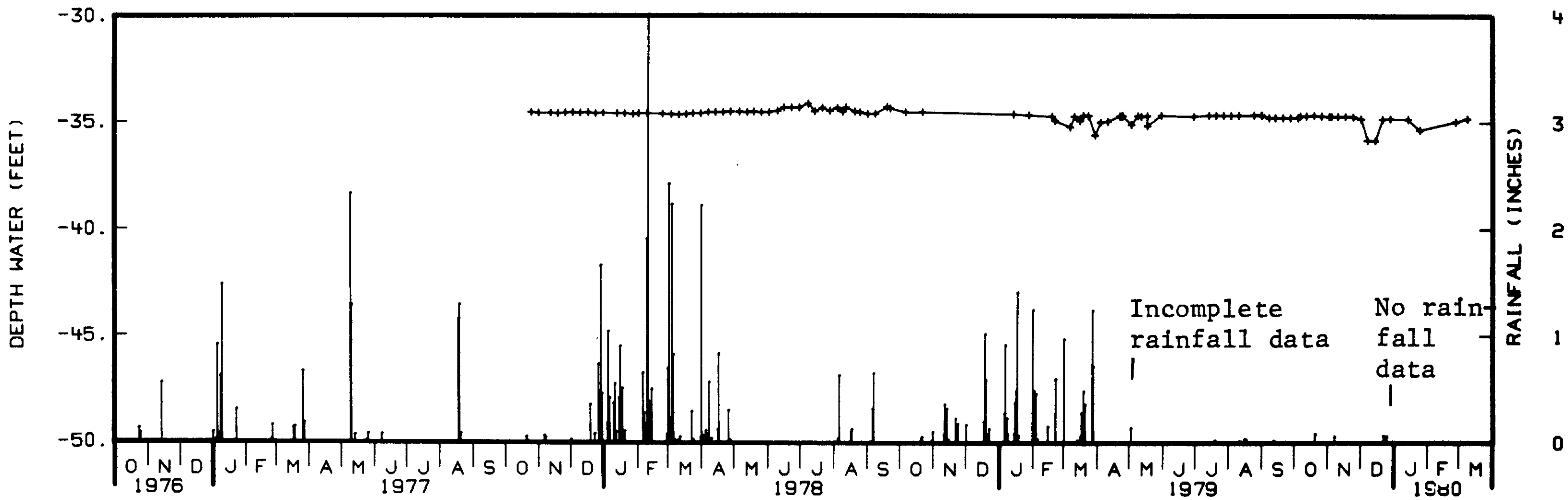

FIGURE 30 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/10W-33R01 DURING 1976-1980, VALYERMO AREA

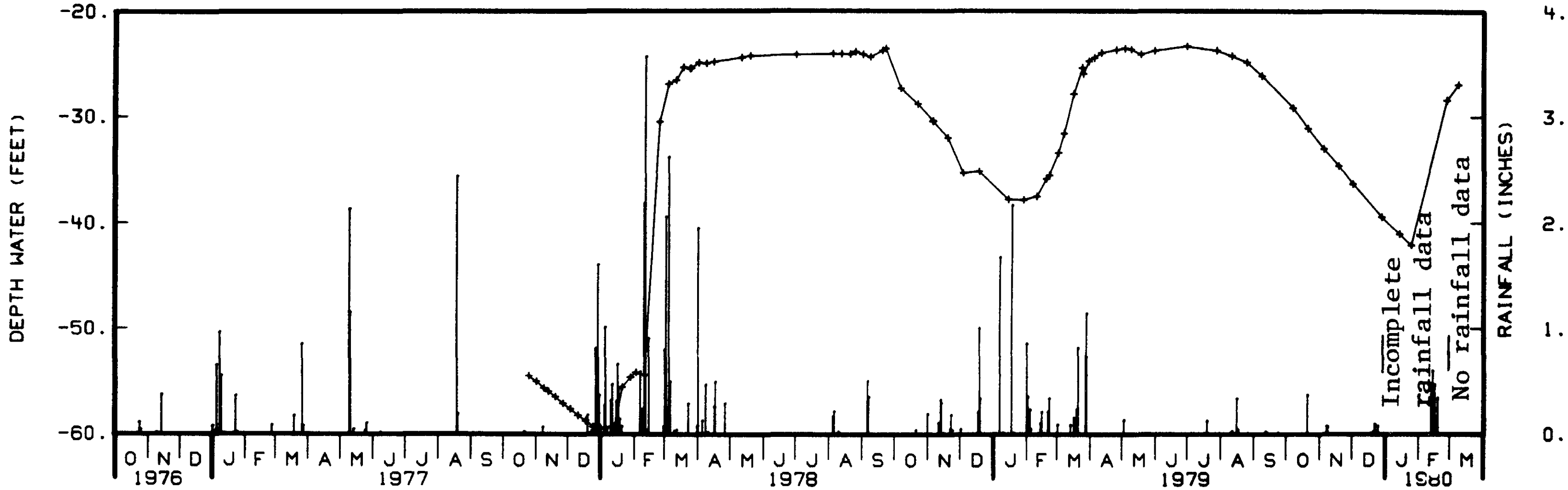

FIGURE 31 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 04N/10W-11B01 DURING 1976-1980, VALYERMO AREA

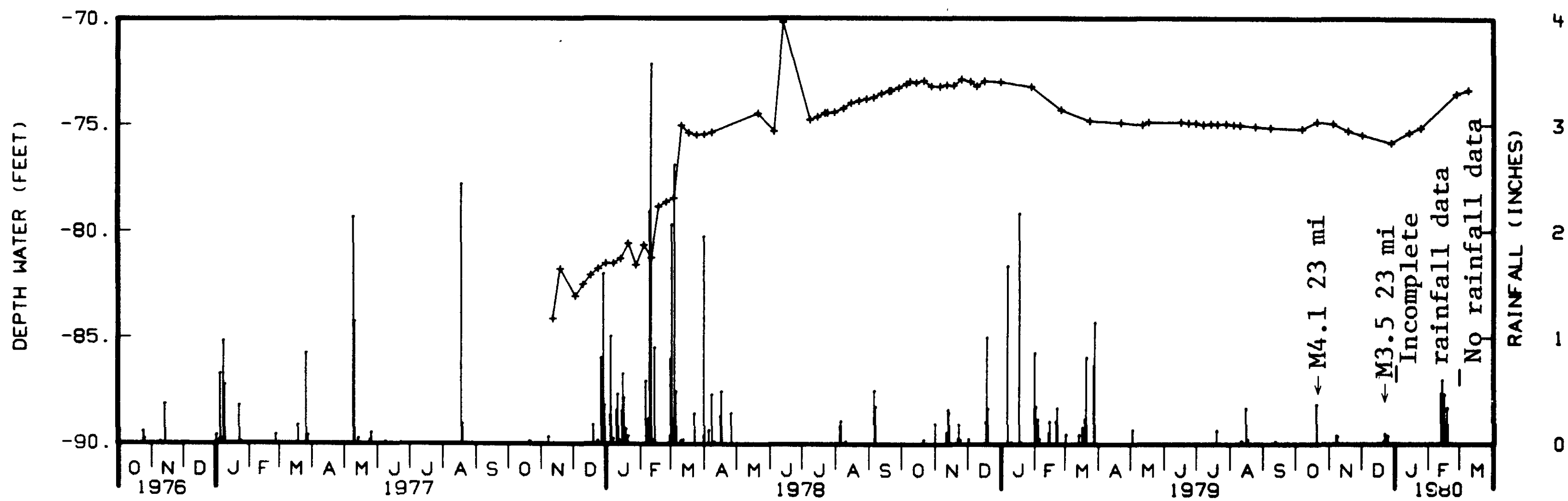

FIGURE 32 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 04N/09W-16L01 DURING 1976-1980, VALYERMO AREA

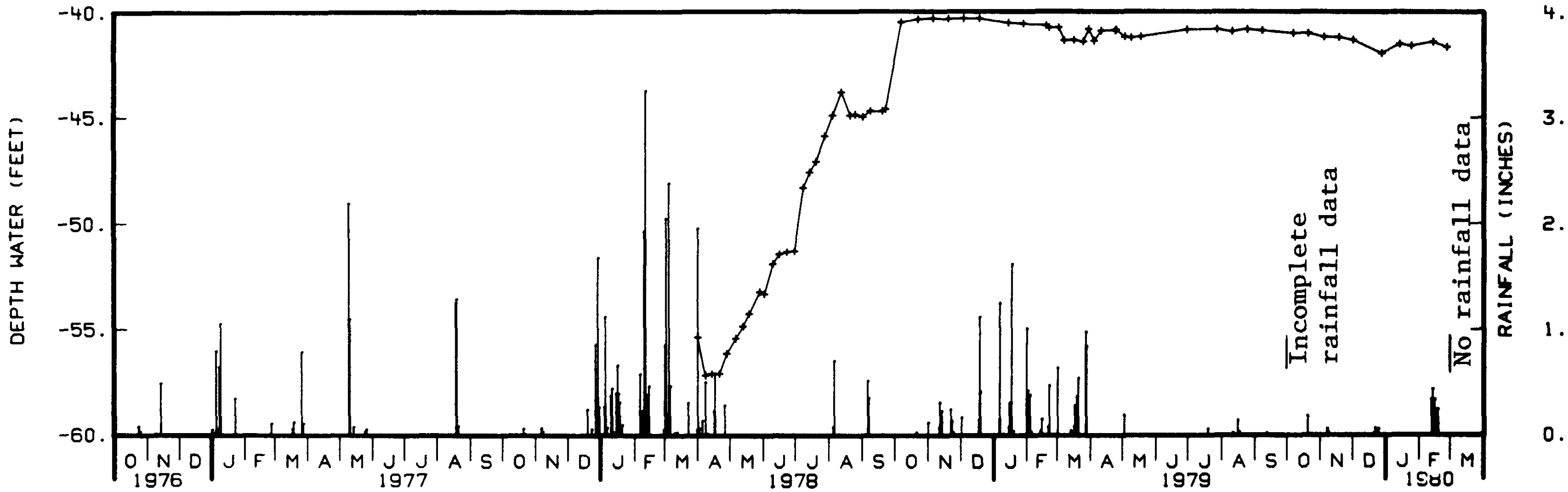

FIGURE 33 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 04N/10W-10Q01 DURING 1976-1980, VALYERMO AREA

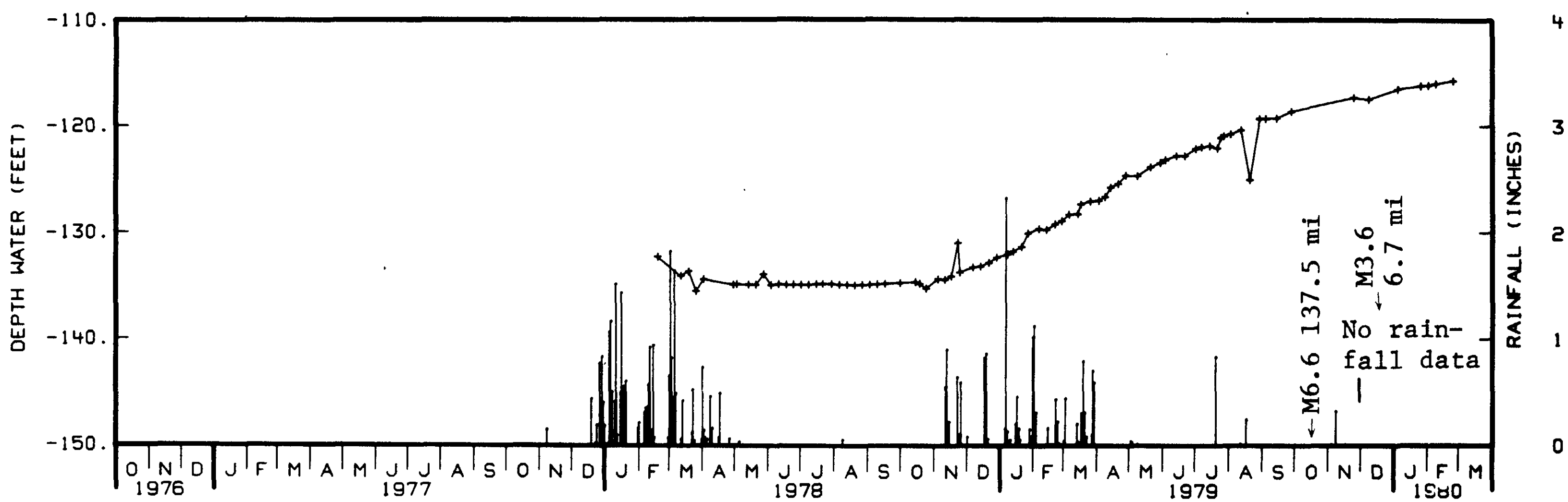

FIGURE 34 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 03S/02W-08E01 DURING 1976-1980, SAN JACINTO VALLEY AREA

The rate of rise has gradually decreased during 1979 and early 1980. No correlation with rainfall and no clear seasonal cycle are evident from the hydrograph. The lack of response to rainfall suggests that this well penetrates a confined aquifer. Because of a crooked casing and depth to water of over 100 feet, a Stevens recorder has not been operated on this well. In contrast, the hydrograph for well 3S/2W-26R1 shows a distinct annual cycle (Fig. 35). The water level rose abruptly 15 feet in response to the storms of February 1980. Levels in well 3S/2W-15F1 have shown a more subdued seasonal cycle (Fig. 36) and an abrupt 9-foot rise during the February 1980 storm period.

Wells 4S/2W-2D1 and -35R1 were not monitored long enough to establish the character of their hydrographs. These wells have been under water since mid-February and have been dropped from the program.

Levels in well 7S/3E-13D5 in Anza (Fig. 7) have gradually risen about 3 feet since monitoring began 2½ years ago and have shown no seasonal variations or fluctuations correlative with rainfall (Fig. 37). Following the peculiar behavior of the water levels in well 7S/3E-23B1 in July of 1979 (Lamar and Merifield, 1979, p. 39 and 48-51), a Stevens recorder was installed on this well. Since the recorder was installed in late July 1979, the water level crested and declined until February of 1980, at which time it began to rise, evidently in response to the heavy rains (Fig. 38). The hydrograph of this well remains one of the most difficult to understand. Previous rainy periods in 1978 and 1979 did not provoke an abrupt response in this well. Stranger still is the rise, fall and subsequent large rise in the water level during mid-1979. The possible relation between these anomalous changes and the October 15, 1979, Imperial Valley earthquake has been discussed previously (Lamar and Merifield, 1979, p. 48-51). Water levels in well 7S/3E-23R1 have shown a somewhat more normal seasonal variation (Fig. 39). Evidently the cumulative effect of the rainy seasons for the past three years is responsible for the over 50 feet of rise since monitoring began. The response to the intense February 1980 rainstorms was much more abrupt than that of previous rainy periods.

Water levels in well 10S/6E-36Q1 (Fig. 40) in the Borrego Springs area (location of wells shown in Fig. 8) have shown an irregular annual cycle over the past two years. The lack of measurements in February and March 1980 is due to the absence of the volunteer in that area. Only a few

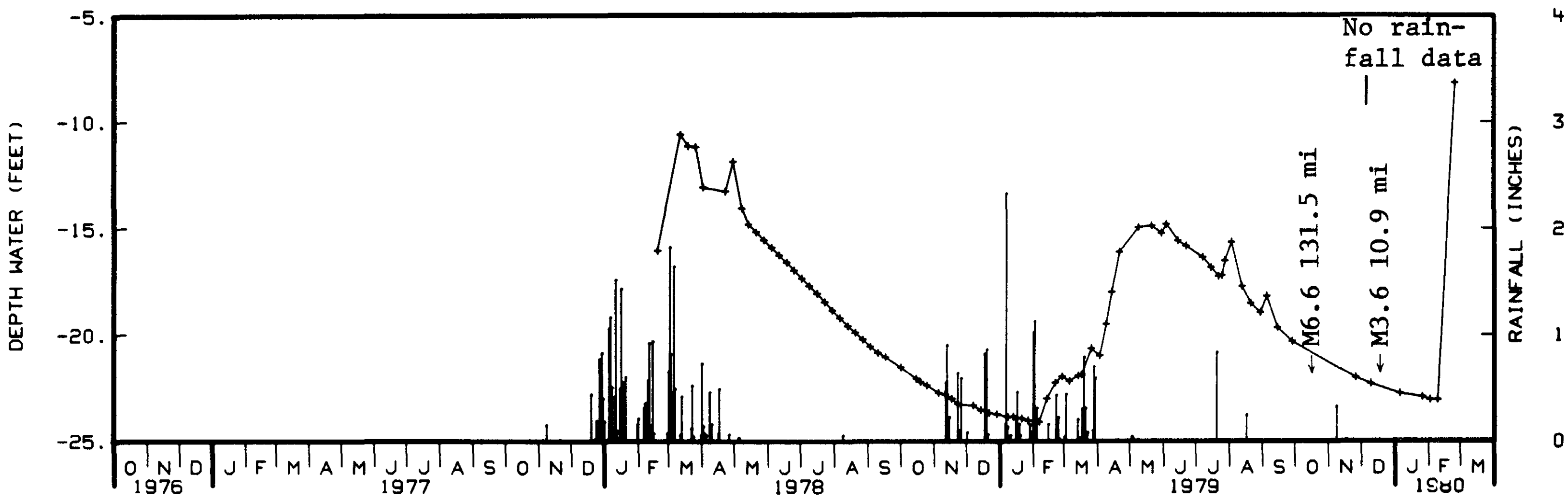

FIGURE 35 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 03S/02W-26R01 DURING 1976-1980, SAN JACINTO VALLEY AREA

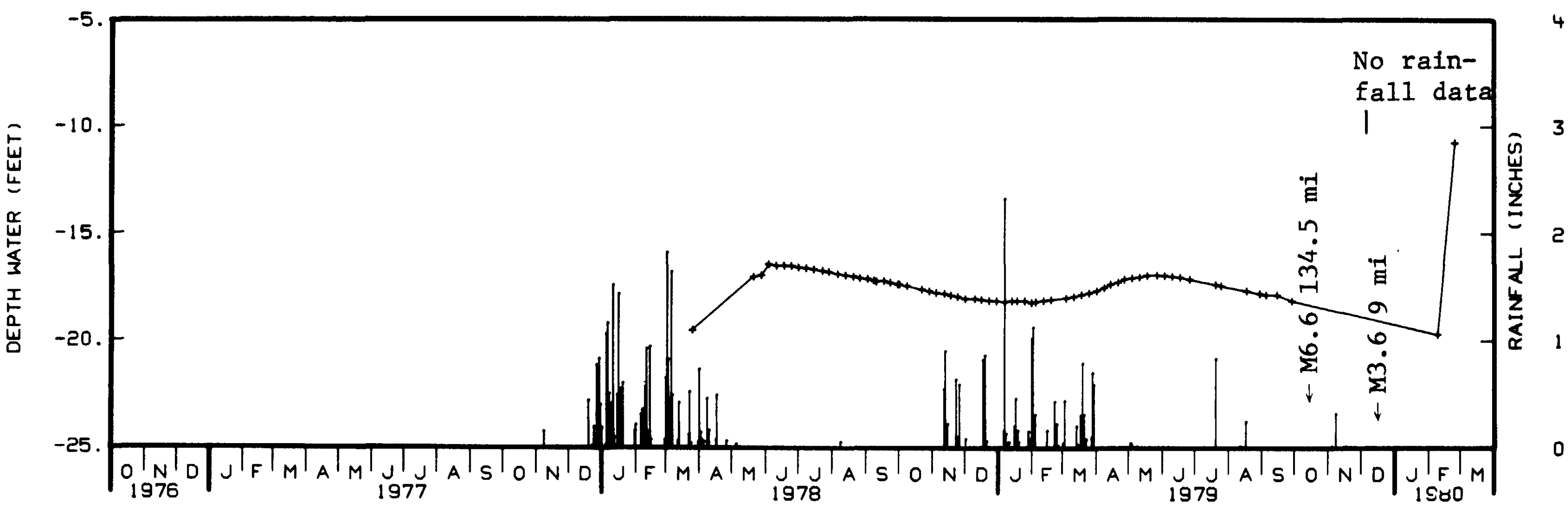

FIGURE 36 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 03S/02W-15F01 DURING 1976-1980, SAN JACINTO VALLEY AREA

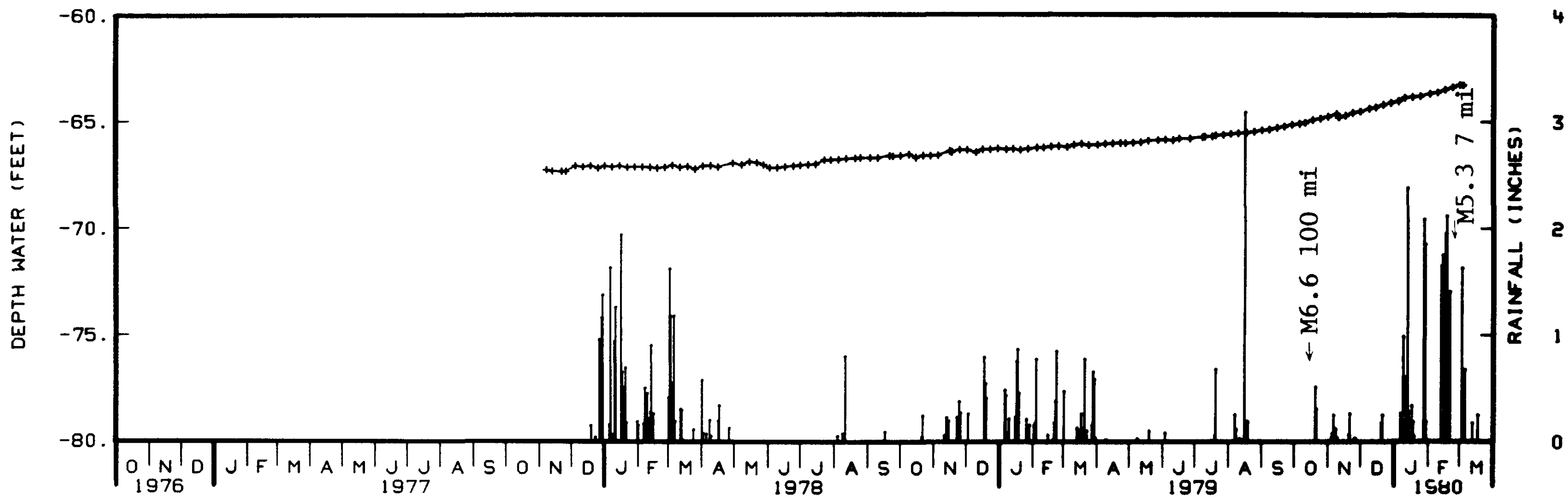

FIGURE 37 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 07S/03E-13D05 DURING 1976-1980, ANZA AREA

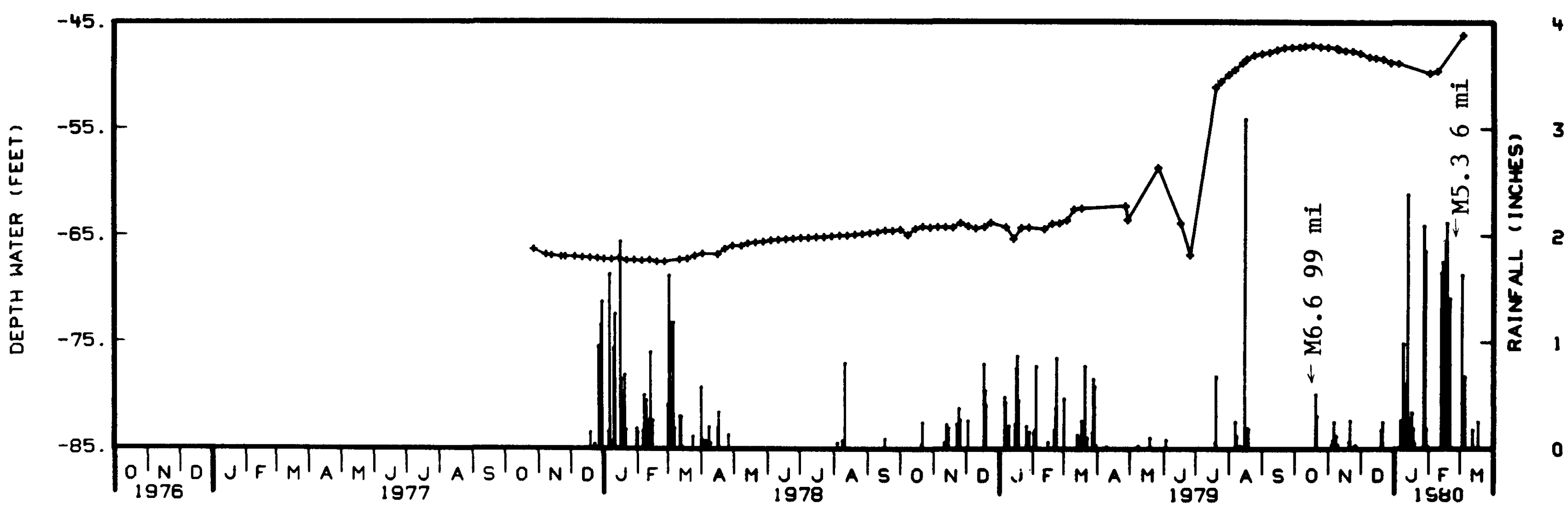

FIGURE 38 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 07S/03E-23B01 DURING 1976-1980, ANZA AREA

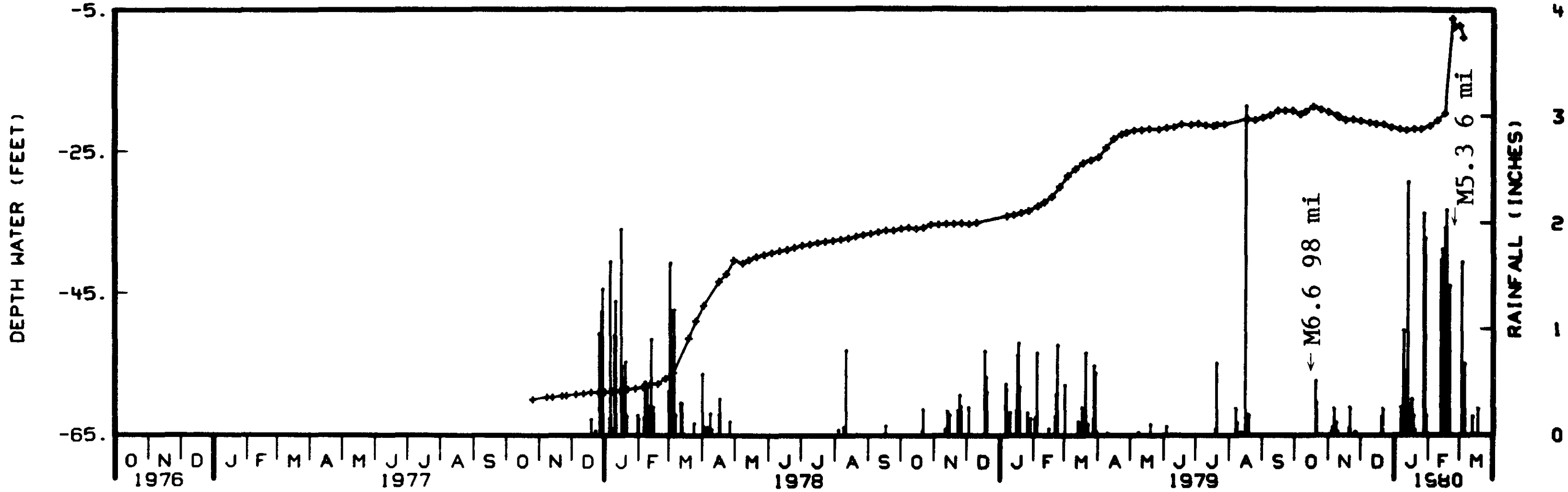

FIGURE 39 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 07S/03E-23R01 DURING 1976-1980, ANZA AREA

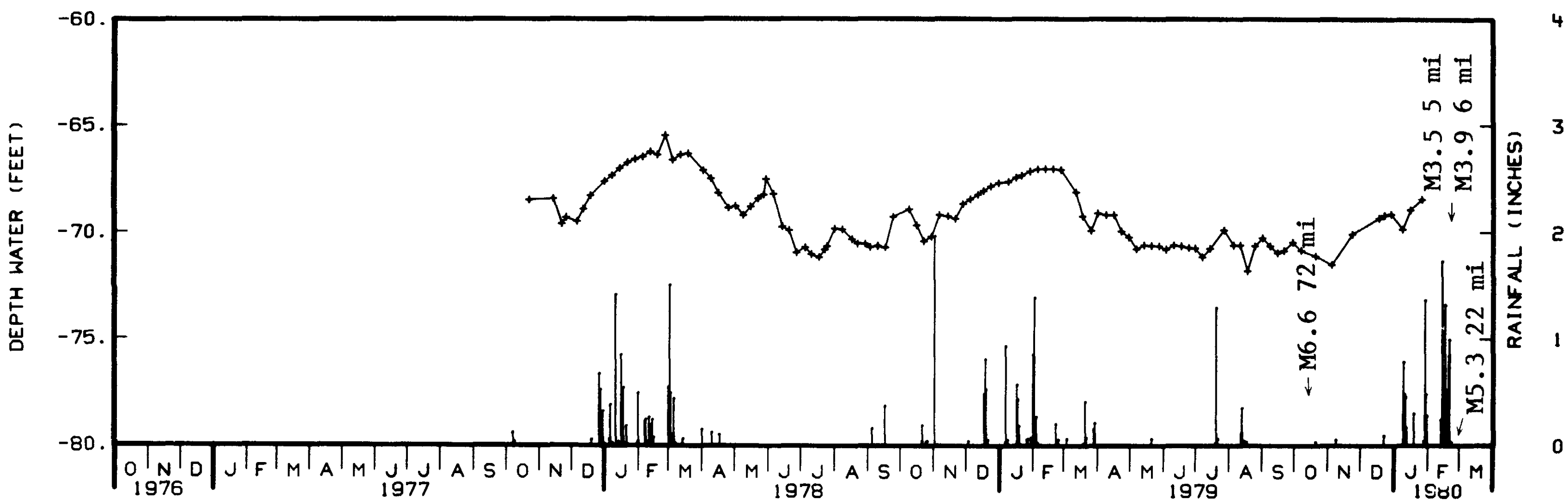

FIGURE 40 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 10S/06E-36Q01 DURING 1976-1980, BORREGO SPRINGS AREA

measurements have been made in well 10S/7E-30G1; consequently, the character of the hydrograph is as yet unknown. Levels in well 11S/6E-1C1 appear to show a very subtle annual cycle with highs in the winter or early spring (Fig. 41). No clear correlation with individual rainstorms is evident, however. Levels in well 11S/6E-3N4 have steadily dropped about 2 feet since monitoring began in October 1977 (Fig. 42). This well has shown no seasonal variation nor detectable response to rainstorms. This well and well 11S/6E-1C1 showed anomalous spikes on Stevens records prior to the 25 February 1980 M5.3 earthquake near Anza; the relationship between these spikes and the earthquake is discussed in a later section.

The three wells in Ocotillo Wells (located in Fig. 9), 11S/8E-33P1 (Fig. 43), 12S/8E-10E1 (Fig. 44) and 12S/8E-9Q1 (Fig. 45), have shown no seasonal variation nor identifiable response to rainfall since monitoring began. The anomalous behavior of 11S/8E-33P1 during mid-1979 has been discussed previously (Lamar and Merifield, 1979). A Stevens recorder is now operating on this well. No anomalous water-level changes have been observed in these three wells during the current reporting period.

EARTHQUAKES AND THEIR RELATION TO WATER LEVELS

M5.3 Earthquake of 25 February 1980 near Anza

According to data from the Caltech Seismological Laboratory, a M5.3 earthquake occurred at 0247 hours, 25 February 1980, between the Buck Ridge and San Jacinto strands of the San Jacinto fault zone, about 8 miles east-southeast of Anza. (See Plate 1.) This is the largest earthquake which has occurred during our monitoring on the portion of the San Jacinto fault zone where we have been operating continuous recorders since November 1977. Table 4 lists the wells along the San Jacinto fault zone which had Stevens continuous water-level recorders operating at the time of the earthquake.

Water levels in well 7S/3E-23R1, located 5.5 miles from the epicenter, began to rise on 30 January, and the rate of rise greatly increased on about 15 February; the water level peaked on 23 February, approximately two days before the earthquake, and has been falling since that time. The total rise since 30 January was 15.8 feet, and 13.7 feet since 15 February. As indicated on the long-term hydrograph (Fig. 39), the most rapid rise occurred during a period of intense rainfall. Water levels in this well have previously shown rapid rises in response to rainfall, and a similar explanation for the pre-

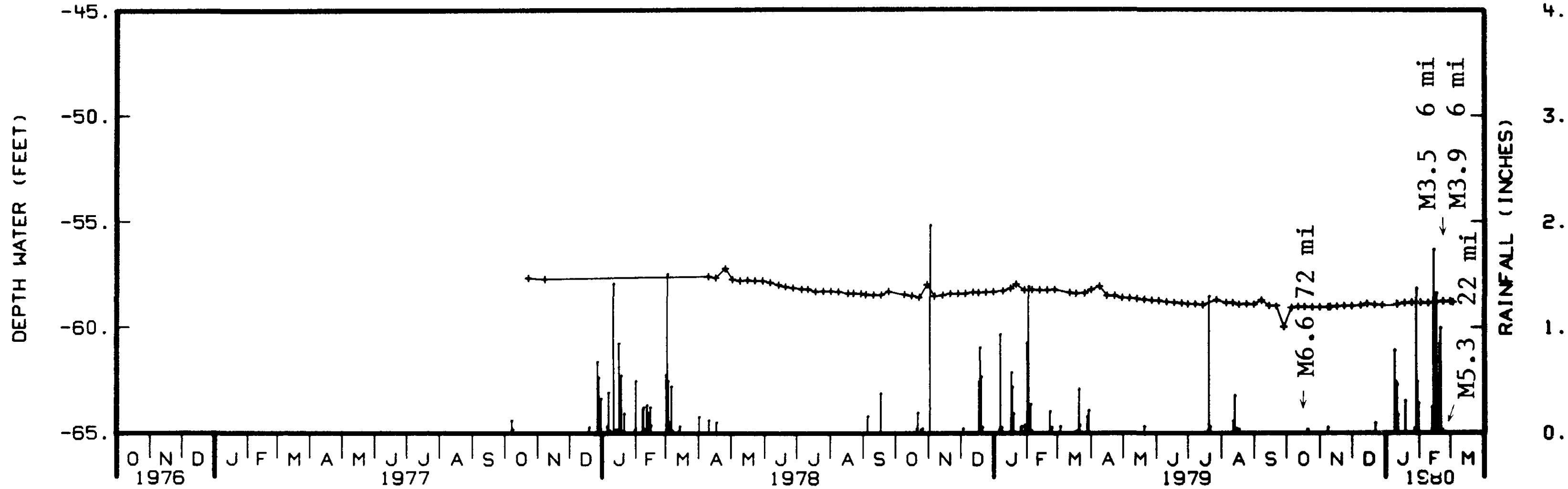

FIGURE 41 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 11S/06E-01C01 DURING 1976-1980, BORREGO SPRINGS AREA

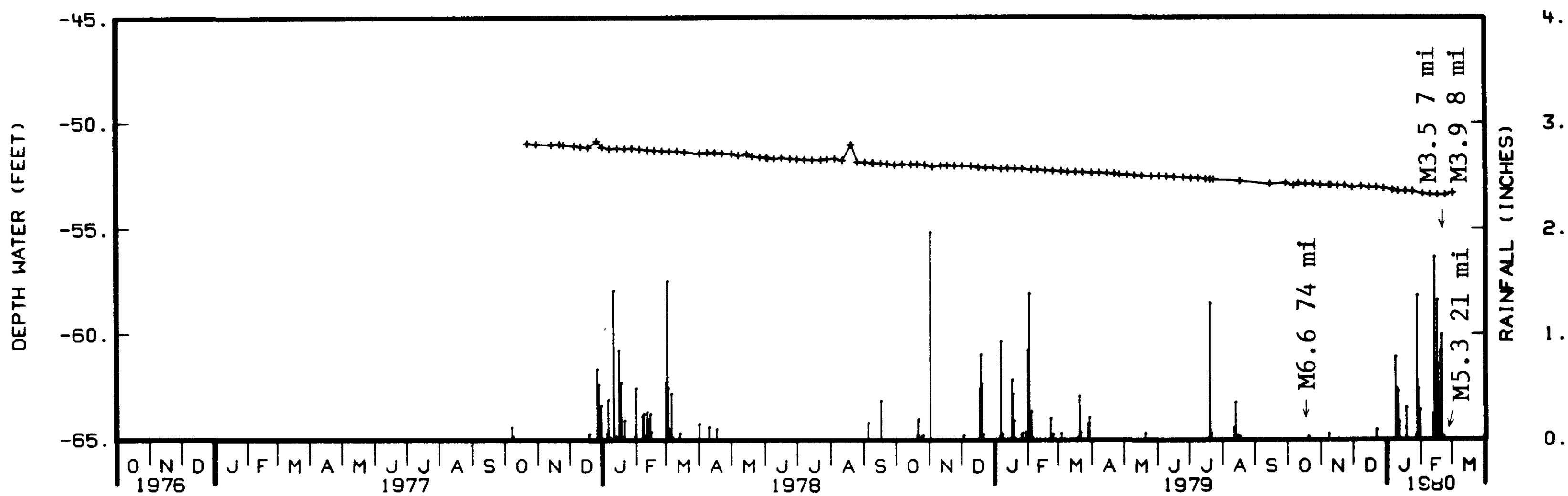

FIGURE 42 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 11S/06E-03N04 DURING 1976-1980, BORREGO SPRINGS AREA

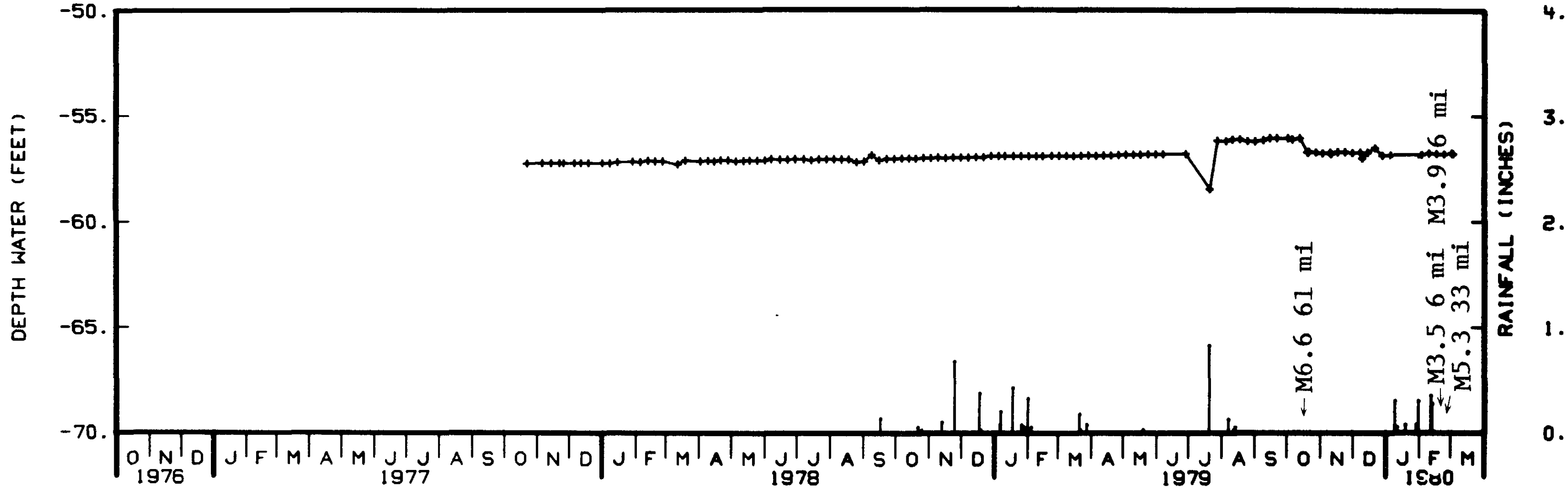

FIGURE 43 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 11S/08E-33P01 DURING 1976-1980, OCOTILLO WELLS AREA

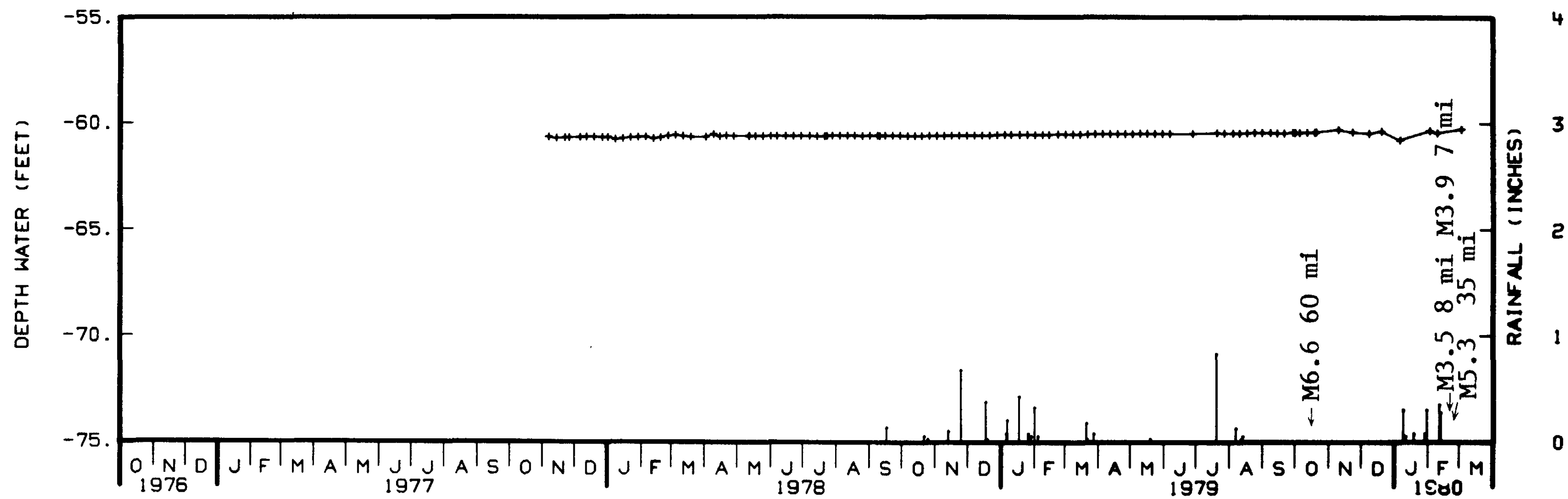

FIGURE 44 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 12S/08E-10E01 DURING 1976-1980, OCOTILLO WELLS AREA

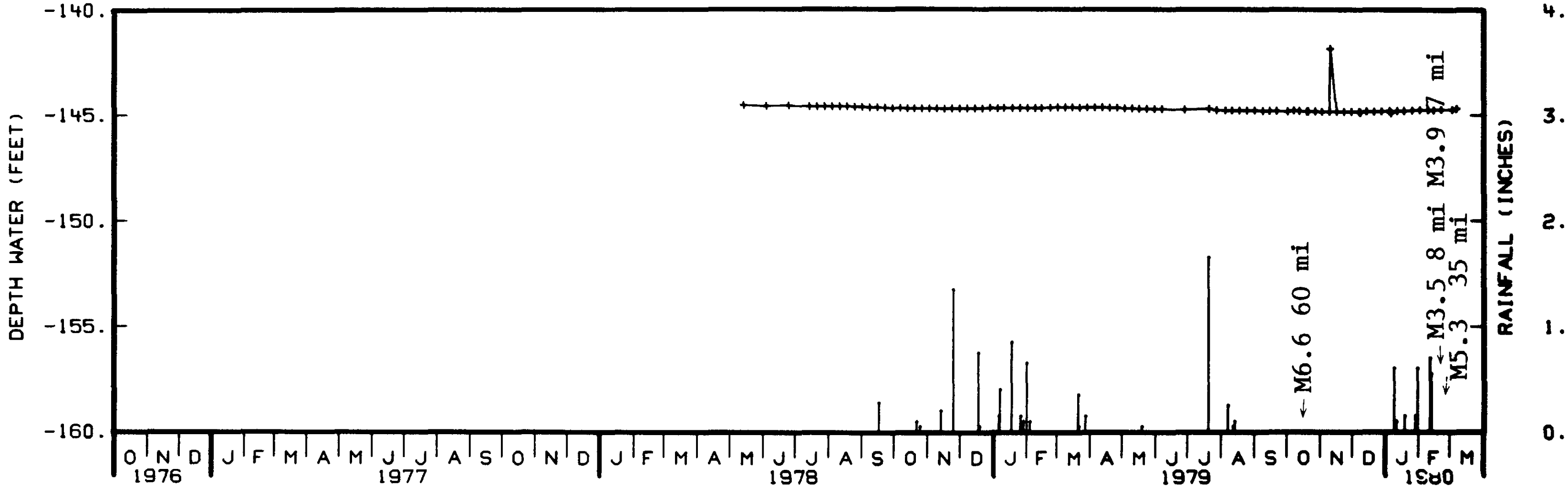

FIGURE 45 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 12S/08E-09Q01 DURING 1976-1980, OCOTILLO WELLS AREA

Table 4 - Summary of water-level records in observation wells in relation to 25 February 1980, M5.3 earthquake located 8 miles east-southeast of Anza, California.

Well locations are shown on Figs. 7, 8, and 9.

Well Number	Depth (feet)	Distance to Epicenter (mi)	Summary of Stevens Water-level Chart
7S/3E-23R1	94	5.5	Abrupt water-level rise which peaked two days prior to earthquake; occurred during period of heavy rainfall and believed to be caused by rainfall.
7S/3E-13D5	83	6.0	No anomaly prior to earthquake.
11S/6E-3N4	71	22.0	Anomalous and unique (for the record of of this well) 1.5-1.6 foot water-level spike about 88 hours prior to earthquake.
11S/6E-1C1	116	22.5	0.1-foot spike in water level about 88 hours prior to earthquake. Would probably not have been recognized as anomalous without comparison with record of wells -3N4 and -33P1.
11S/8E-33P1	374	34.0	No anomaly prior to earthquake.

earthquake rise is considered probable. To illustrate this correlation, daily rainfall for the two precipitation stations in Anza and the daily water levels between January 23 and February 25, 1980, are shown in Figure 46.

Beginning on January 23, prior to the January 28-30 storm period, depths to water fluctuated over a narrow range between 21.81 and 22.05 feet. Beginning on January 30, water levels began to rise; this rise began within 2-3 days of the beginning of the storm period. The rise in water level continued at a fairly constant rate until February 4-6, when the water level rose over two feet in two days (.90 feet during February 4-5, and 1.17 feet during February 5-6) 7 to 9 days after the storm. Water levels generally continued to rise, but at a slower rate until February 15, when water levels rose .61 foot between February 15 and 16. This increase in the rate of rise also began 2-3 days after the beginning of the intense storm period which began on February 13; and the period of most rapid rise, 4.60 feet between February 20 and 21, also occurred about 7-8 days after the beginning of the storm. Rainfall ceased on February 21, and the water level in the well peaked within 2-3 days on February 23. Water levels have dropped from February 23 until April 25, the end of the period covered by our most recent recorder chart.

Based on this analysis it is concluded that the pre-earthquake rise in water level in well 7S/3E-23R1 can be entirely explained by the intense storm period which preceded the earthquake. Water-level changes as a result of tectonic strain premonitory to the earthquake, if any, would have been masked by the effects of the storm. Because of variations in rain distribution, surface flow and groundwater recharge during individual storms, we cannot justify any attempt to "subtract" the effects of rainfall immediately prior to the earthquake by detailed analyses of the response of water level to previous storms. The Stevens recorder chart for well 7S/3E-23R1 covering the time of the earthquake has not been included because the principal feature prior to the earthquake is a series of almost vertical lines caused by rapid rotation of the drum (one revolution for each one foot of water-level rise).

Fig. 47 shows the Stevens recorder chart covering the time of the earthquake for well 7S/3E-13D5, located near Anza 6.0 miles from the epicenter. The chart shows small (± .01 foot), short-term (9-11 hours) fluctuations superimposed on a three- to seven-day cycle having an amplitude of ± .15 foot.

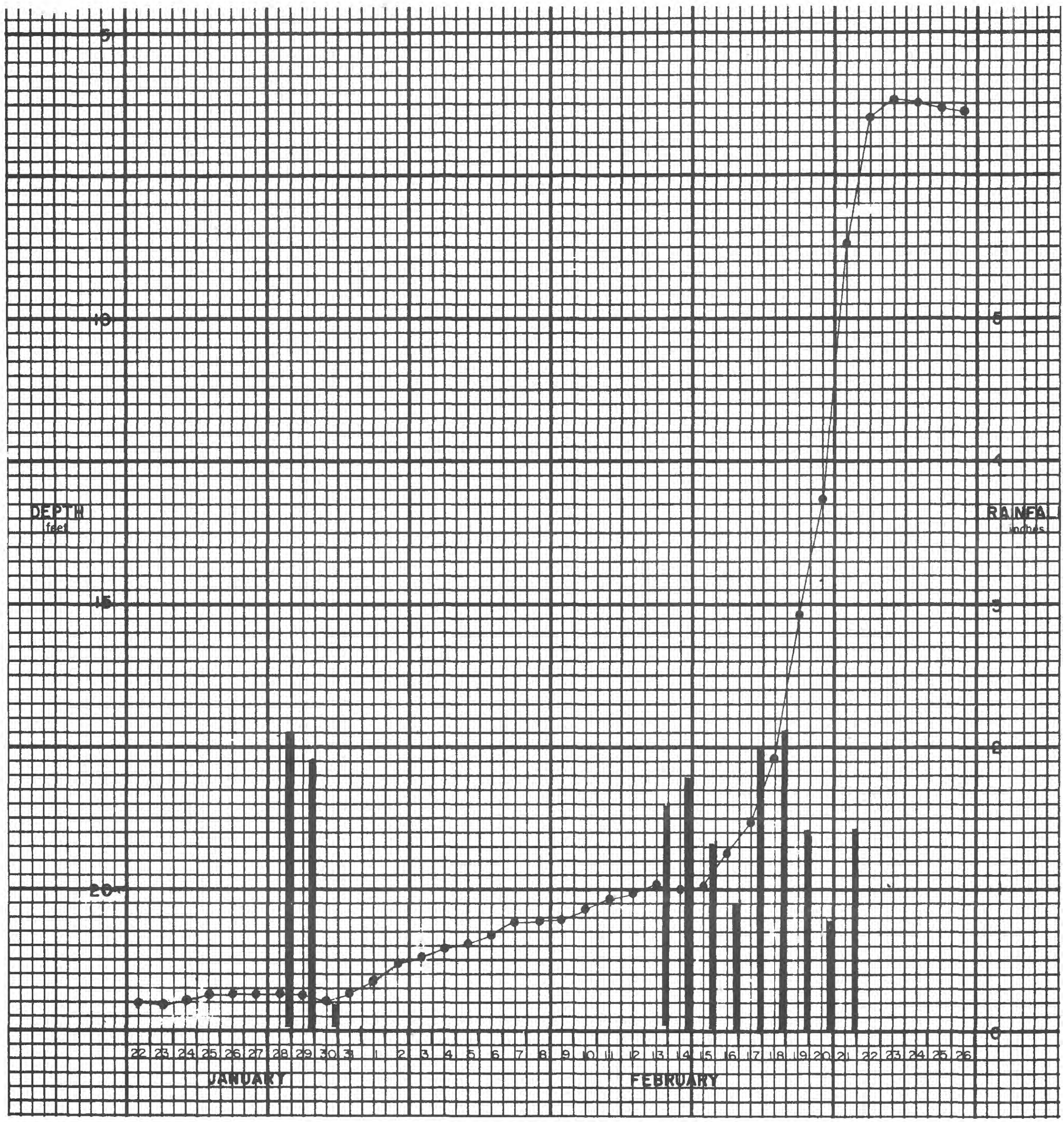

Figure 46 - Daily observations of water level and rainfall in well number 7S/3E-23R1 for period January 22 - February 26, 1980, Anza area. Rainfall is average of precipitation stations PSID16Q and PSID23R.

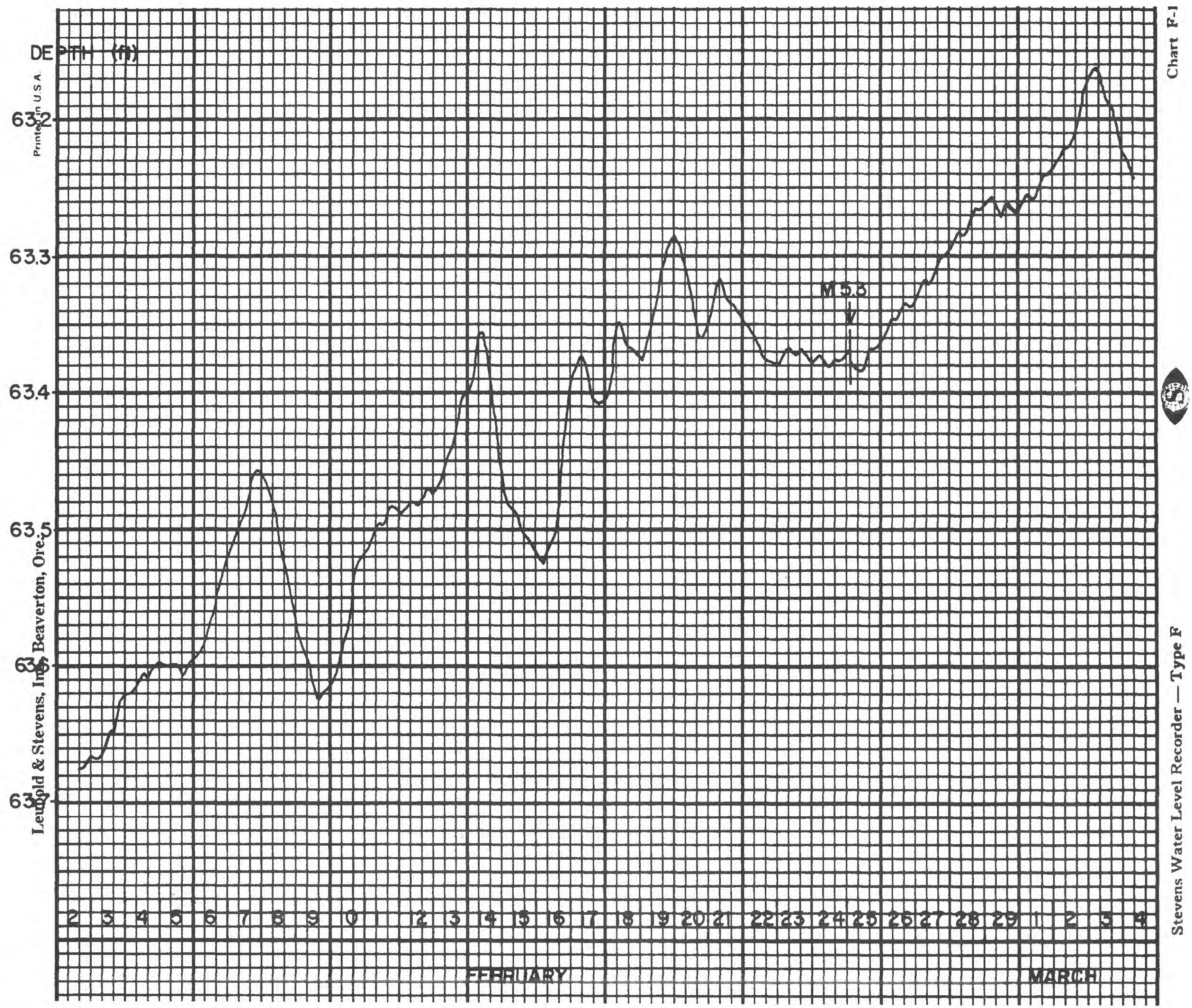

Figure 47 - Stevens water-level recorder chart for well number 7S/3E-13D5, near Anza, for period February 2 - March 4, 1980.

Based on comparisons with hydrographs shown on Figs. 6.9 and 6.16 of Todd (1959, pgs. 159 and 167), the short-term variations are believed to be caused primarily by tides with perhaps some contribution from diurnal barometric pressure changes. Comparison with Fig. 6.9 of Todd (1959, p. 167) suggests that the long-term cycles are due to barometric pressure changes. Based on comparison with previous records of this well, we see no anomalous water-level changes prior to the earthquake.

Fig. 48 shows the Stevens recorder chart for well 11S/6E-3N4 located in Borrego Valley about 22 miles southeast of the epicenter. Study of the vertical lines on the chart original indicate that during a period of about four hours beginning near midday 21 February, the water level rose 1.5 to 1.6 feet and returned to its prior level. This is one of the most remarkable short-term water-level fluctuations observed during our monitoring program; it occurred about 88 hours prior to the earthquake. This well has been monitored since October 1977 and has had a Stevens recorder since October 1978. Long-term water levels have been remarkably steady compared to those in other wells we are monitoring (Fig. 42). Since October 1977, the water level has gradually and steadily dropped about two feet and has shown no seasonal variation and no identifiable response to rainfall. We cannot conceive of any non-tectonic cause for the 1.5-foot spike in water level in this well.

The record for well 11S/6E-1C1 (Fig. 49), which is also located in Borrego Valley 22.5 miles from the epicenter, showed a much smaller (0.1-foot) spike in water level at the same time as the spike in well 11S/6E-3N4 (Fig. 48). However, the water-level spike in well -1C1 is not significantly greater than other, similar spikes which are believed to be caused by atmospheric pressure changes and would not have been recognized as anomalous without the unusual event in well -3N4 for comparison. The short-term (9-11 hours) fluctuations in well 11S/6E-1C1 are somewhat smaller than in well 11S/6E-3N4, and the longer term (3-7 days) fluctuations are slightly greater than in well -3N4. As noted above, comparison with Figs. 6.9 and 6.16 of Todd (1959, pgs. 159 and 167) suggests that the short-term variations are the result of earth tides and the longer term variations are the results of atmospheric pressure changes. This suggests that well -3N4, which showed the greatest pre-earthquake spike, is more responsive to tides than is well

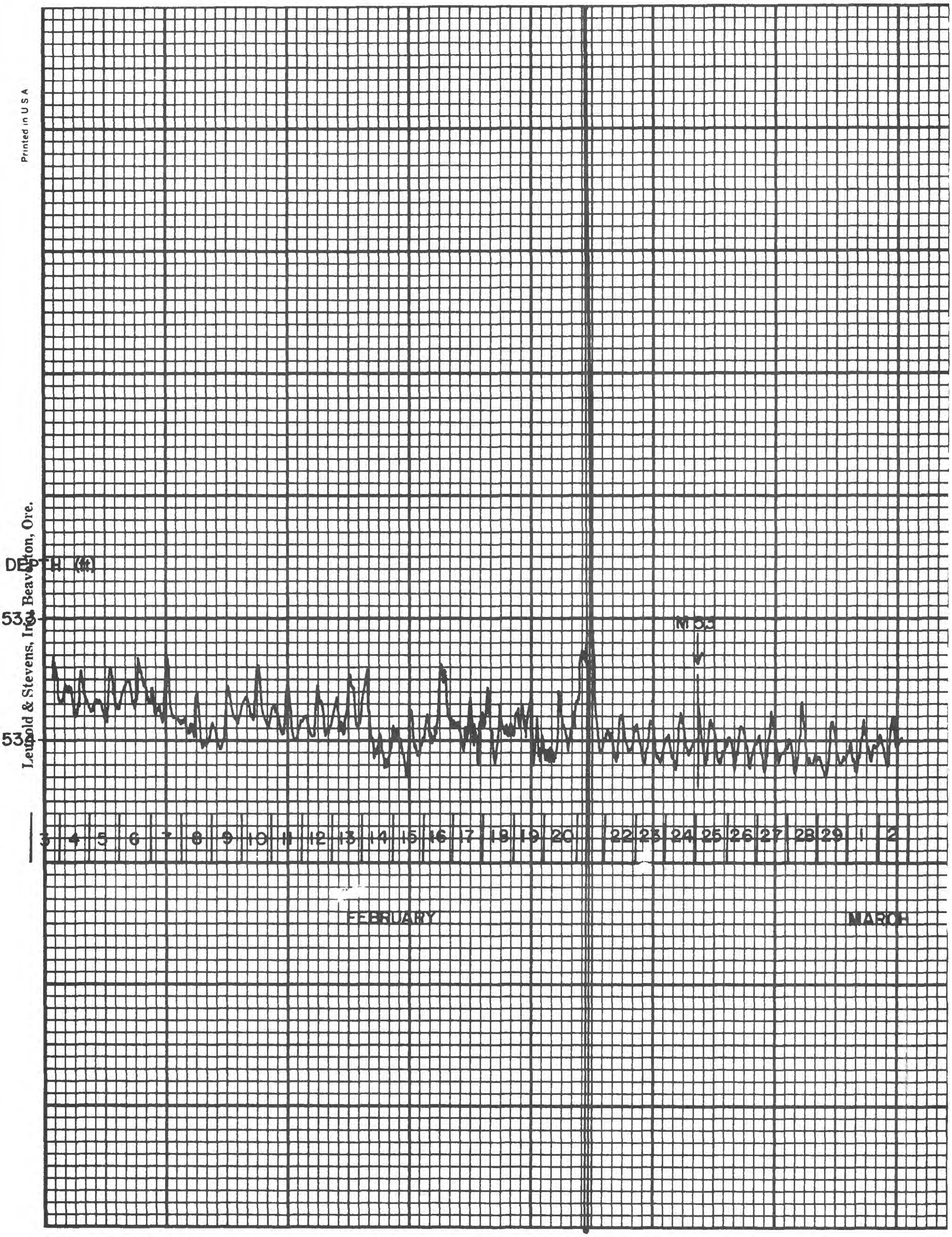

Figure 48 - Stevens water-level recorder chart for well number 11S/6E-3N4, Borrego Valley, for period February 3 - March 2, 1980.

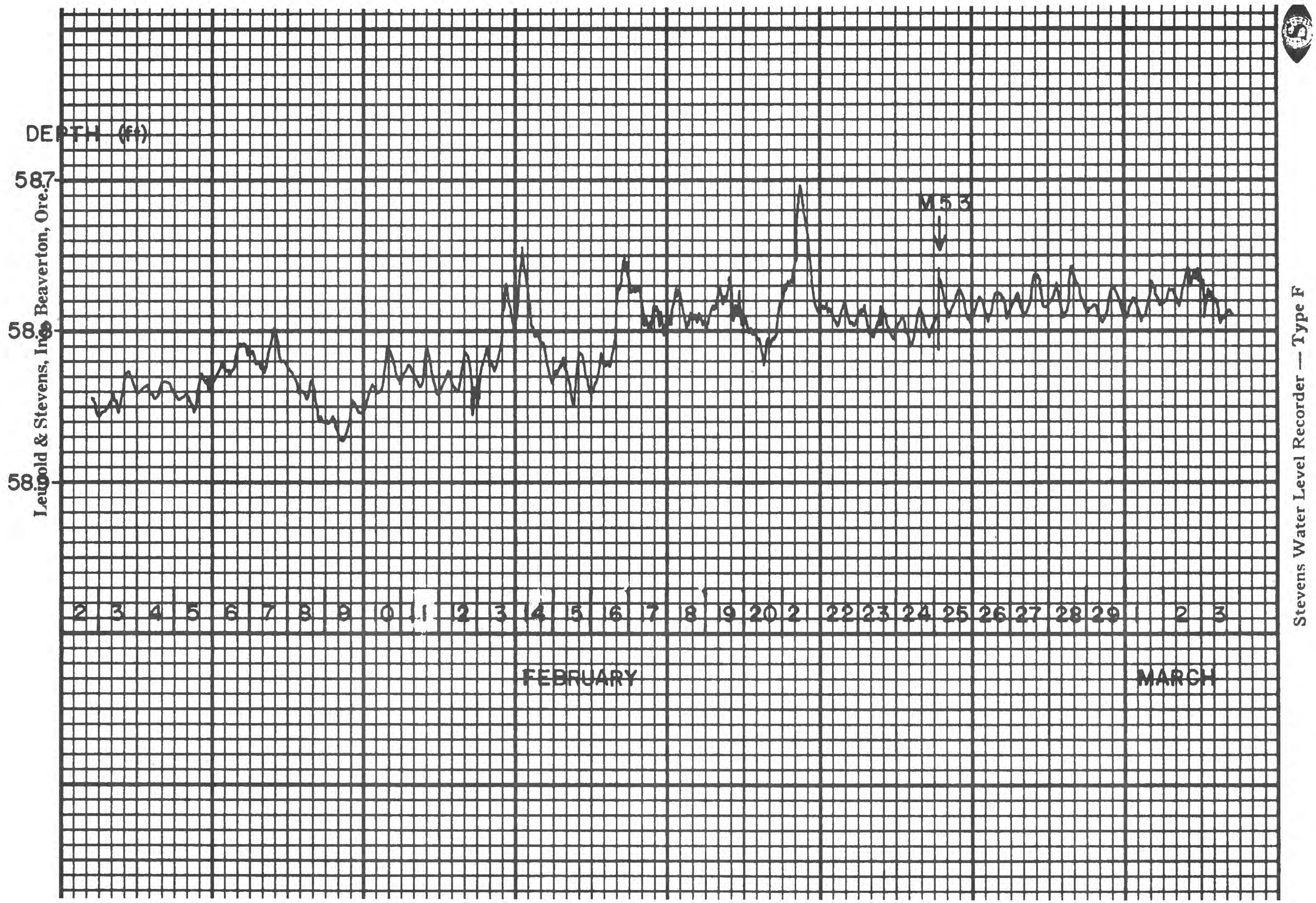

Fig. 49 - Stevens water-level recorder chart for well number 11S/6E-1C1, Borrego Valley, for period February 2 - March 3, 1980.

-1C1. A few spikes, somewhat similar to the 21 February event in well 11S/6E-3N4, have appeared only on the records of one other well that we are monitoring, viz. well 5N/12W-14C1 located near Palmdale (Fig. 2). During John Bredehoeft's visit in February 1980, we showed him a 0.7-foot spike which had occurred over an 8-hour period on the record of February 1978 for well -14C1; he suggested it might be caused by a creep event. The long-term continuous record for well -14C1 is similar to that of well 11S/6E-3N4 in that it shows more prominent short-term (9-11 hours) fluctuations and less prominent long-term (3-7 days) variations, which suggest that this well is more responsive to tides than to barometric pressure.

A continuous recorder was installed on well 11S/8E-33P1, located near Ocotillo Wells, on 10 February 1980 (Fig. 50). This well shows no spike on 21 February or any other fluctuations which can be identified as earthquake precursors. Other details of the record for this well are remarkably similar to the record for well 11S/6E-1C1 in that short-term (9-11 hours) fluctuations are small relative to those in -3N4, and the long-term (3-7 days) changes are greater relative to -3N4. This could mean that well -33P1 is also more responsive to atmospheric pressure and that atmospheric pressure changes are similar in Borrego Valley and Ocotillo Wells. (Continuous barometric records are not available for either location.) This provides a further indication that the 21 February spike in well -1C1 is not related to atmospheric pressure. The lack of a spike in well -33P1 also provides some further support for the suggestion that wells which show greater short-term fluctuations and smaller long-term fluctuations may better record strain-induced spikes, although the lack of a spike in the record of well -33P1 could also be explained by greater distance from the postulated creep event. The location of the postulated creep event is, of course, unknown.

The spikes on the hydrographs of two wells (11S/6E-3N4 and -1C1) in Borrego Valley which occurred about 88 hours before the 25 February 1980, M5.3 earthquake east of Anza must be considered anomalous and are believed to be caused by tectonic strain, possibly a creep event. The wells which showed the spikes in water level are located about 22 miles from the earthquake epicenter. Well 7S/3E-23R1 in Anza, 5.5 miles from the epicenter, showed an abrupt rise which peaked two days prior to the earthquake. The rise occurred during a period of heavy rainfall and is considered a result

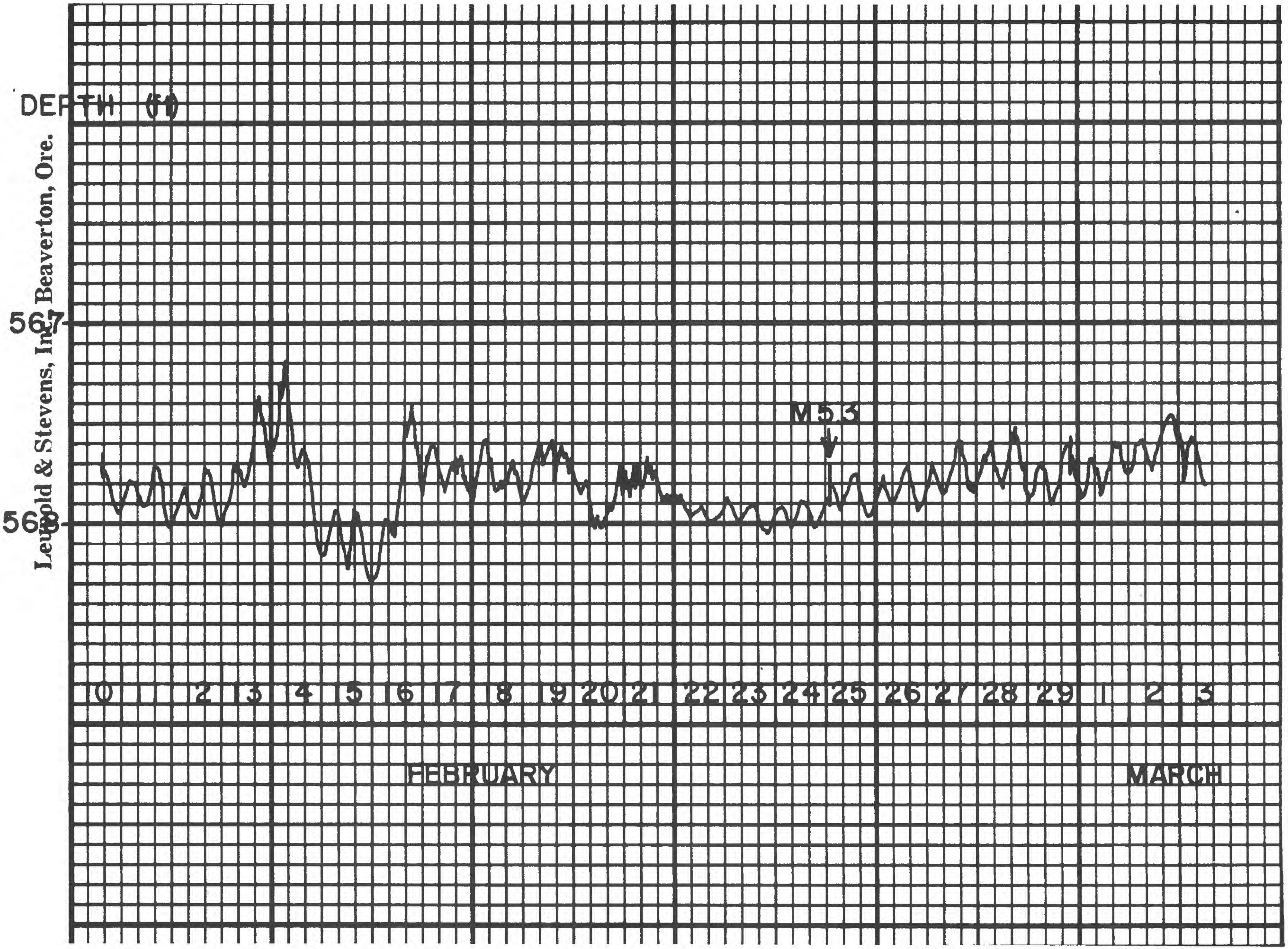

Figure 50 - Stevens water-level recorder chart for well number 11S/8E-33P1, near Ocotillo Wells, for period February 10 - March 3, 1980.

of rainfall. Well 7S/3E-13D5 in Anza, 6.0 miles from the epicenter, showed no anomaly prior to the earthquake. However, the long-term record suggests that this well may be more responsive to atmospheric pressure changes than to diurnal variations in the tide raising force. Comparison of the height of the water-level spikes and long-term records in the two wells in Borrego Valley and a well near Palmdale, which has also recorded anomalous spikes, suggests that wells sensitive to tides may better detect tectonically induced water-level changes, possible creep events.

If the 21 February water-level spikes in well 11S/6E-3N4 and -1C1 record a creep event, the event may have occurred on the Coyote Creek fault, which is the closest strand of the San Jacinto fault zone. The relationship between the possible creep-induced water-level spikes and the 25 February earthquake is unknown; however, since the spikes in wells -3N4 and -1C1 are unique for the long-term record of these wells, they may represent precursors to the earthquake. Two earthquakes of M3.5 and M3.9 occurred on 22 February 1980 between the observation wells in Borrego Valley and Ocotillo Wells. The possible creep-induced spikes in wells 11S/6E-3N4 and -1C1 (Figs. 48 and 49) could perhaps be precursors to these events, located 5.6 to 9.8 miles away, rather than the more distant M5.3 25 February 1980 earthquake. However, the absence of a possible creep-induced spike in the Stevens chart for well 11S/8E-33P1 (Fig. 50) located in Ocotillo Wells argues against this possibility because well -33P1 is located at a similar distance (5.6 to 9.6 miles) from the 22 February events as the observation wells in Borrego Valley which showed spikes. Nothing can be seen on the long-term hydrographs of the observation wells in Borrego Valley or Ocotillo Wells (Figs. 40-45) which can be considered precursors of either the 22 February or 25 February earthquakes.

Of perhaps more significance to our program at this time is the fact that these rare spikes have only occurred in wells which show strong short-term (9-11 hours) fluctuations in water level and weaker fluctuations with a 3-7 day period. We suggest that such wells may be more responsive to tides than to atmospheric pressure. Additional analysis is required to determine the response to tides and atmospheric pressure of wells which do and do not show sharp spikes, possibly related to creep events. If it can be shown that wells with a stronger response to tides also record creep events, then it may be appropriate to record water levels in such wells on an expanded time scale.

Other Earthquakes

Data on M ≥ 3.0 earthquakes from the Caltech Seismological Laboratory since 1 March 1979 are plotted on Plate 1; those of M ≥ 3.5 which occurred since 1 October 1979 (end of period covered by our last progress report; Lamar and Merifield, 1979) are shown on the long-term hydrographs (Figs. 13-45) if the epicenter is within 25 miles of the well. An exception is the M_L6.6, 15 October 1979 Imperial Valley earthquake, which is shown on all of the hydrographs of wells along the San Jacinto fault zone. The relationship of this earthquake to water-level changes is discussed in our previous progress report (Lamar and Merifield, 1979).

Only two events occurred within 25 miles of one observation well along the Palmdale-Valyermo segment of the San Andreas fault zone; the epicenters were 23 miles southeast of well 4N/9W-16L1 (Fig. 32) located at the southeast end of the Valyermo group of observation wells. No anomalous water-level variations prior to these earthquakes appear on the long-term hydrograph for well -16L1 (Fig. 32). The Stevens recorder on this well was moved to another well in August 1979; thus no Stevens recorder charts are available for the period immediately prior to these earthquakes.

Only one earthquake (M3.6, 18 December 1979) of M ≥ 3.5 occurred within 25 miles of the San Jacinto Valley observation wells since 1 October 1979. As indicated on Figs. 34-36, no significant water-level changes in the San Jacinto Valley wells occurred prior to these earthquakes. Stevens recorders have not been operating on any San Jacinto Valley wells since August 1979. The M5.3 earthquake of 25 February 1980 discussed above is the only M ≥ 3.5 earthquake which has occurred within 25 miles of the Anza observation wells since 1 October 1979. The two earthquakes, M3.5 and M3.9 which occurred on 22 February 1980 between Borrego Valley and Ocotillo Wells, are discussed in the preceding section.

SUITABILITY OF WELLS AS STRAIN METERS

Observation wells utilized under this program are abandoned water wells identified as a result of a field search. Almost no data on the nature of the rocks penetrated and perforations are available. However, pertinent well characteristics can be determined from the response of water levels in the wells to seasonal rainfall, individual rainstorms, atmospheric pressure and earth tides. As outlined in the above discussion of the M5.3, 25 February 1980 earthquake near Anza, it is believed that wells which show the greatest response to tides and the least response to other influences are the best detectors of short-term strain events. Water levels in most of our observation wells have been sufficiently monitored on short-term (Stevens recorder) and long-term (long-term hydrograph) bases to determine their response characteristics and thus their suitability as strain meters.

Our water-level monitoring program has been discussed with John Bredehoeft of the U.S. Geological Survey with the objective of identifying wells which would be suitable for installation of satellite platforms for monitoring water level, atmospheric pressure and other environmental data. Caltech Remote Observatory Support Systems (TIMS) to telemeter water-level data have also been installed on two wells convenient to telephone lines. Because of difficulty in obtaining sufficiently noise-free telephone lines, the TIMS systems to telemeter data from these two wells are not yet operational. However, if the problems are solved, additional TIMS may be installed on other wells convenient to telephone lines. In order to make best use of the satellite platforms and TIMS systems, wells which are the best strain meters, convenience to telephone lines and exposure to vandalism must be considered. Table 5 summarizes the pertinent characteristics of each well.

As outlined in the discussion of the M5.3, 25 February 1980 earthquake near Anza, a 3-7 day cycle of water-level changes on the Stevens recorder charts is believed to be caused by variations in atmospheric pressure. A "none" on Table 5 indicates that a 3-7 day cycle is not apparent on the Stevens recorder charts. If such a 3-7 day cycle is apparent, the maximum amplitude estimated from study of the Stevens recorder charts is given. Fig. 47 is an example of a Stevens recorder chart which shows fluctuations in water level with a 3-7 day cycle believed to be related to atmospheric pressure variations. As noted in the discussion of the M5.3 earthquake near Anza, a 9-11 hour cycle of water-level changes on the Stevens recorder charts is believed to be caused by earth tides. A "none" on Table 5 indicates that a tidal cycle is not apparent on the Stevens recorder charts. If such a tidal cycle is apparent, the maximum amplitude estimated from study of the Stevens recorder charts is given. Fig. 48 is an example of a Stevens recorder chart which shows fluctuations in water level with an 9-11 hour cycle believed to be caused by earth tides. An "unknown" on Table 5 under response to atmospheric pressure and earth tides indicates that a Stevens

Table 5 - Summary of well characteristics pertinent to installation of satellite platforms and Caltech Remote Observatory Support Systems (TIMS).

See Table 1 for basis of assignment of state well numbers and source of depth data.
See text for discussion of response to atmospheric pressure and earth tides.

State Well Number	Depth (feet)	Response to Atmospheric Pressure (feet)	Response to Earth Tides (feet)	Protection from Vandalism	Convenient to Telephone Lines	Remarks
Palmdale Area						
5N/12W-						
1N1	149.3	None	Weak (0.01)	Good	Yes	
1N2	47.3	Unknown		Good	Yes	
2J1	91.0	Unknown		Poor	Yes	
2K5	-	Fair (0.10)	Fair (0.02	Fair	Yes	
2K6	56.8	Unknown		Fair	Yes	
3D2	26.0	None	Fair (0.02)	Poor	Yes	
3N1	442.0	Good (0.35)	Good (0.06)	Fair	Yes	Good strain meter.
4H1	130.8	Excellent (0.50)	Excellent (0.10)	Fair	No	Good strain meter.
4J2	69.1	Unknown		Excellent	Yes	
4J4	222.3	Fair (0.15)	Good (0.05)	Good	Yes	Good strain meter.

Table 5 (continued)

State Well Number	Depth (feet)	Response to Atmospheric Pressure (feet)	Response to Earth Tides (feet)	Protection from Vandalism	Convenient to Telephone Lines	Remarks
5N/12W-						
4L2	142.0	Unknown		Fair	Yes	
14C1	646	None	Good (0.04)	Fair	No	Good strain meter.
5N/11W-						
7G2	-	None	Poor (0.01)	Unknown		
24G1	-	Good (0.20)	Excellent (0.10)	Unknown		Good strain meter.
Valyermo Area						
5N/10W-						
30L1	196	Poor	Poor	Poor	No	
33K1	44	None	None	Excellent	Yes	TIMS installed, not operating.
33R1	-	None	None	Fair	No	
4N/10W-						
10Q1	868	Poor	Poor	Good	Yes	
11B1	260	Good (0.25)	Good (0.05)	Good	Yes	Good strain meter.

Table 5 (continued)

State Well Number	Depth (feet)	Response to Atmospheric Pressure (feet)	Response to Earth Tides (feet)	Protection from Vandalism	Convenient to Telephone Lines	Remarks
4N/9W-						
16L1	152	Good (0.30)	Good (0.05)	Good	Yes	Good strain meter
San Jacinto Valley Area						
3S/2W-						
8E1	181	Unknown		Poor	Yes	
15F1	-	Unknown		Poor	No	
26R1	-	Unknown		Fair	Yes	
Anza Area						
7S/3E-						
13D5	83	Good (0.20)	Poor (0.01)	Excellent	Yes	
23B1	185	Good (0.30)	Good (0.06)	Excellent	Yes	Good strain meter, TIMS installed, not operating.
23R1	94	Good (0.30)	Fair (0.03)	Excellent	Yes	
Borrego Valley Area						
10S/6E-						
36Q1	330	Unknown		Poor	No	

Table 5 (continued)

State Well Number	Depth (Feet)	Response to Atmospheric Pressure (feet)	Response to Earth Tides (feet)	Protection from Vandalism	Convenient to Telephone Lines	Remarks
10S/7E-						
30G1	-	Unknown		Poor	No	
11S/6E-						
1C1	116	Fair (0.10)	Fair (0.02)	Poor	No	Good strain meter.
3N4	71	Poor (0.05)	Good (0.05)	Poor	Yes	Good strain meter.
<u>Ocotillo Wells Area</u>						
11S/8E-						
33P1	374	Fair (0.10)	Fair (0.03)	Poor	No	
12S/8E-						
9Q1	± 200	Unknown		Poor	No	
10E1	110	Unknown		Poor	No	

recorder has never been installed on the well.

Wells which have been identified as good strain meters on the basis of their response to earth tides are noted on Table 5. Installation of satellite platforms or TIMS should be considered for these wells.

POSSIBLY ANOMALOUS LONG-TERM WATER-LEVEL CHANGES IN AREA OF SOUTHERN CALIFORNIA UPLIFT

As noted in the preceding section on "Long-Term Water-Level Changes", several wells in the area of the southern California uplift (Castle et al, 1976) between Palmdale and Valyermo have shown peculiar changes in water level within the past year or so. A longer period of observation is required to determine whether the changes are anomalous. They may very well be the result of delayed response to seasonal rainfall, following a long drought, or due to other variations in surface or subsurface flow, and probably would not have been considered significant by themselves. However, changes in the strain pattern and other phenomena have also been observed in the southern California area during about the same period as the water-level changes. Details of the nature and timing of other geophysical changes have not been formally released, thus we cannot make direct comparisons between our observations and those of other investigators.

The solid lines in Fig. 51 are the hydrographs (Figs. 22-25, 27, 28, 32, 33) for the eight wells in the Palmdale-Valyermo area which show water-level changes since early 1979 different from what would have been predicted based on the previous history of water-level changes and seasonal rainfall. The dashed lines represent the hydrograph which would have been predicted. If the water-level changes (Fig. 51) are the result of tectonic strain, the mechanism and significance are unknown. However, it is interesting that five of the eight wells with possibly anomalous water-level changes have been identified as good strain meters based on their response to earth tides (Table 5). The response to earth tides of well 5N/12W-4J2 is unknown, and wells 5N/10W-30L1 and 4N/10W-10Q1 show poor response to earth tides. The six wells which show an unexpected rise in water level are located west of the earthquake swarm that occurred in 1976-1977 (McNally et al, 1978), whereas those which show water levels lower than would have been predicted are located east of the earthquake swarm.

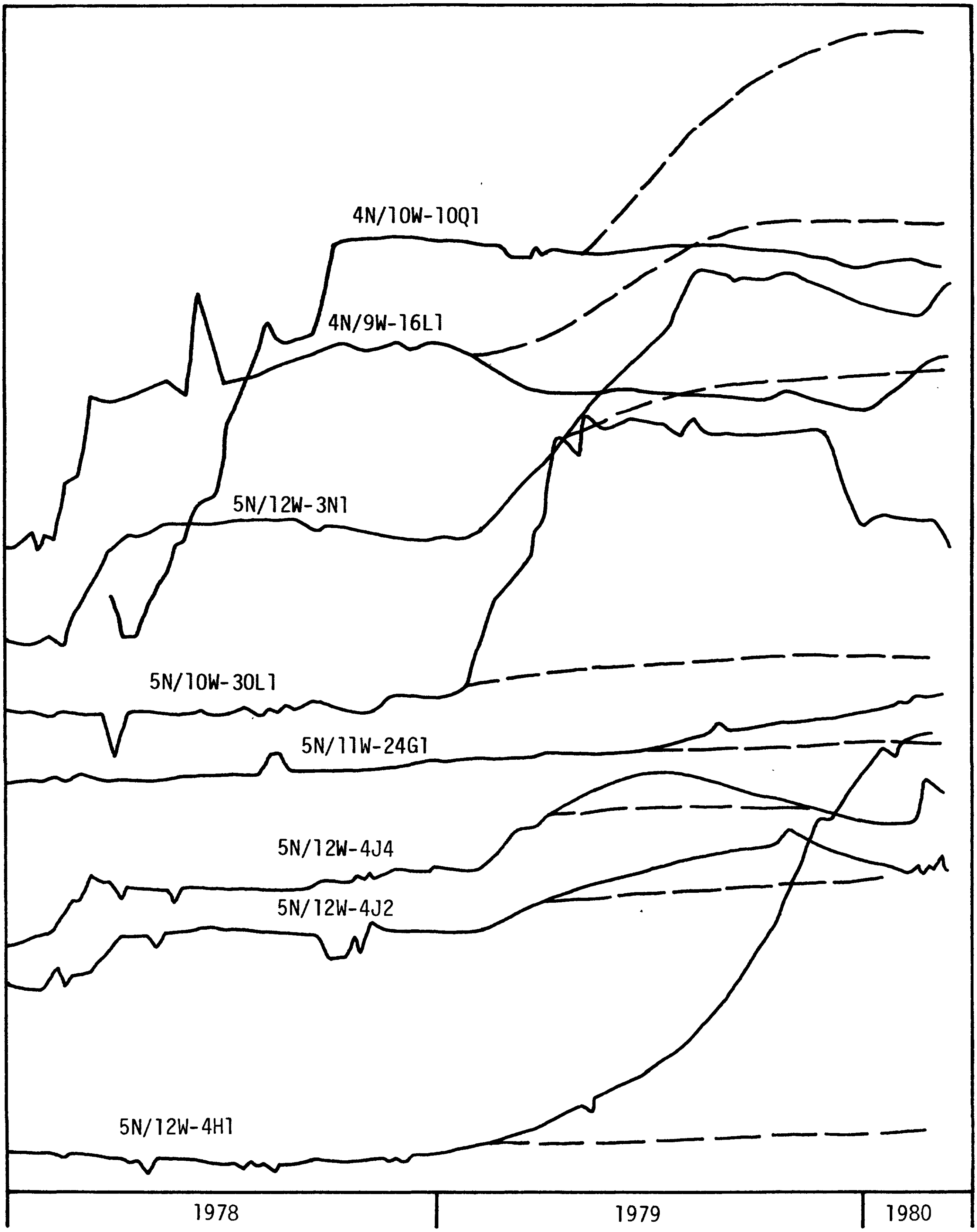

Figure 51 - Comparison of actual (solid lines) and predicted (dashed lines) water-level changes in observation wells, Palmdale-Valyermo area. See Figs. 22-25, 27, 28, 32 and 33 for complete hydrographs.

CURRENT ACTIVITIES AND FUTURE PLANS

An effort has been made during the first half of the current contract period to increase the reliability of measurements and to identify wells that appear to be good strain meters and are least affected by rainfall. Toward these ends, additional mechanical digital gauges are being fabricated to simplify measurements by volunteers. After nearly three years endeavoring to develop a continuous recording device that would fit entirely into the well casing and thus be essentially vandal-proof, this effort has been terminated because of the unreliability and inaccuracy of the devices. Instead, concrete block and steel housings are being constructed around Stevens recorders in vandal-prone areas. These installations have been effective to date.

Lamar-Merifield personnel have been instructed to follow standardized field procedures detailed in their field notebooks. The chalked tape has been substituted for the self-potential meter for probing wells with Stevens recorders to minimize the possibility of error in water-level measurements at the time the charts are changed.

Three satellite platform water-level recorders provided by John Bredehoeft of the U.S. Geological Survey are planned for the Palmdale-Valyermo area. One is planned for well 5N/12W-14C1 (Fig. 2), the second is planned for 4N/10W-16L1 (Fig. 3) and the third is planned for the new well drilled by the Geological Survey at the Crystalaire Country Club, two miles north of Valyermo.

Additional TIMS units may be installed on well-protected wells convenient to telephone lines if the two experimental units can be made to function properly. To date, excessive noise on the phone lines between Caltech and the wells has prevented transmittal of the water well data.

Several wells have yet to be tested for their response to earth tides and atmospheric pressure with Stevens recorders. To the extent that funds permit, these wells will be prepared for Stevens recorders, and additional wells will be selected for possible installation of either satellite platforms or TIMS.

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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 two 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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