UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# GROUND-WATER-LEVEL MONITORING FOR EARTHQUAKE PREDICTION--

# A PROGRESS REPORT BASED ON DATA COLLECTED IN SOUTHERN CALIFORNIA, 1976-79

By W. R. Moyle, Jr.

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, SECRETARY

GEOLOGICAL SURVEY

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## CONVERSION FACTORS AND ABBREVIATIONS

Factors for converting the inch-pound system to the International System (SI) of units are listed below. All units reported in this publication are those actually measured on instruments by the author or by other investigators or agencies. Both inch-pound units and SI units have been used because small errors arise from rounding before computation and because of the massive amount of data involved that will soon be computerized for use in any units desired.

| Multiply | By | To obtain |
|---|---|---|
| acre | 0.40470 | ha (hectare) |
| ft (foot) | 30.48 | cm (centimeter) |
| gal/min (gallon per minute) | 0.06309 | L/s (liter per second) |
| in (inch) | 25.4 | mm (millimeter) |
| mi (mile) | 1.609 | km (kilometer) |

Use the following to convert degrees Fahrenheit to degrees Celsius:
Temp °C = (temp °F-32)/1.8

Abbreviations used in text:

Pacific daylight time (P.d.t.) + 7 hours = Universal time coordinated (u.t.c.)
Pacific standard time (P.s.t.) + 8 hours = Universal time coordinated (u.t.c.)
Greenwich mean time (G.m.t.) = Universal time coordinated (u.t.c.)

National Geodetic Vertical Datum of 1929 is a geodetic datum derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts and as such does not necessarily represent local mean sea level at any particular place. To establish a more precise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level."

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## ABSTRACT

The U.S. Geological Survey is conducting a research program to determine if ground-water-level measurements can be used for earthquake prediction. Earlier studies suggest that water levels in wells may be responsive to small strains on the order of $10^{-8}$ to $10^{-10}$ (dimensionless).

Water-level data being collected in the area of the southern California uplift show response to earthquakes and other natural and manmade effects. When computer analysis is completed, the data may indicate the presence of precursory earthquake information.

## INTRODUCTION

### Background

Changes in water levels in artesian wells have been suggested as possible precursors to earthquakes. Studies by Bredehoeft (1967) showed that an aquifer-well system is responsive to Earth tides and should be responsive to small strains on the order of $10^{-8}$ to $10^{-10}$. In 1976 the U.S. Geological Survey began collecting hydrologic data from nine water wells in southern California in a research program designed to identify water-level changes that may reflect strain in the Earth's crust in the area of the southern California uplift. The knowledge gained has been thought to have potential value in predicting earthquakes.

### Purpose and Scope

The purpose of this study is to collect ground-water-level data and other pertinent hydrologic data in the area of the southern California uplift and to provide these data to scientists of the U.S. Geological Survey's earthquake prediction program for coding and computer analysis. Data collected between September 1976 and January 1979 are presented in this progress report, along with some of the preliminary findings. Correlations between water-level data and known seismic activity, as well as some factors that control optimum well location, are discussed.

Water levels in wells may be influenced by Earth tides, atmospheric pressure change, other wells pumping, precipitation, underground nuclear tests, heavy vehicles passing, and earthquakes. To observe and evaluate all these effects, data are being continuously collected by using analog water-level recorders, recording microbarographs, and, in one place, a recorder to monitor changes in the ground-water temperature at the bottom of a well in the San Andreas fault zone. In addition, pumpage, seismic, and weather records are being evaluated.

The study began in September 1976 with the installation of five water-level recorders and one microbarograph along a 19-mile segment of the San Andreas fault near Palmdale, Calif. (fig. 1). This area was selected because it generally parallels the axis of the southern California uplift (fig. 2), an active tectonic swell in land surface discovered by Castle, Church, and Elliot (1976). Further evaluation of leveling data by Castle (Science News, 1977) indicated that the area of the southern California uplift was much larger than originally mapped. Comparison of figures 2 and 3 shows this difference. A review of data for the locations of earthquake epicenters in southern California (fig. 1) indicated that little seismic activity was occurring in that part of the San Andreas fault zone where the five water-level recorders were located. The water-level monitoring program was therefore expanded to include, by March 1978, areas with a higher frequency of seismic activity. Recorders have been placed on wells near the towns of Imperial, Twentynine Palms, Sunfair, Newhall, and at Koehn Lake. One additional recorder was installed on well 2S/1E-25J1 on the Morongo Indian Reservation in January 1979.

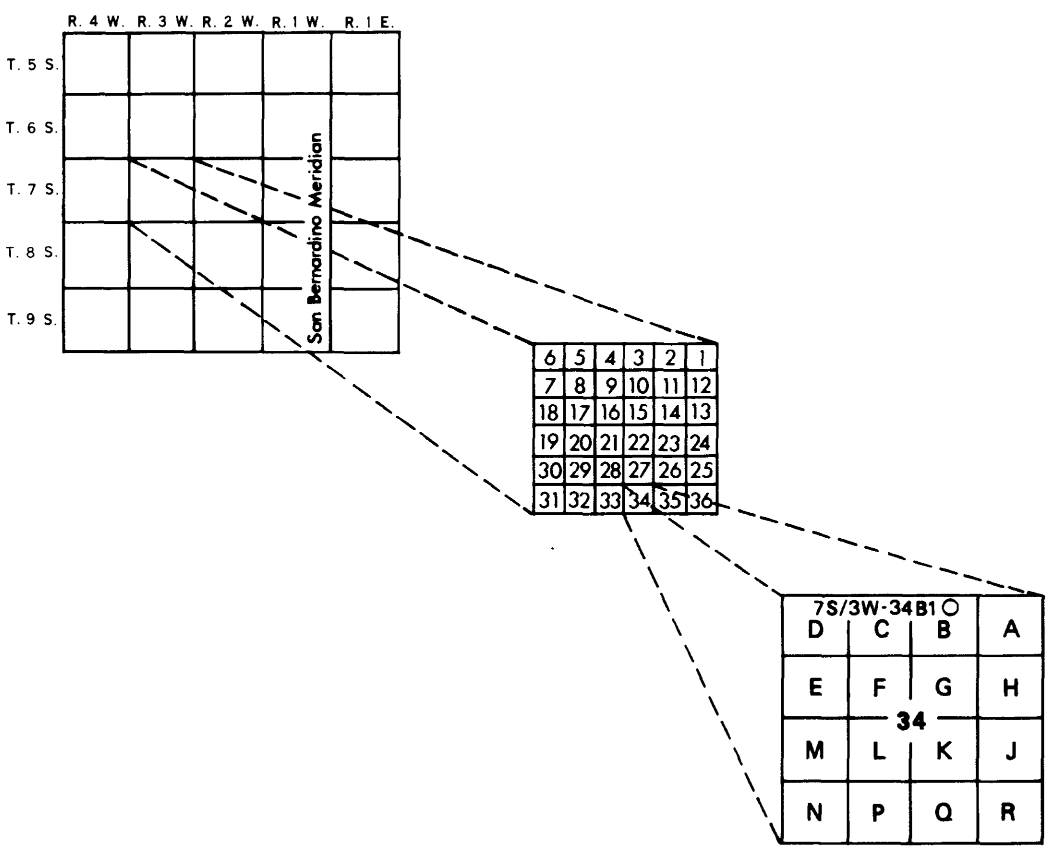
The data collected for this study are presently being prepared for computer analysis by Dr. Philip Westlake at Environmental Dynamics, Inc., in Los Angeles, Calif., under a grant from the Geological Survey. Computer programs are being developed in an attempt to separate natural and manmade effects from possible earthquake precursory data contained in the water-level records. The original records are stored at the Geological Survey office in Laguna Niguel, Calif. Microfilm copies of these records have been provided to the U.S. Geological Survey Office of Earthquake Studies, Menlo Park, Calif., and to Environmental Dynamics, Inc.

## Acknowledgments

Many people have aided in the collection of the data shown in this report. Some have given permission to use their wells, some have collected data, and others have supplied data from their files. The following persons have helped materially in the collection of data, and their help is greatly appreciated: Donald J. Colville, Chief Ranger, National Park Service Headquarters, Twentynine Palms, Calif.; John and Nadine Crawford, Granada Hills, Calif.; Marion Fisher, Shelton, Wash.; Charles Kindshita, Los Angeles, Calif.; Ken Larklow, Palmdale Water District, Palmdale, Calif.; Victor Madrid, foreman, Frank Arciero Ranch, Cantil, Calif.; William Manetta, Manager, Santa Clarita Water Co., Newhall, Calif.; Gloria O'Brien, Beautiful Valley Real Estate Co., Leona Valley, Calif.; Dr. F. Kirk Odencrantz, U.S. Naval Weapons Center, China Lake, Calif.; James F. Rogers, Utility Engineer, U.S. Marine Corps Base, Twentynine Palms, Calif.; R. G. Wilkinson, Regional Park Division, San Bernardino County, Calif.; Robert Wilson, Imperial Irrigation District, Imperial, Calif.; and the Mission Indians on the Morongo Indian Reservation.

## Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public land. For example, in the well number 7S/3W-34B1, the part of the number preceding the slash indicates the township (T. 7 S.), the part between the slash and the hyphen indicates the range (R. 3 W.), the number between the hyphen and the letter indicates the section (sec. 34), and the letter indicates the 40-acre subdivision of the section according to the lettered diagram below. Within the 40-acre tract wells are numbered serially, as indicated by the final digit. An S is placed at the end of the well number to indicate the San Bernardino base line and meridian. Thus, well 7S/3W-34B1S is the first well to be listed in the NW¼NE¼ sec. 34, T. 7 S., R. 3 W., San Bernardino base line and meridian. Well 30S/37E-13C1M is the only well in this report that is numbered from the Mount Diablo base line and meridian.



# WATER-LEVEL DATA

## Current Observations

Water-level measurements for this study began when the first recorder was installed in September 1976. Figure 1 shows the location of recording stations used for this study. Figures 4-13 show the depth to water in each well, the length of time each recorder has been in operation, and the magnitude of daily water-level fluctuations. The figures also show the daily barometric pressure change and amount of precipitation near each well. Figure 12 shows the daily change in water temperature at the bottom of well 6N/13W-8Q1 compared with the daily maximum and minimum air temperatures.

The hydrographs in figures 4-13 were constructed from the daily high and low water-level measurements taken from continuous water-level charts. The hydrograph for well 30S/37E-13C1 (fig. 4) shows a rising water level beginning in May 1978 due to ground-water recharge from heavy precipitation in February and March 1978. The hydrograph for well 3N/8E-29C1 (fig. 6) shows a small amount of decline caused by a well pumping 2,300 ft from the recording well. Daily pumpage from this nearby well (3N/8E-29L1) is included on the same graph (fig. 6). The hydrograph for well 4N/15W-22H1 (fig. 7) shows the effects of nearby pumping. This well, in an area of high seismic activity, was destroyed by a flash flood caused by heavy rains in January and February 1978. The salvaged recorder was placed on well 4N/16W-27H1 (fig. 8) and shows recovery of the water level during March and April 1978 due to recharge from flooding on the nearby Santa Clara River. From April through September 1978 the water level declined because of local pumping in the area. Wells 5N/11W-7G2 (fig. 9) and 6N/13W-8Q1 (fig. 12) were both drilled in the San Andreas fault zone, and both show annual fluctuations of water levels caused by recharge from precipitation. Except in well 6N/13W-8Q1, the 1978 water-level fluctuations caused by recharge are greater than those in 1977 because of the greater-than-normal precipitation in 1978. The hydrograph for well 5N/11W-24G1 (fig. 10) shows that the well has a relatively stable water level that has fluctuated less than 1 ft in more than 2 years. Well 15S/14E-18C1 (fig. 13) also has a stable water level. The casing in well 5N/12W-2K5 (fig. 11) collapsed and the well went dry; it therefore was dropped from the monitoring program.

This report includes data on each recorder well and on other wells that may affect the recorder well because of pumping. Tables 1-3 contain these hydrologic and seismic data. Table 1 describes wells that are presently being monitored by recording equipment and some wells that were formerly monitored. The table also includes some pumping wells that may affect the monitored wells. Table 2 contains chemical analyses of water from several wells, and table 3 presents drillers' logs for wells.

## Relation of Current Water-Level Changes to Earthquakes or Unknown Phenomena

Several of the water-level recorder charts show fluctuations at the time of earthquakes. Most of the charts that have recorded earthquakes do not show any apparent precursory data. Computer processing of the data may show results that are not readily apparent.

Four charts show spiked fluctuations. A spiked fluctuation is a sharp fluctuation indicated by movement of the pen up and down over the same trace through one or more cycles in a short interval of time. Two of these spiked fluctuations can be correlated with the times of nearby earthquakes. Figure 14 shows the effect of an earthquake on water levels in well 5N/12W-2K5 near Palmdale, Calif. This earthquake, with a magnitude of 4.1 on the Richter scale, occurred October 16, 1976, at 10:38:11.9 p.m. P.d.t. The earthquake was centered about 8 mi northeast of Newhall and about 20 mi from the recorder. The chart shows at least two fluctuations: the first was 0.07 ft and the second was 0.035 ft. It also shows that the water level was offset by 0.01 ft in a downward direction after the earthquake. This offset may represent a dilatational strain produced by the earthquake. As noted on the chart, the gradual declining trend of the water level during the 2-week period prior to the earthquake ceased for 3 days immediately following the earthquake. It could be speculated that this 3-day period of almost no change in water level, which interrupts the trend, may have been produced by the earthquake.

Figure 15 shows the recorder chart for well 4N/15W-22H1, which recorded the effect of an earthquake with a magnitude of 4.4 on August 11, 1977, at 7:19 p.m. P.d.t. The resultant water-level fluctuation was 0.05 ft. The epicenter for this earthquake was 3 mi southwest of the recorder on the San Gabriel fault. This recorder was using a 1:10 gear ratio to accommodate large fluctuations in the water level caused by a pumping well 247 ft away. The pumping rate of the well was changed from 630 gal/min to 530 gal/min the day before the earthquake. Even though the pumping rate was changed, the water level seems to have been reacting unusually from about 12 hours before the earthquake until 10 hours after. A projection of the water-level trend after the earthquake does not line up with the water-level trend before the earthquake. Furthermore, the water level does not show the normal curve expected from a well that has had the pumping rate reduced. The sigmoidal shape of the drawdown curve suggests that the water level was affected after the earthquake. The 1:10 gear ratio makes interpretation difficult. Pumping stopped at about noon on August 19, and the chart shows the water-level recovery. This well was destroyed in February by flooding from storms in January and February 1978. The recorder was removed and has since been installed on well 4N/16W-27H1, located a few miles to the west, on the other side of the San Gabriel fault.

Figures 16 and 17 show two recorder charts that appear to have recorded the same event on June 6, 1977. The Geological Survey's monthly publication, "Preliminary Determination of Epicenters," did not list an earthquake or nuclear detonation for this time. A third recorder about 25 mi away may have also recorded this event, but its correlation is speculative. Both recorder wells, 6N/13W-8Q1 and 5N/11W-7G2, are near Palmdale within the San Andreas fault zone and about 13 mi apart. Both recorders indicated an initial downward spike on the charts of 0.045 ft and 0.025 ft, respectively. Prior to the event, well 6N/13W-8Q1 had a declining water level and well 5N/11W-7G2 had a rising water level. Well 8Q1 stopped declining for 2 days after the event before returning to a normal decline. The water level in well 7G2 continued to rise. No unusual changes in water-level trends or fluctuations were apparent prior to the event. The microbarograph at Palmdale recorded this same event as a sharp increase in barometric pressure. An increase in barometric pressure could cause a lowering of the water level, which is what happened in this case. Barometric pressure does not normally change in this manner over such a great distance (at least 13 mi and possibly as great as 25 mi). Perhaps a small local earthquake shook the microbarograph and caused the fluctuation. The other possibility is that a sonic boom caused the fluctuation. The author, however, was standing at a well during a sonic boom and did not observe any fluctuation. Many sonic booms occur in the Palmdale area and do not cause problems with the recording instruments.

## Historical Observations

A review of water-level recorder charts in the files of the Geological Survey identified three wells (figs. 18, 19, and 20) in the study area in which water levels responded to strong earthquakes that occurred in Chile during May and June 1960. These earthquakes occurred about 4,000 mi from the recorders. The three wells are near Twentynine Palms, Calif., within 5 mi of one another. Figure 21 shows the location of wells with relation to the Surprise Spring fault, which is a ground-water barrier (Riley and Bader, 1961). The charts, all from wells tapping artesian aquifers, were recorded at the same time that a sequence of 134 earthquakes were occurring in Chile between May 21 and 31, 1960. The strongest earthquake in this sequence had a magnitude of 8.3 (revised from 8.4, Saint-Amand, 1961) on the Richter scale, with several other earthquakes above magnitude 7 and many above magnitude 5. Table 4 shows the dates and times of some of the stronger earthquakes (Saint-Amand, 1961).

The charts from these three wells are included to demonstrate that strong earthquakes affect water levels in wells that are at great distances from the earthquake epicenter. One of these wells (3N/8E-29C1) is presently being monitored. Well 2N/7E-2C1 shows the largest water-level fluctuations from the Chilean earthquakes and is nearest the Surprise Spring fault.

## FACTORS AFFECTING WATER-LEVEL DATA

Water levels in wells fluctuate for many reasons. Some fluctuations are caused by activities of man, while others are caused by processes of nature. Most of the major factors causing water-level fluctuations are discussed in the following paragraphs.

### Barometric Pressure

Barometric-pressure data are being collected so that the effect of pressure changes can be removed from water-level records. An inverse relation exists between barometric pressure and water-level measurements, particularly in confined aquifers: when the barometric pressure increases the water level tends to go down, and vice versa. Initially, only one microbarograph was recording in conjunction with the five water-level recorders operating near Palmdale. Three additional microbarographs were installed to collect data near the water-level recorders when the program was expanded to include water-level data from other areas in southern California. Figures 4-13 show the daily fluctuations in barometric pressure for the period of record for each well on the same graph with the water-level hydrograph to show its relation to water-level change. A gap in the record for the microbarograph at Palmdale (fig. 12) begins April 10, 1978, when vandals stole the instrument. This record resumed after a new instrument was placed in the field at a safer location. Other microbarograph recorders were installed later at Koehn Lake, Twentynine Palms, and Imperial. These records can be used to extrapolate barometric pressure to Palmdale during the period the record was not collected.

Barometric pressure is also being recorded at the Joshua Tree National Monument headquarters at Twentynine Palms by the National Park Service. Between November 15, 1977, and January 30, 1978, the barometric pressure at Twentynine Palms was recorded on a standard barograph; after January 30, 1978, it was recorded on a microbarograph to enhance the definition of the vertical scale.

### Earthquake Epicenters

Figure 1 shows all earthquake epicenters reported in southern California between September 30, 1976, and May 1, 1978. The first water-level recorder was installed September 30, 1976. This map was drawn from data supplied by the U.S. Geological Survey and published in "Preliminary Determination of Epicenters" (1976-78). The earthquakes reported in these publications generally are of magnitude 3 or larger. Earthquakes below magnitude 3 are not reported unless they are centered or felt in populated areas. Many small fluctuations on water-level charts may be due to minor local earthquakes not reported.

## Earth Tides

Water levels in wells show some fluctuations that generally occur twice daily. These fluctuations are referred to as Earth tides and are caused mainly by the gravitational attraction of the Moon and to a lesser extent by the Sun. These are the same forces that cause the tides in the oceans; however, the ocean has a tidal lag due to friction and land masses blocking flow, and Earth tides do not. The difference in time between Earth tides in wells in southern California and ocean tides in the Los Angeles outer harbor is about 10 hours; thus, they are about 150 degrees out of phase. Because the Moon rises about 50 minutes later each day, the daily high and low water levels in wells also occur 50 minutes later each day for a period of 28 days, when the cycle repeats.

The magnitude of water-level fluctuations in wells varies with change in phase of the Moon. The largest water-level fluctuations occur during periods of new or full Moon when the Moon, Sun, and Earth are in alinement and the tidal forces are the greatest. The smallest water-level fluctuations occur during the first and third quarters of the Moon when the three heavenly bodies are unalined and the tide-producing forces are smallest.

Water-level data collected for this study indicate that in shallow nonartesian wells Earth tides induce water-level fluctuations of less than 0.3 cm and in deep artesian wells they induce fluctuations of as much as 4 cm. According to Bredehoeft (1967), strains of approximately $10^{-8}$ should be measurable in wells that produce Earth-tide fluctuations of 1-2 cm. Strahler (1963) indicated that some wells show water-level fluctuations as large as 7-15 cm due to Earth tides. Wells with large fluctuation of water levels due to Earth tides will probably manifest smaller amounts of strain in the formation than wells with small water-level fluctuations.

## Precipitation

Precipitation data are being collected at Palmdale, Mojave, Newhall, Imperial, Palm Springs, and Twentynine Palms by various individuals and published by the U.S. National Oceanic and Atmospheric Administration (1976-78). These data are being used to assess the changes in ground-water levels due to rainfall and flooding. Many wells being monitored in this program show rises in water level due to recharge from infiltration of local precipitation and from floodwater. Figures 4-13 show the daily precipitation from nearby rain gages along with the hydrographs for the period that the recorder wells were in operation.

## Temperature

Continuous temperature measurements are being made in the bottom of well 6N/13W-8Q1 in the San Andreas fault zone near Leona Valley to determine if the water temperature changes before an earthquake. The well is 155 ft deep and has a water level 22 ft below land-surface datum, or less, depending on recharge from precipitation. The daily fluctuations in temperature in this well (fig. 12) are between 0.01°C and 0.07°C; however, the maximum daily fluctuation in temperature was 0.25°C on October 18, 1978.

The temperature-recording equipment has been removed twice from this well since it was installed May 3, 1977. It was removed August 23, 1977, at the request of the well owner for a pumping test and again May 3, 1978, to repair the recorder. In both cases the centering on the recorder was slightly changed; therefore, the temperature data shown in figure 12 are slightly offset before and after these dates. The water-temperature graph shows relative temperature ranges rather than absolute values. This graph does show one large anomaly beginning September 6, 1978. Before this date the daily fluctuations are small; after this date they are much larger. Some precipitation occurred on this date, but larger amounts of precipitation that have occurred in the past have not caused this type of change. The daily maximum and minimum air temperatures for Palmdale are shown in figure 12 with the water temperatures for well 6N/13W-8Q1 for comparison. These air- and water-temperature measurements show some apparent correlation. Both changes occurred near the end of summer after the peak temperature in August. It is also interesting to note that the change in water temperature in well 6N/13W-8Q1 took place at about the same time (Oct. 4-6) that 15 earthquakes occurred near Tom's Place on the California-Nevada border about 170 mi north of the recorder. These earthquakes had magnitudes that ranged from 3.6 to 5.7 on the Richter scale.

Figure 22 gives an example of the daily water-temperature fluctuations. The fluctuations in temperature for May 4 and 5, 1977, represent the normal regimen, and the larger fluctuations on February 24 and 25, 1978, probably are the result of recharge from heavy rain and snow that occurred in January and February 1978.

No known earthquakes of magnitude 3 or above have occurred near the well since the temperature recorder was installed; therefore, whether the temperature might change in the well during or preceding an earthquake has not been determined.

## Pumpage

Pumpage records have been collected for some areas where water-level recorders are affected by nearby pumping. Figure 23 is an example of a water-level recorder well (3N/8E-29C1) being affected by a pumping well (3N/8E-29L1, fig. 6) 2,300 ft away. Both figures 6 and 23 show the measured pumpage and the effect of pumping on the water level recorded at the observation well. Figure 6 shows the complete record; figure 23 is a copy of the actual recorder graph. The pumping well was pumped intermittently for about 4 months during 1978. The rest of the year the recorder well was not affected by pumping.

A magnitude 4.4 earthquake occurred near Big Bear, about 35 mi from well 3N/8E-29C1, on February 28, 1978. This earthquake does not appear on the hydrograph for this well, perhaps because pumping from well 3N/8E-29L1 helped to mask any fluctuation the earthquake might have caused.

# WATER-LEVEL DATA REDUCTION

The data presented in this report are being reviewed by the Survey to determine if precursory earthquake information is present in water-level hydrographs. In the author's view, additional work is needed on the following aspects of the data which appear to hold the best promise of precursory information.

1. The barometric efficiency of individual wells may change with the rate of atmospheric loading. The barometric efficiency can be calculated from the data being collected.

2. A shift in phase between water-level fluctuations on the hydrograph and theoretical fluctuations occurs on some charts. This phase shift was first noted by Bredehoeft (1967, p. 3077) when he wrote, "In this investigation a shift in phase of up to 25° was found between the theoretical dilatation produced by the individual waves and the harmonic components reduced from the data. This phase shift is difficult to explain."

3. Water-level fluctuations larger than those expected to be caused by Earth tides and changes in barometric pressure sometimes occur in areas removed from pumping. Some wells show fluctuations that appear to have more than the two cycles of diurnal Earth tides and do not appear to correlate with changes in barometric pressure.

4. The trends of water levels may be changed because of small changes in porosity within the aquifer caused by changes in stress. The effects of barometric pressure and Earth tides must be removed before these effects can be analyzed.

## SUMMARY

The report includes several illustrations showing water-level recorder charts that reflect effects of known earthquakes. Some of the charts collected include water-level changes that may be related to small earthquakes, sonic booms, sudden changes in barometric pressure, nuclear tests, mine blasts, or some unknown phenomenon.

The data are presently being processed for computer analysis by Environmental Dynamics, Inc., under a grant from the U.S. Geological Survey.

Most wells presently being monitored by the Survey are privately owned, and some of them are in areas where ground water is being pumped for various agricultural and domestic purposes. The hydrographs of these wells show the effects of pumping, which may mask water-level changes related to earthquake activity. In order to minimize or eliminate these effects, wells may have to be drilled in isolated areas removed from pumping.

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 (p. 13 follows)

ILLUSTRATIONS

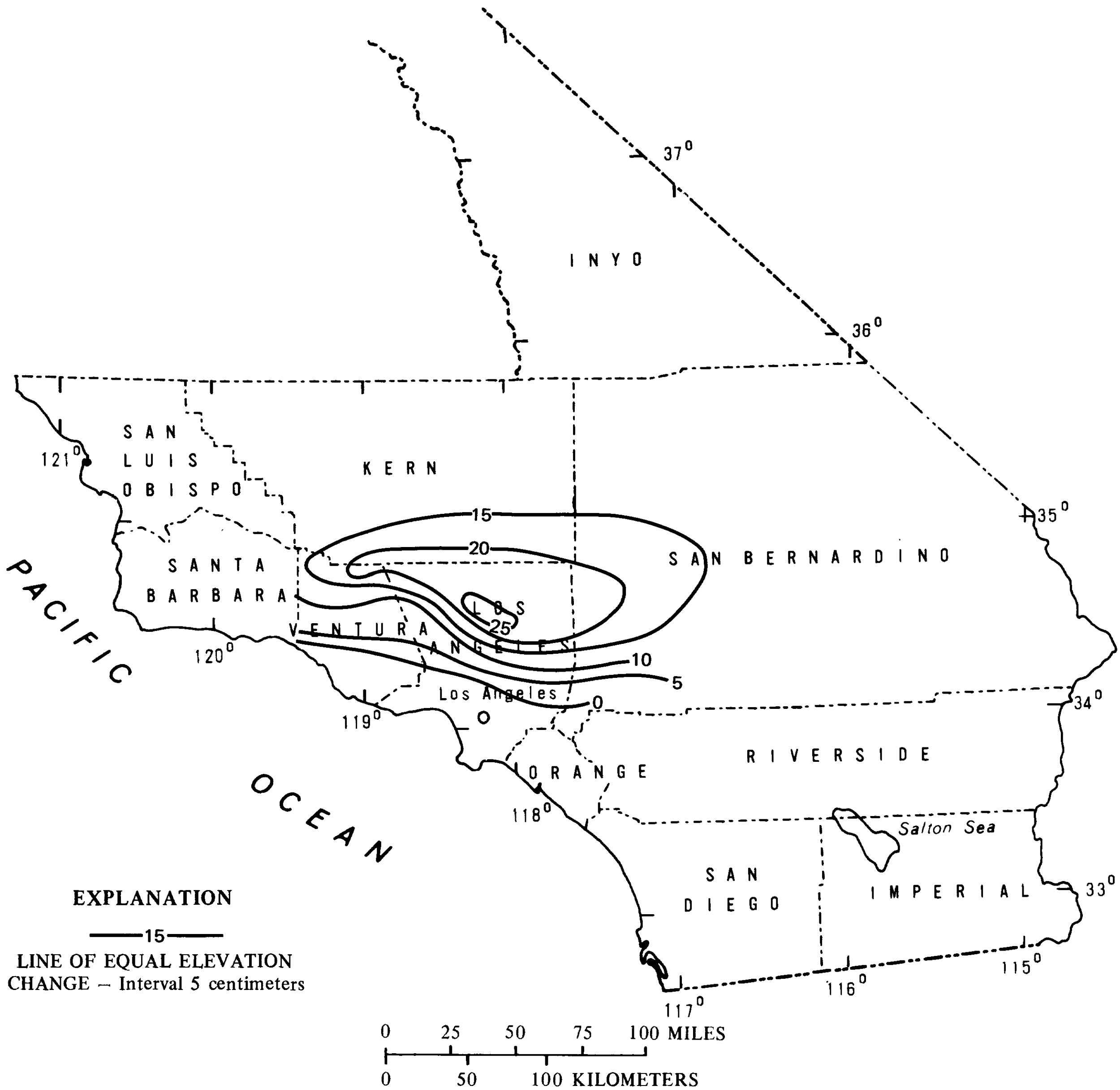



FIGURE 2.--Location and configuration of southern California uplift as depicted by Castle, Church, and Elliot, 1976, (copyright 1976 by the American Association for the Advancement of Science).

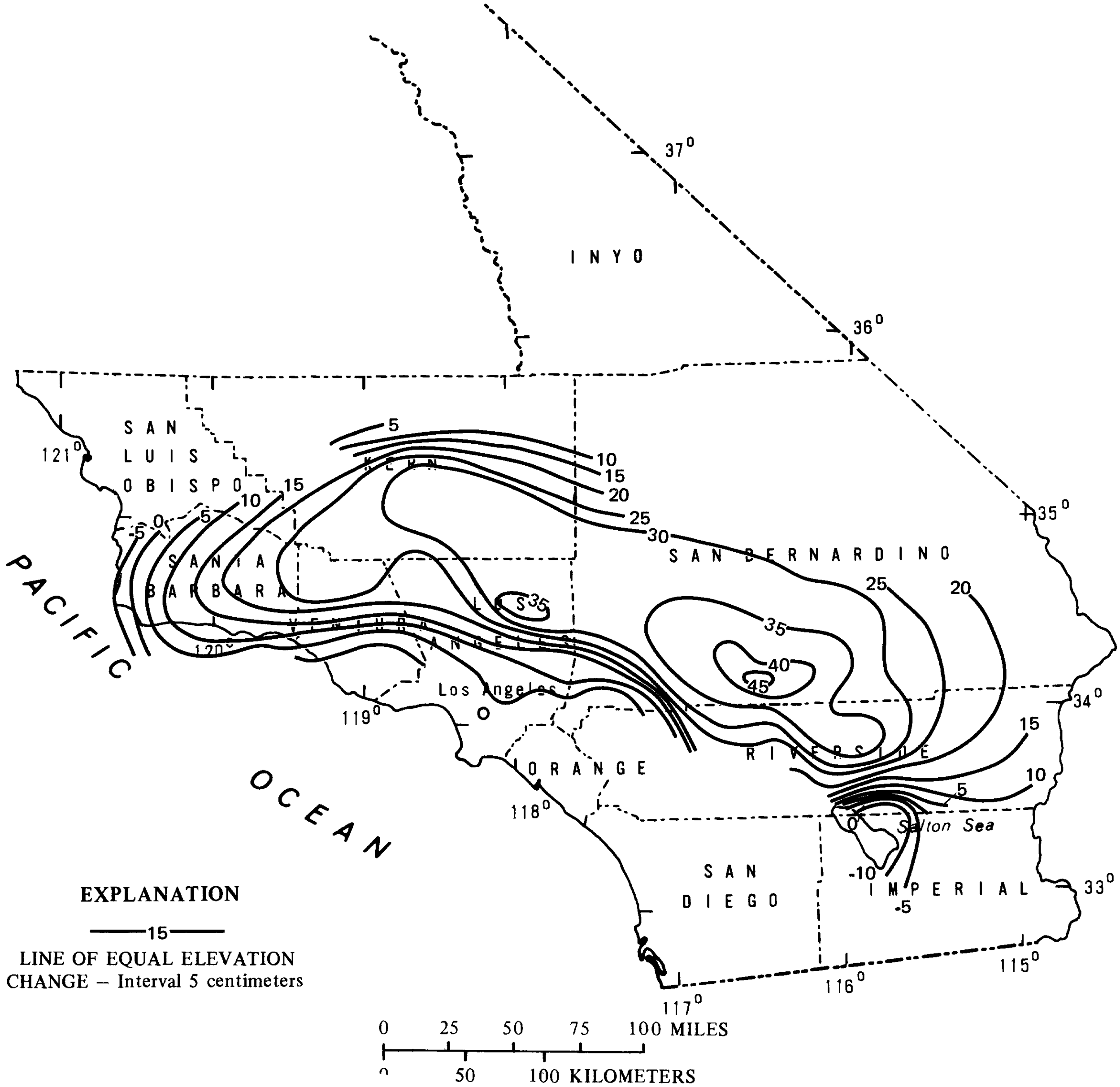



FIGURE 3.--Location and configuration of southern California uplift as depicted in Science News, 1977.

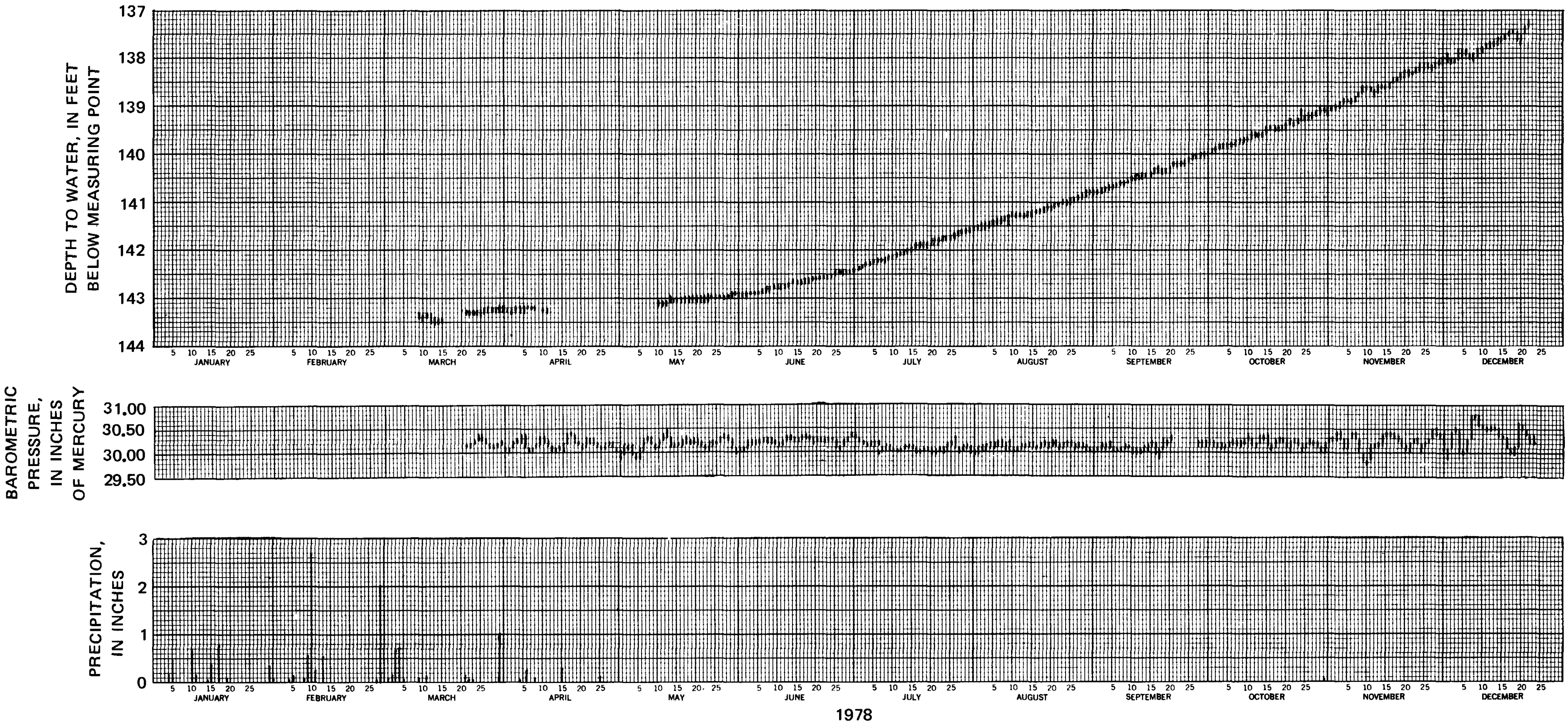



FIGURE 4.--Depth to water for well 30S/37E-13C1, barometric pressure in Fremont Valley, and precipitation at Mojave, 1978.

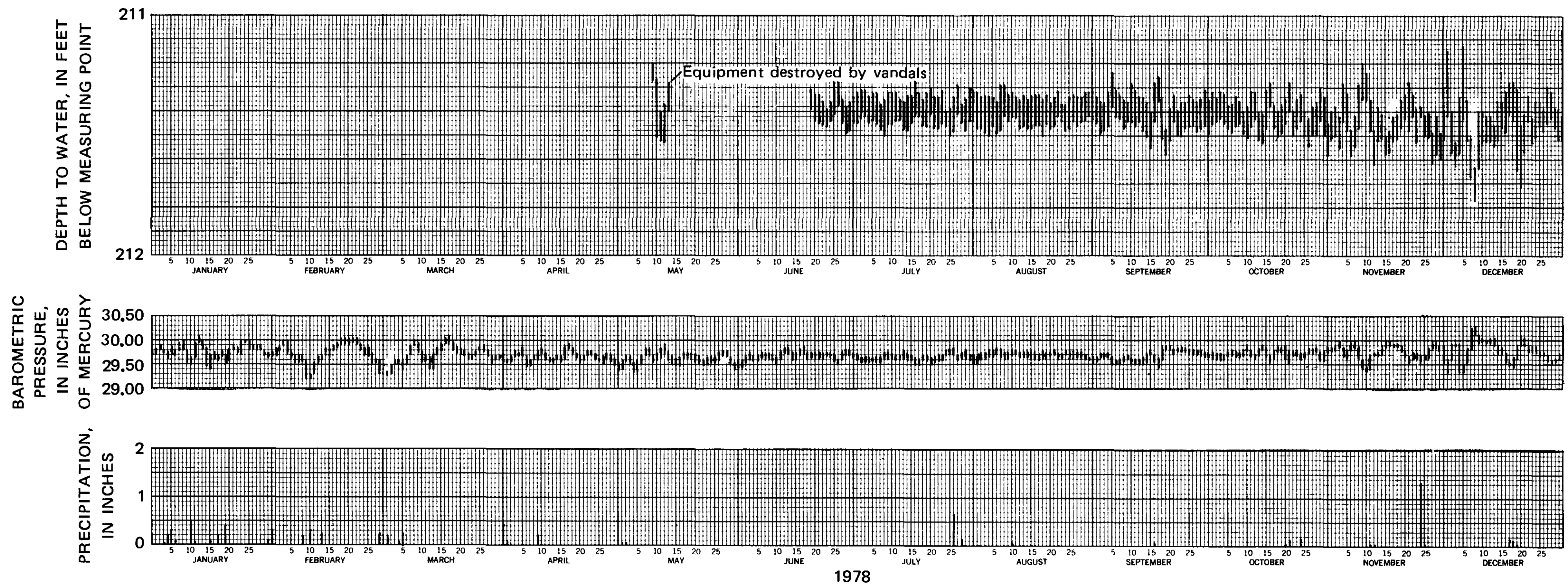



FIGURE 5.--Depth to water for well 1N/7E-23A1 and barometric pressure and precipitation at Twentynine Palms, 1978.

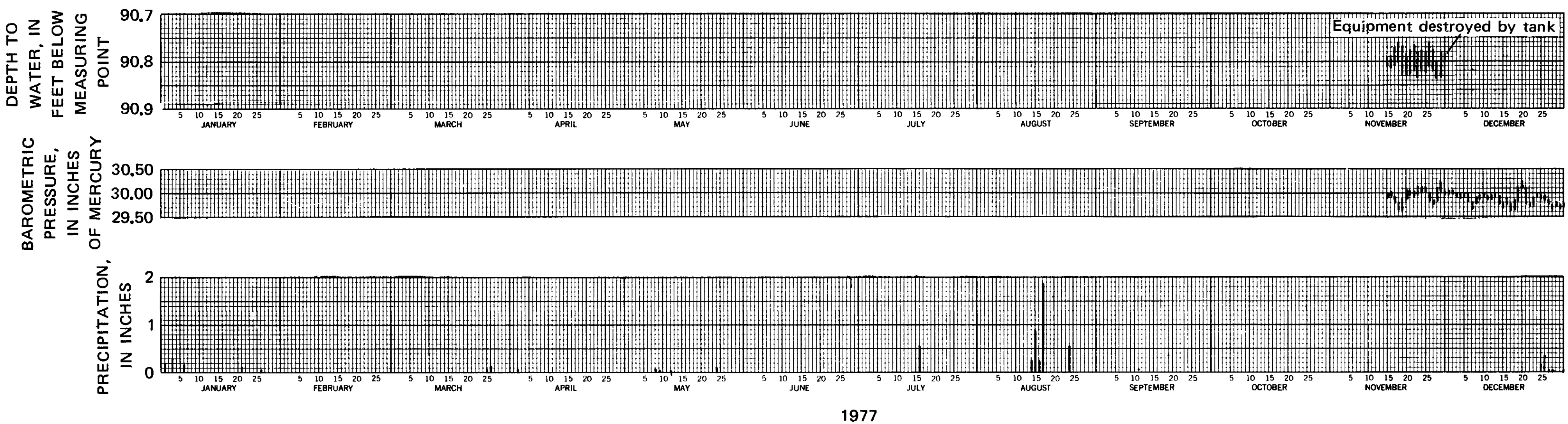



FIGURE 6.--Depth to water for well 3N/8E-29C1, barometric pressure and precipitation at Twentynine Palms, 1977 and 1978, and pumpage from well 3N/8E-29L1, 1978.

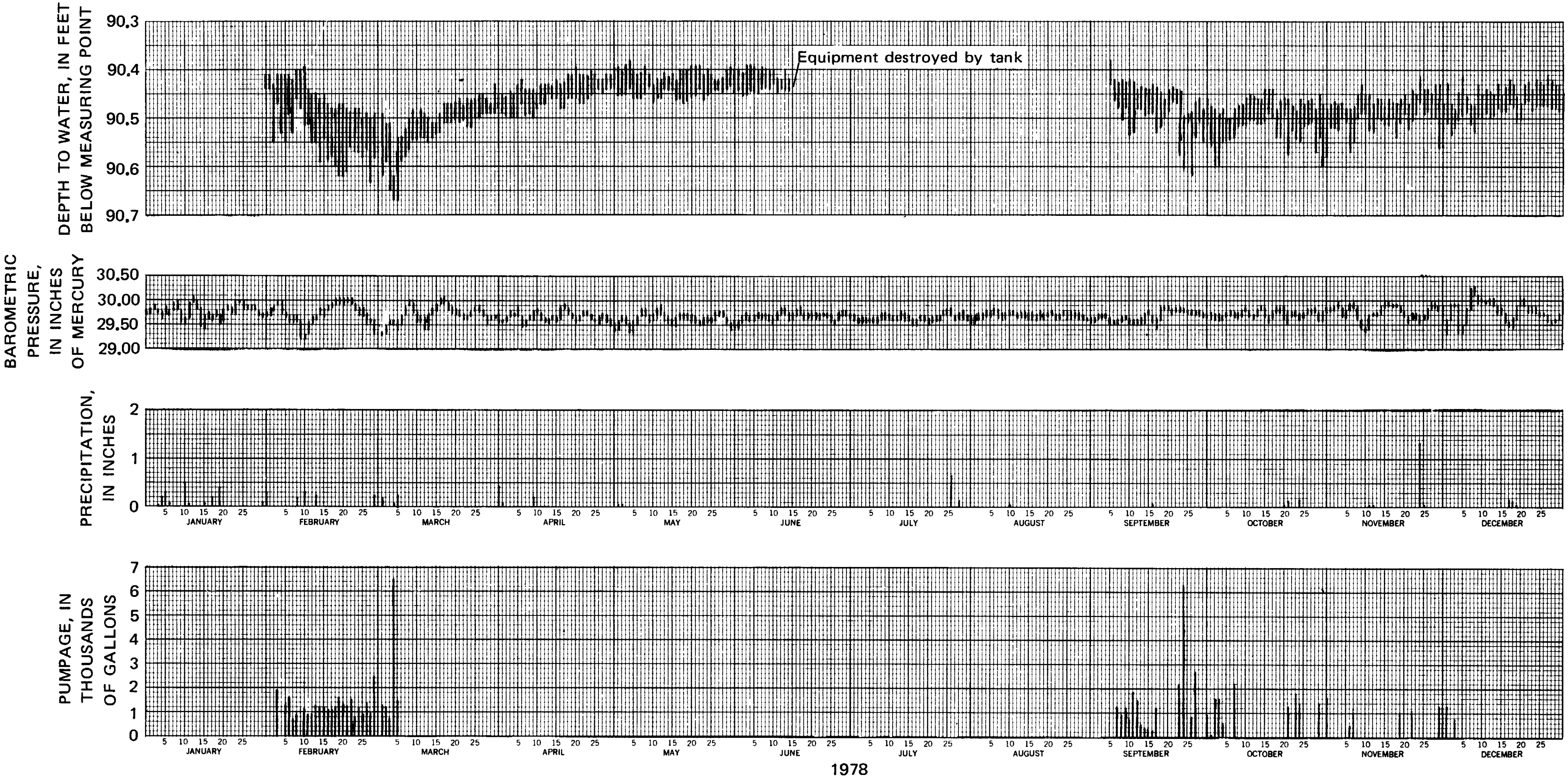



FIGURE 6.--Continued.

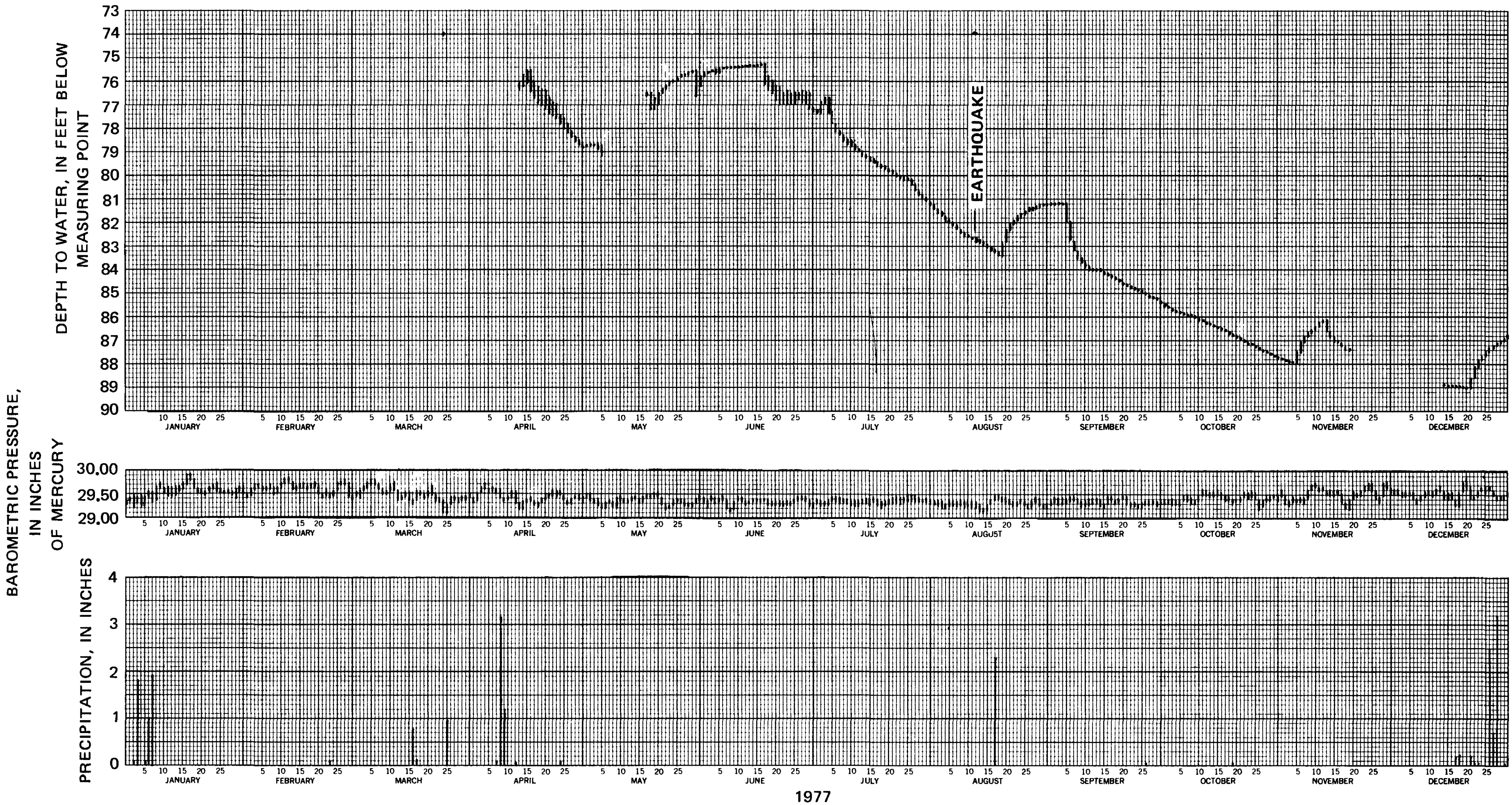



FIGURE 7.--Depth to water for well 4N/15W-22H1, barometric pressure at Palmdale, and precipitation at Newhall, 1977 and 1978.

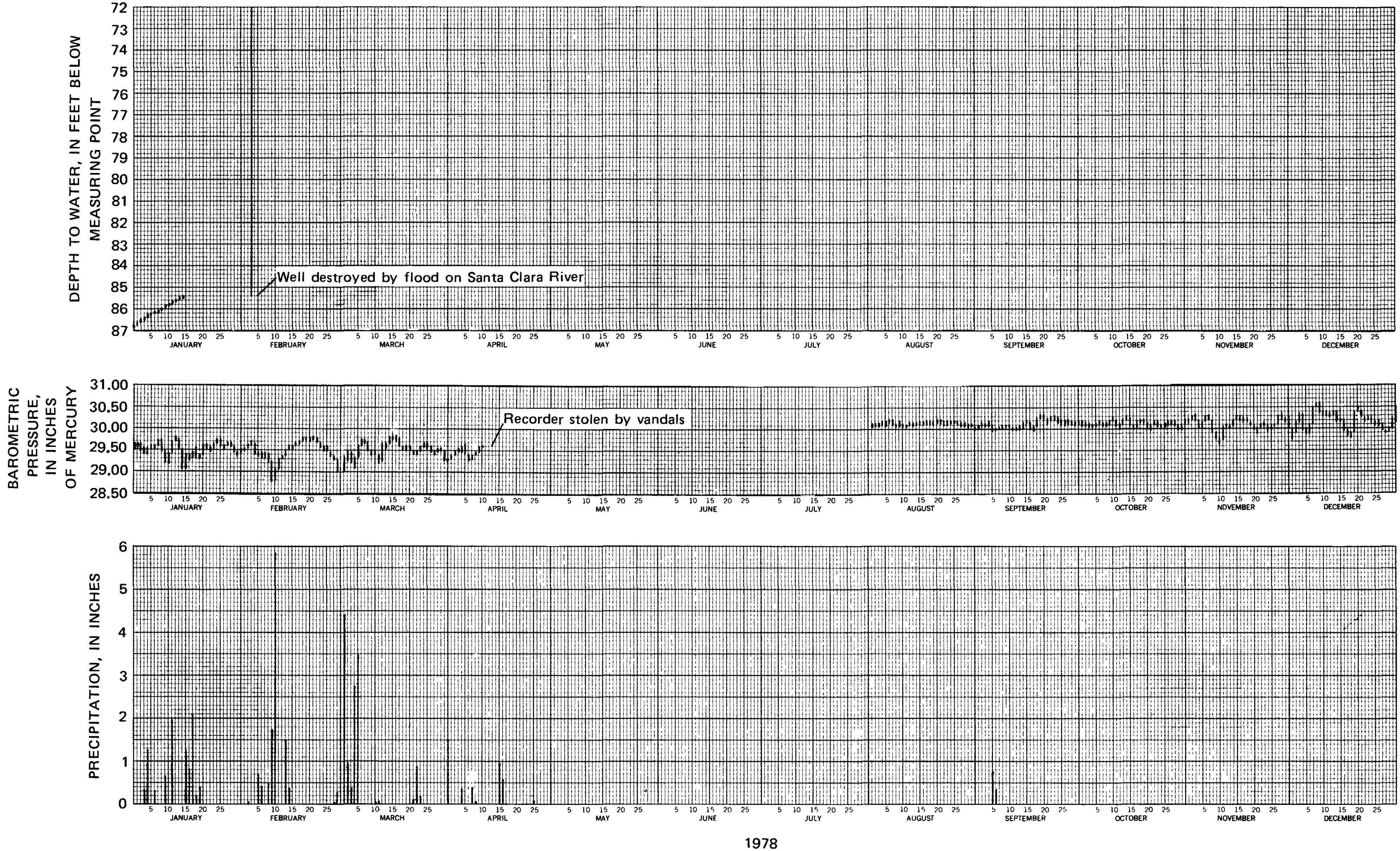



FIGURE 7.--Continued.

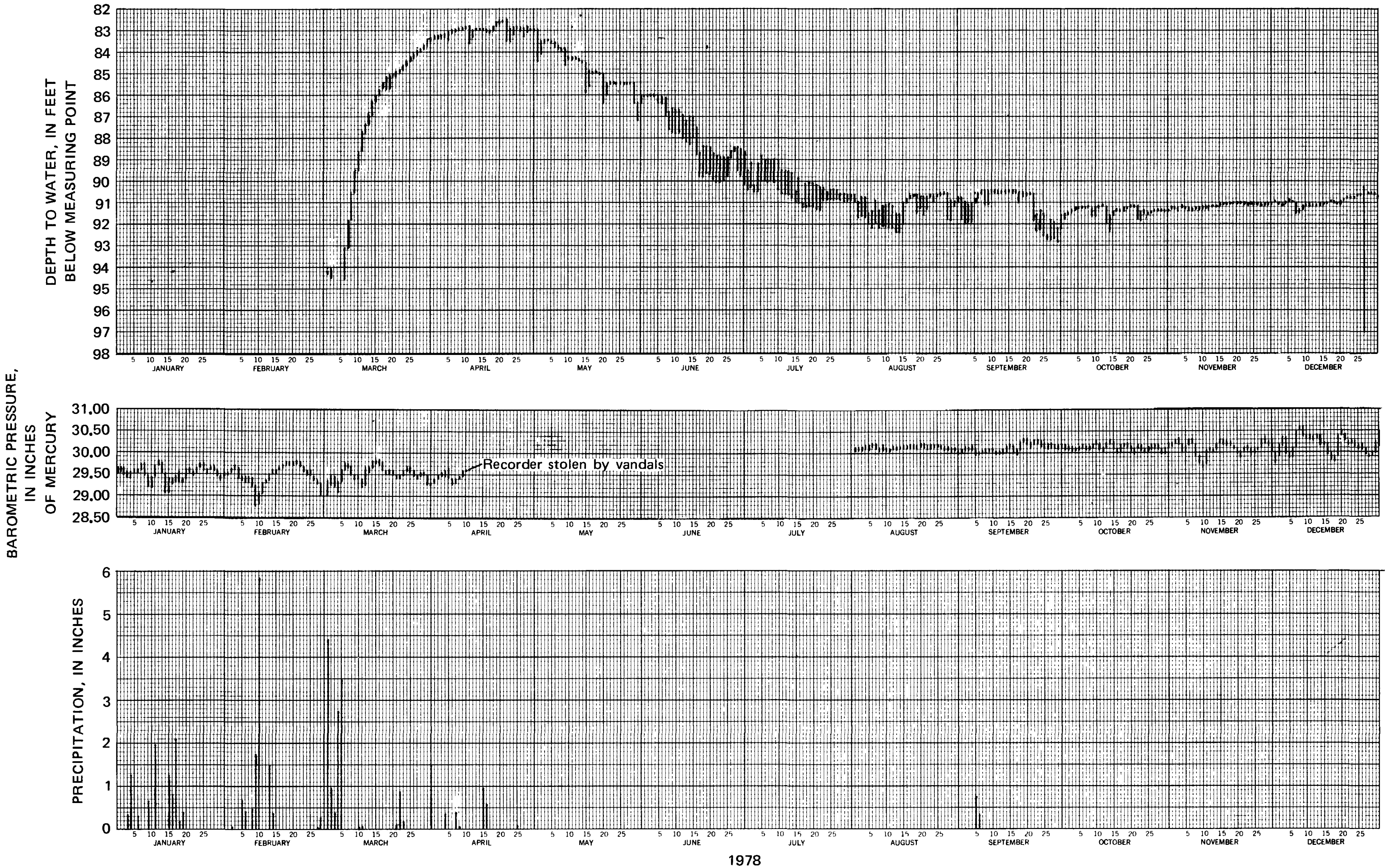



FIGURE 8.--Depth to water for well 4N/16W-27H1, barometric pressure at Palmdale, and precipitation at Newhall, 1978.

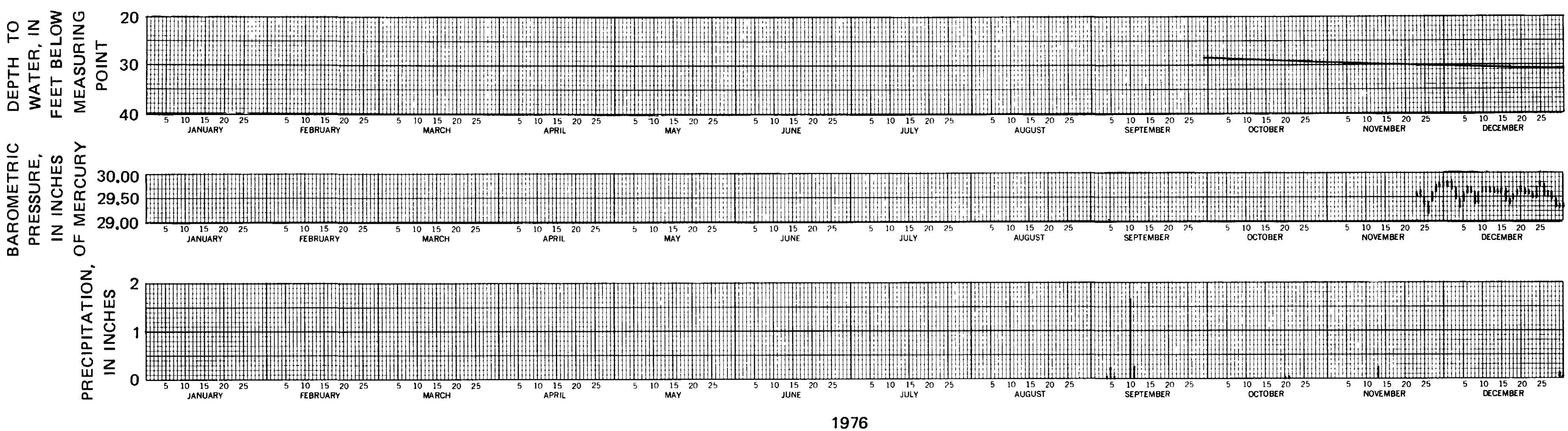



FIGURE 9.--Depth to water for well 5N/11W-7G2 and barometric pressure and precipitation at Palmdale, 1976, 1977, and 1978.

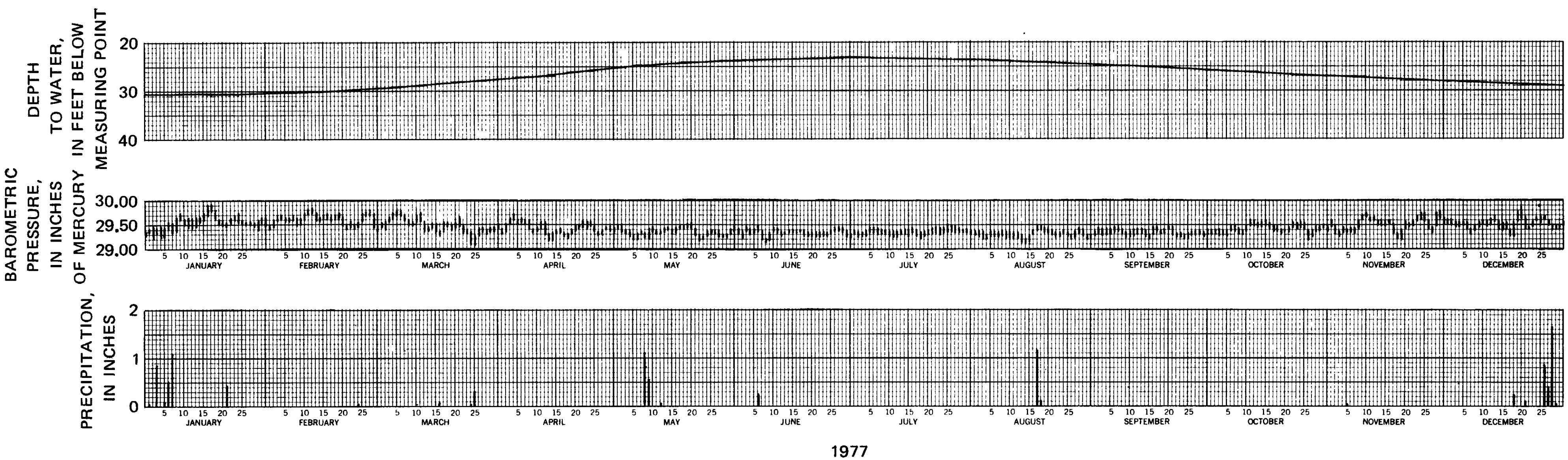



FIGURE 9.--Continued.

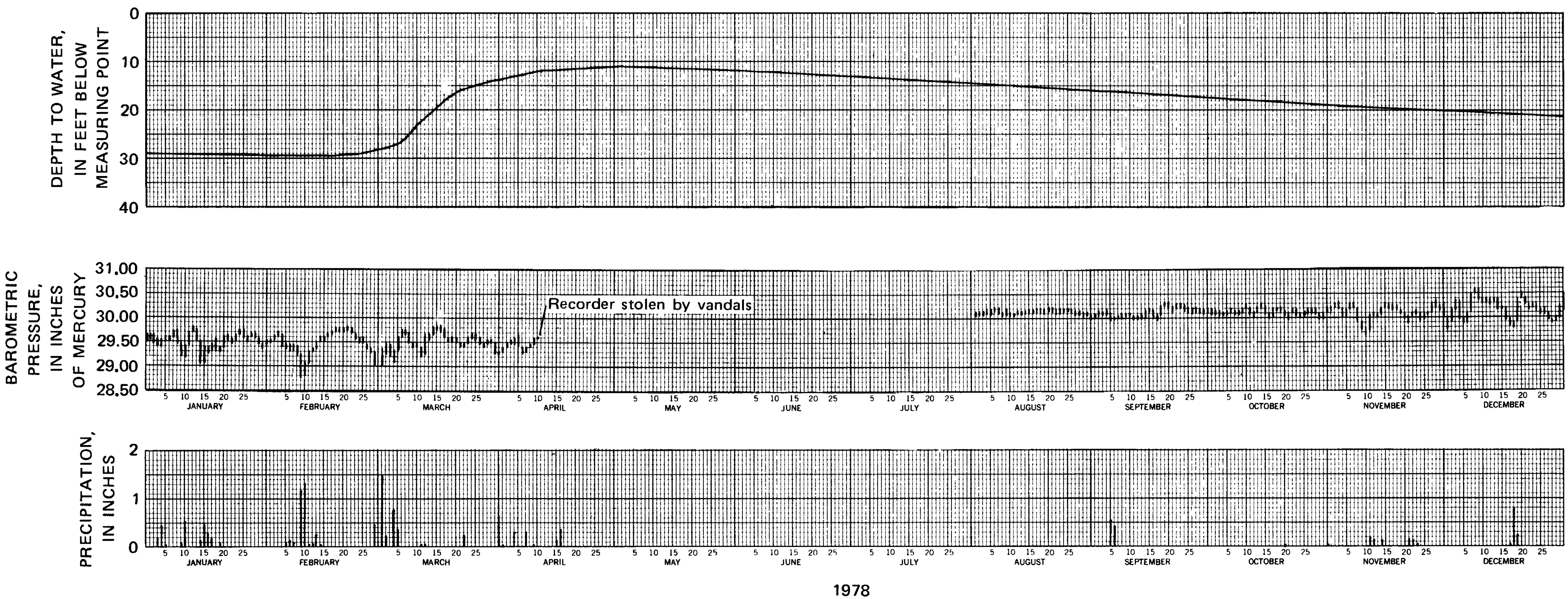



FIGURE 9.--Continued.

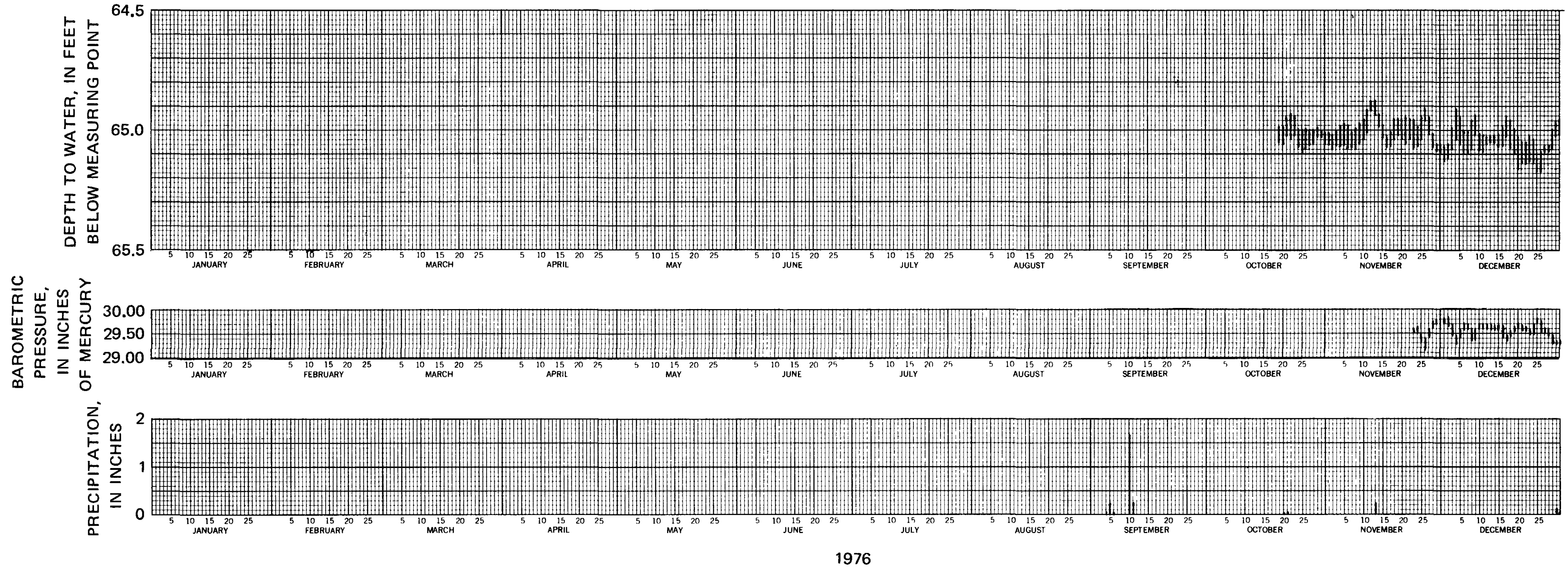



FIGURE 10.--Depth to water for well 5N/11W-24G1 and barometric pressure and precipitation at Palmdale, 1976, 1977, and 1978.

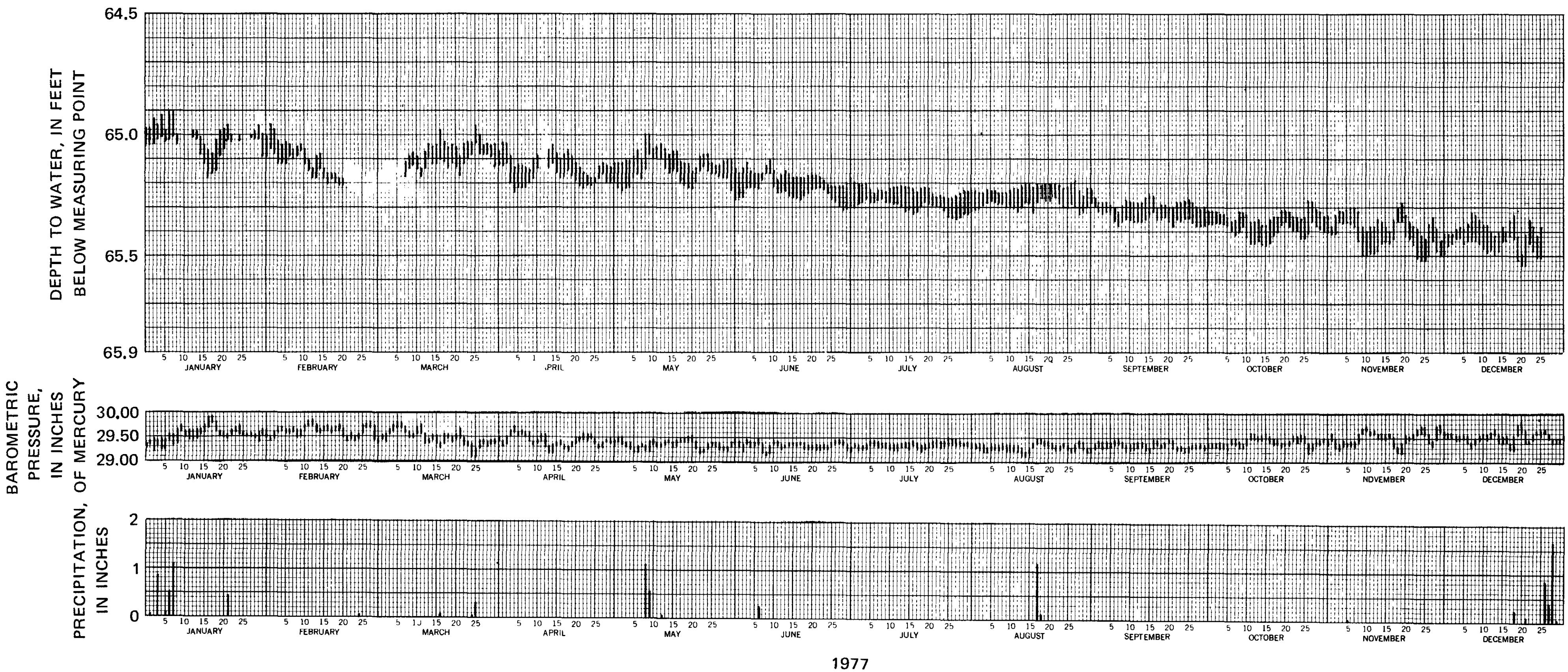



FIGURE 10.--Continued.

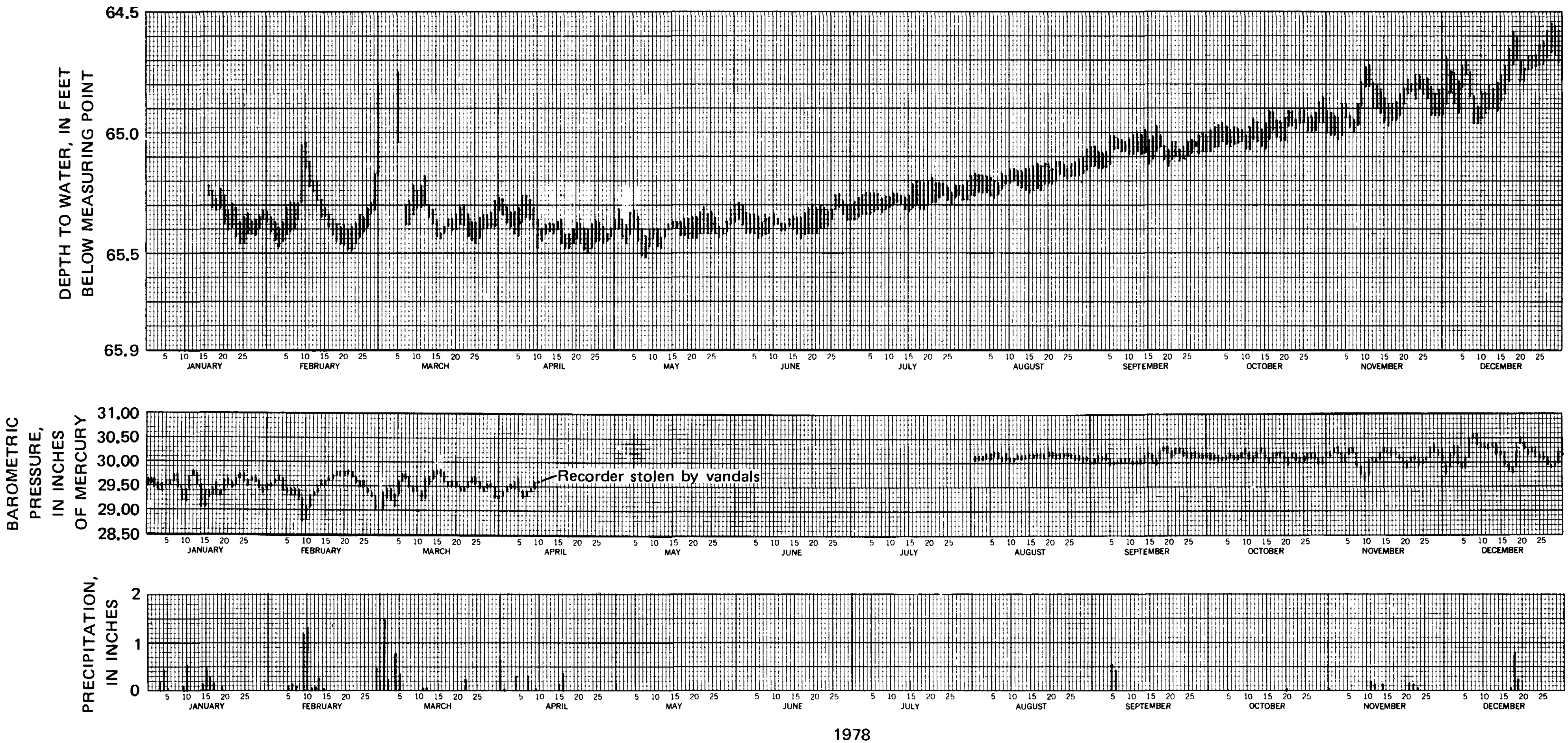



FIGURE 10.--Continued.

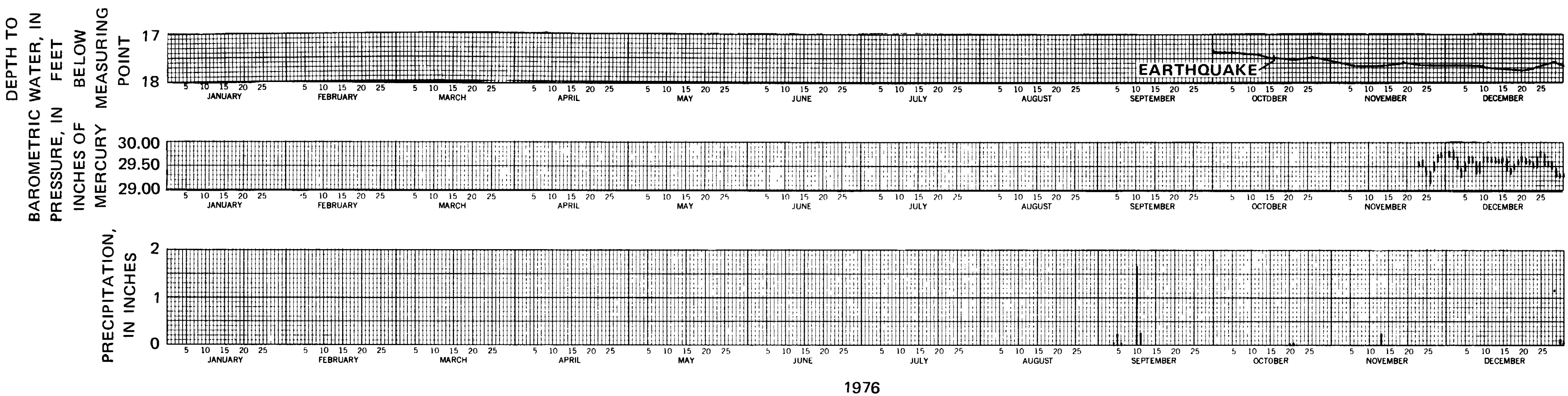



FIGURE 11.--Depth to water for well 5N/12W-2K5 and barometric pressure and precipitation at Palmdale, 1976 and 1977.

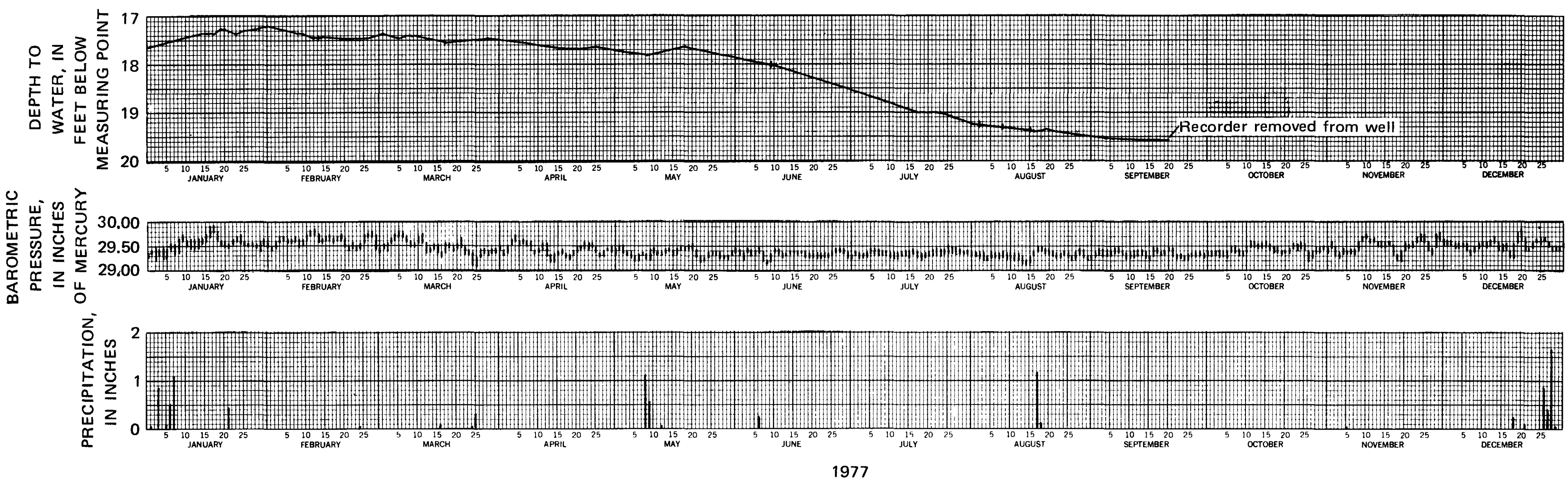



FIGURE 11.--Continued.

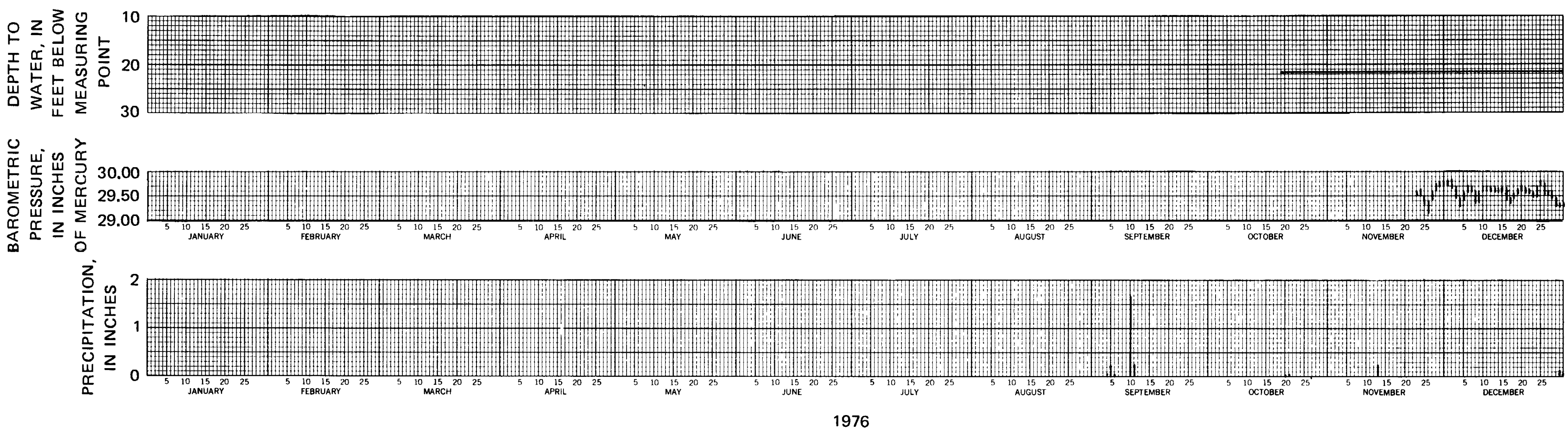



FIGURE 12.--Depth to water for well 6N/13W-8Q1 and barometric pressure and precipitation at Palmdale, 1976, 1977, and 1978; relative water temperature at bottom of well 6N/13W-8Q1, 1977 and 1978; and maximum and minimum air temperatures at Palmdale, 1978.

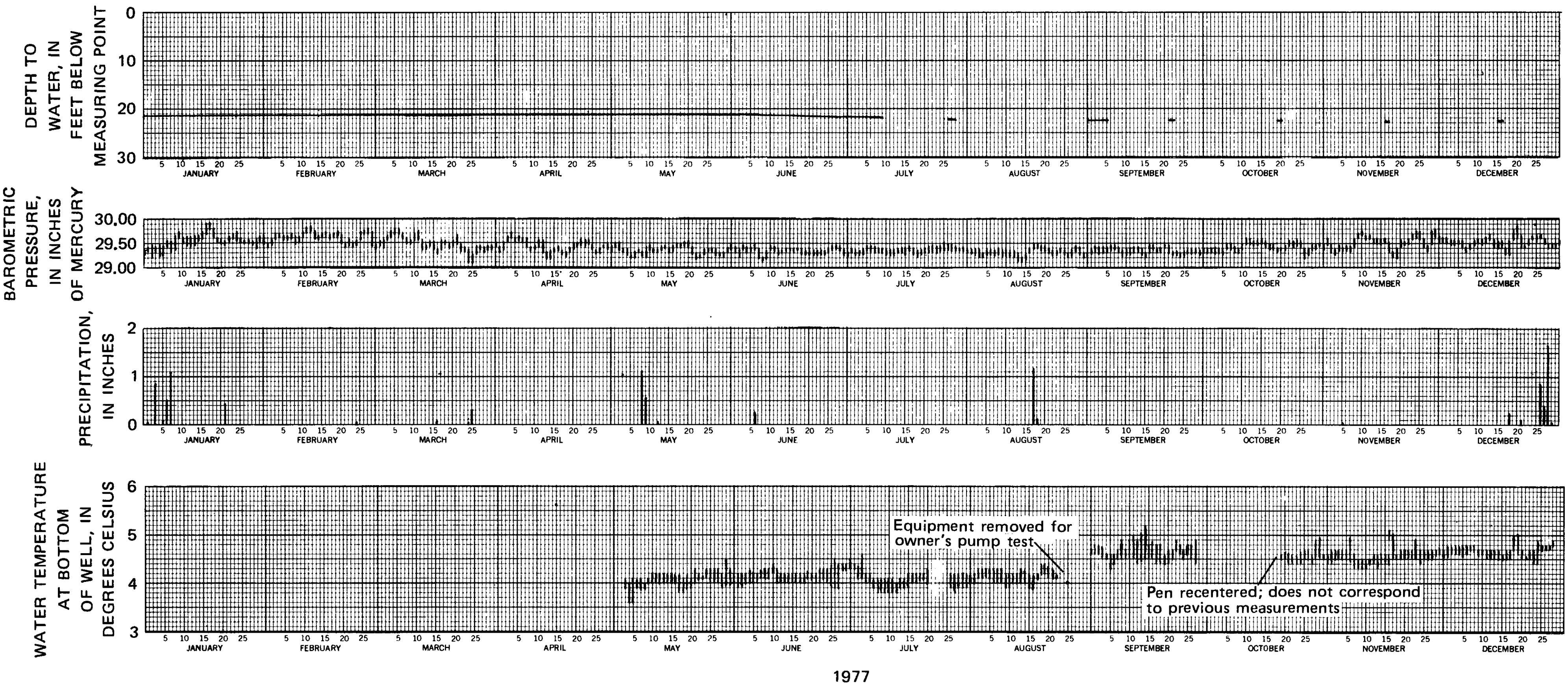



FIGURE 12.--Continued.

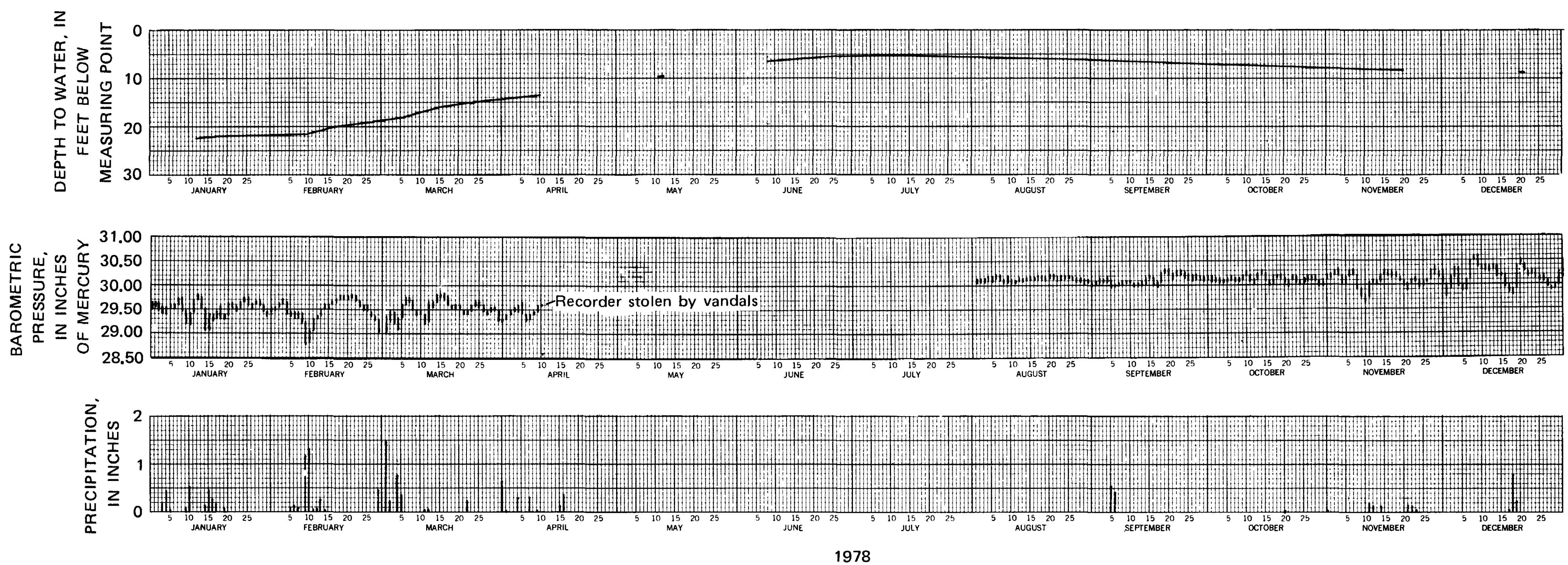



FIGURE 12.--Continued.

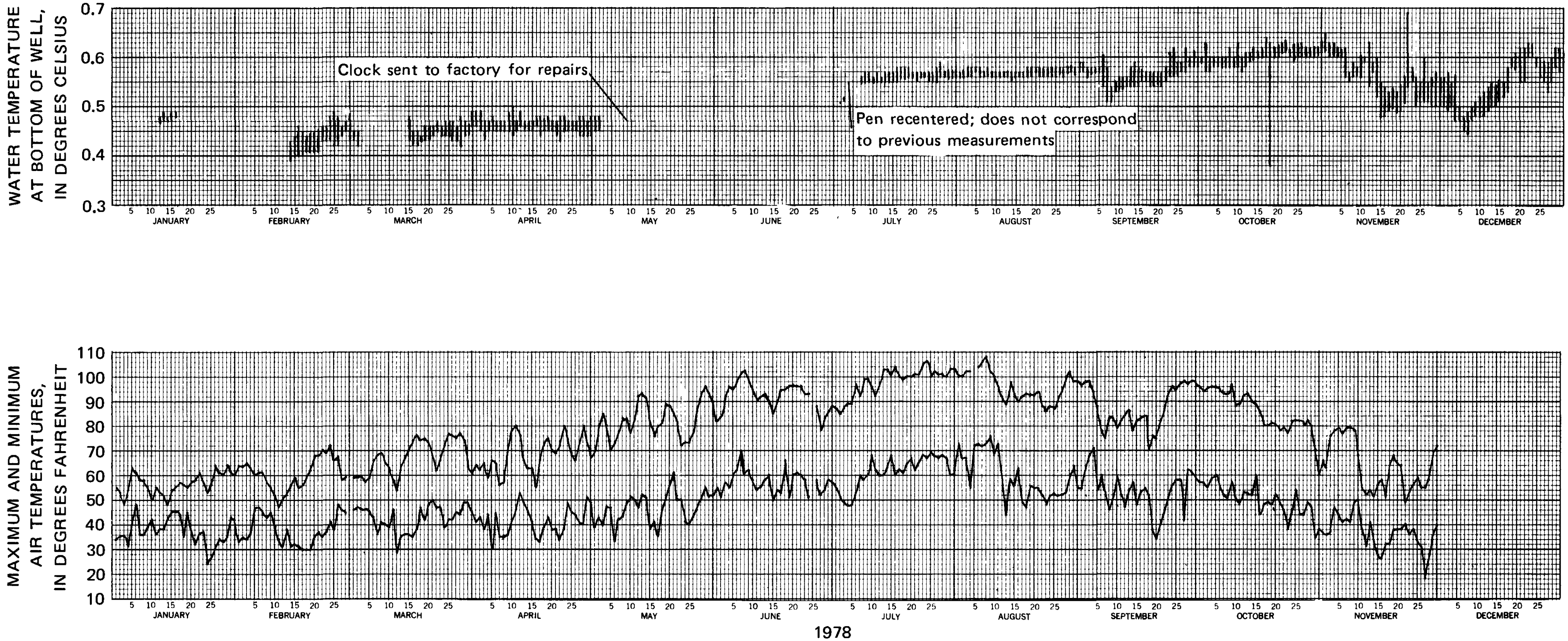



FIGURE 12.--Continued.

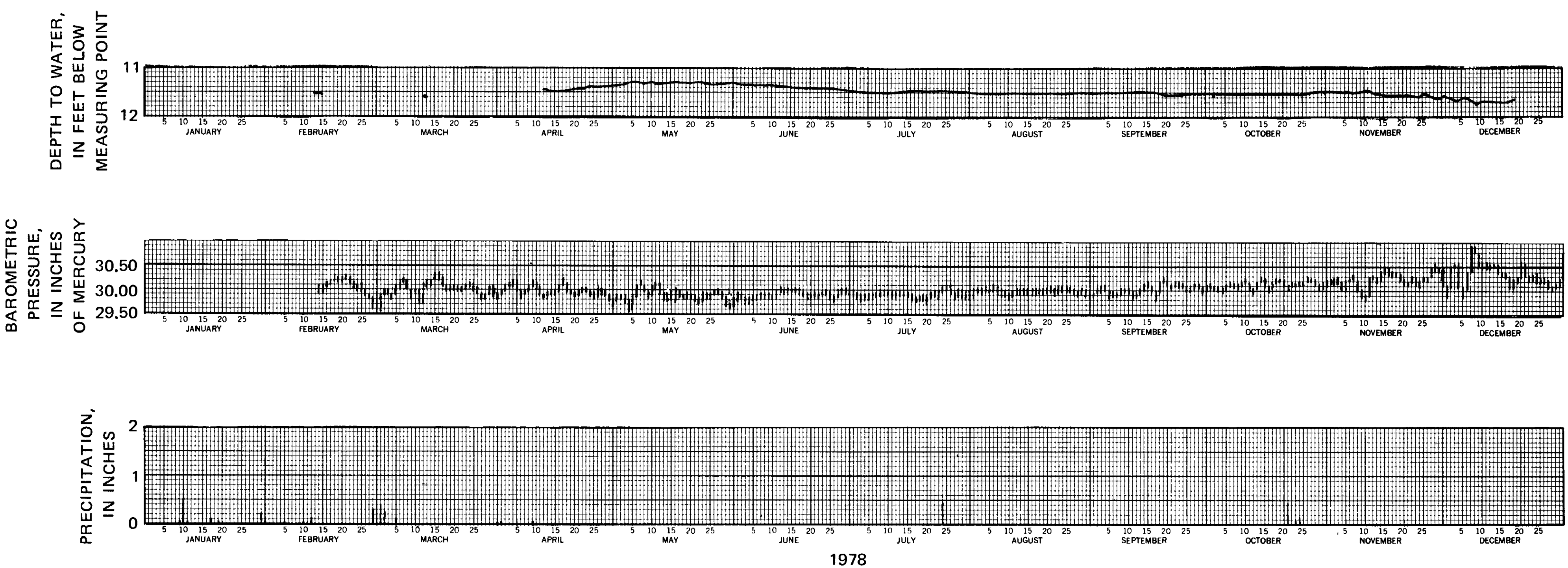



FIGURE 13.--Depth to water for well 15S/14E-18C1 and barometric pressure and precipitation at Imperial, 1978.

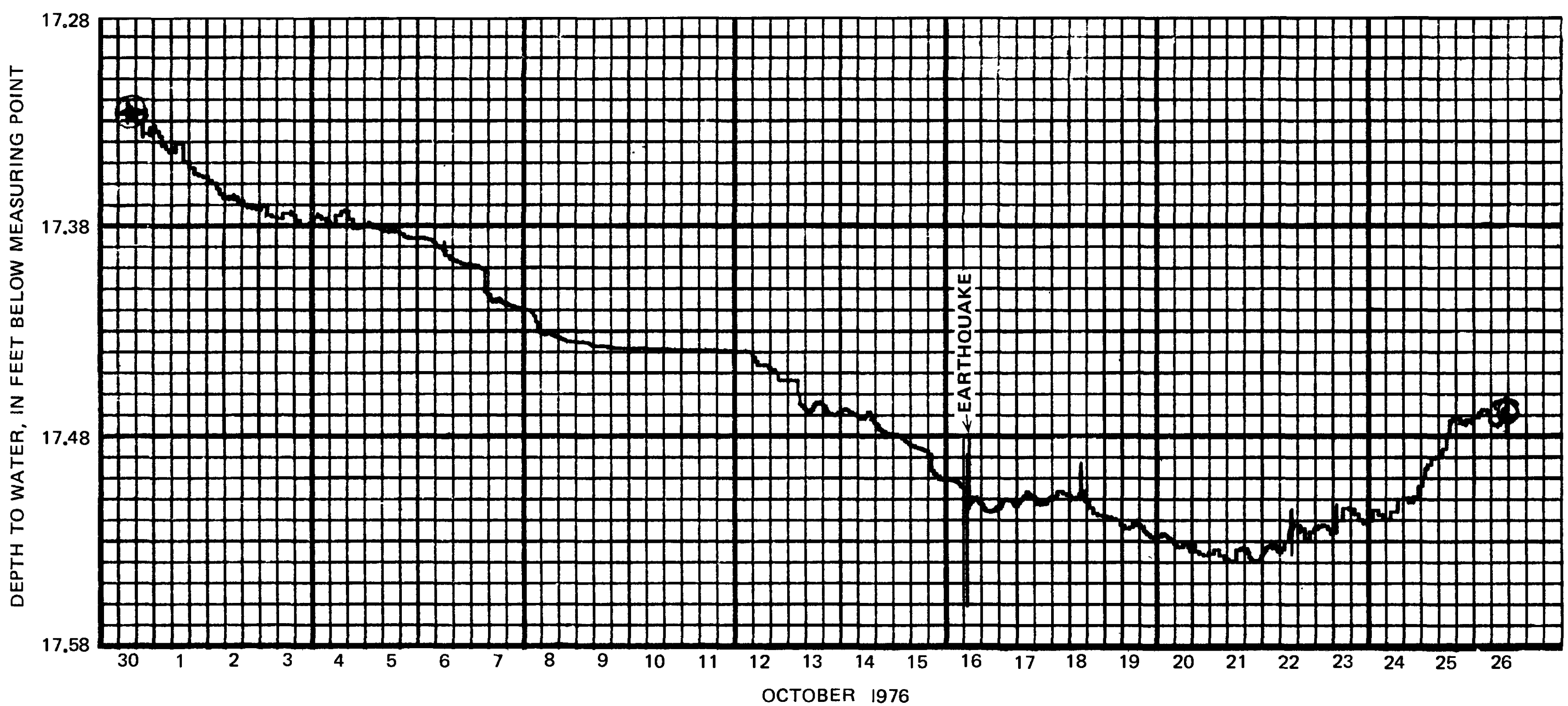



FIGURE 14.--Water-level recorder chart for well 5N/12W-2K5, showing effect of earthquake of October 16, 1976.

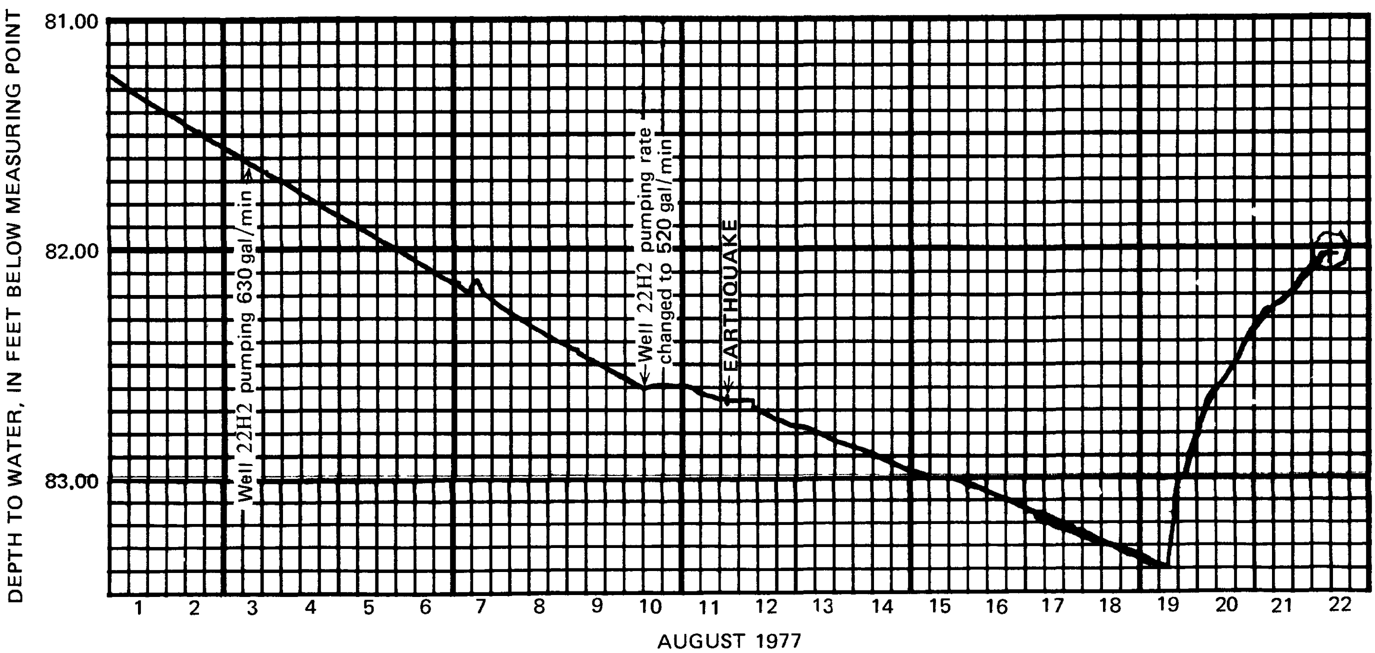



FIGURE 15.--Water-level recorder chart for well 4N/15W-22H1, showing effect of earthquake of August 11, 1977.

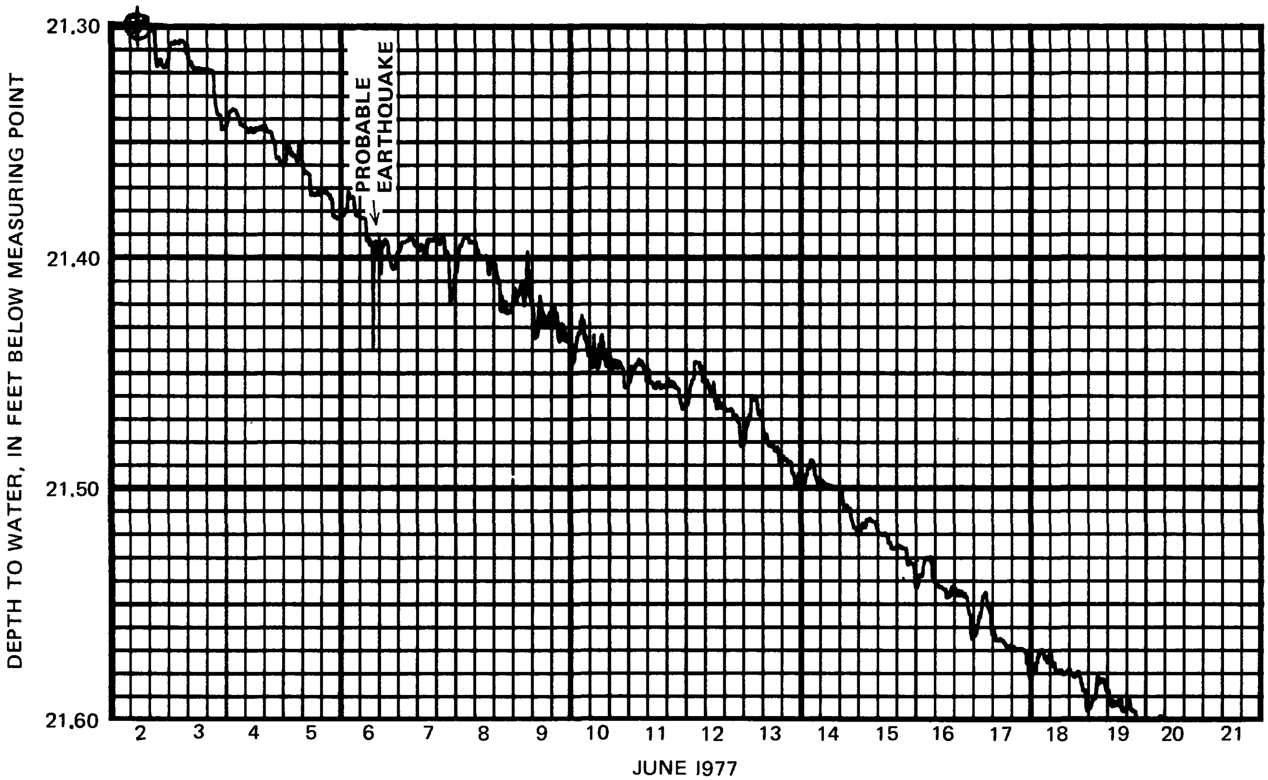



FIGURE 16.--Water-level recorder chart for well 6N/13W-8Q1, showing possible effect of probable earthquake of June 6, 1977.

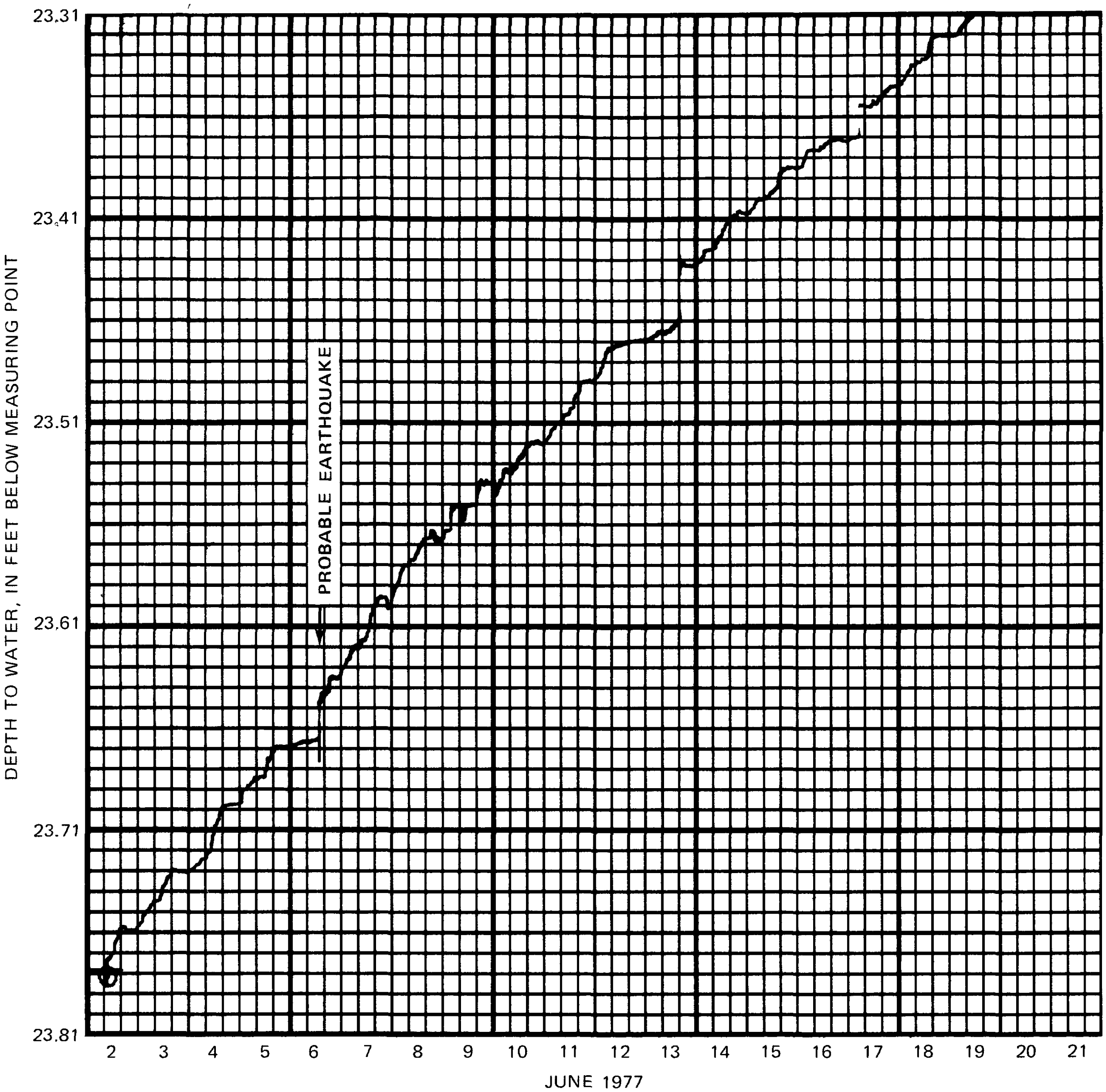



FIGURE 17.--Water-level recorder chart for well 5N/11W-7G, showing possible effect of probable earthquake of June 6, 1977.

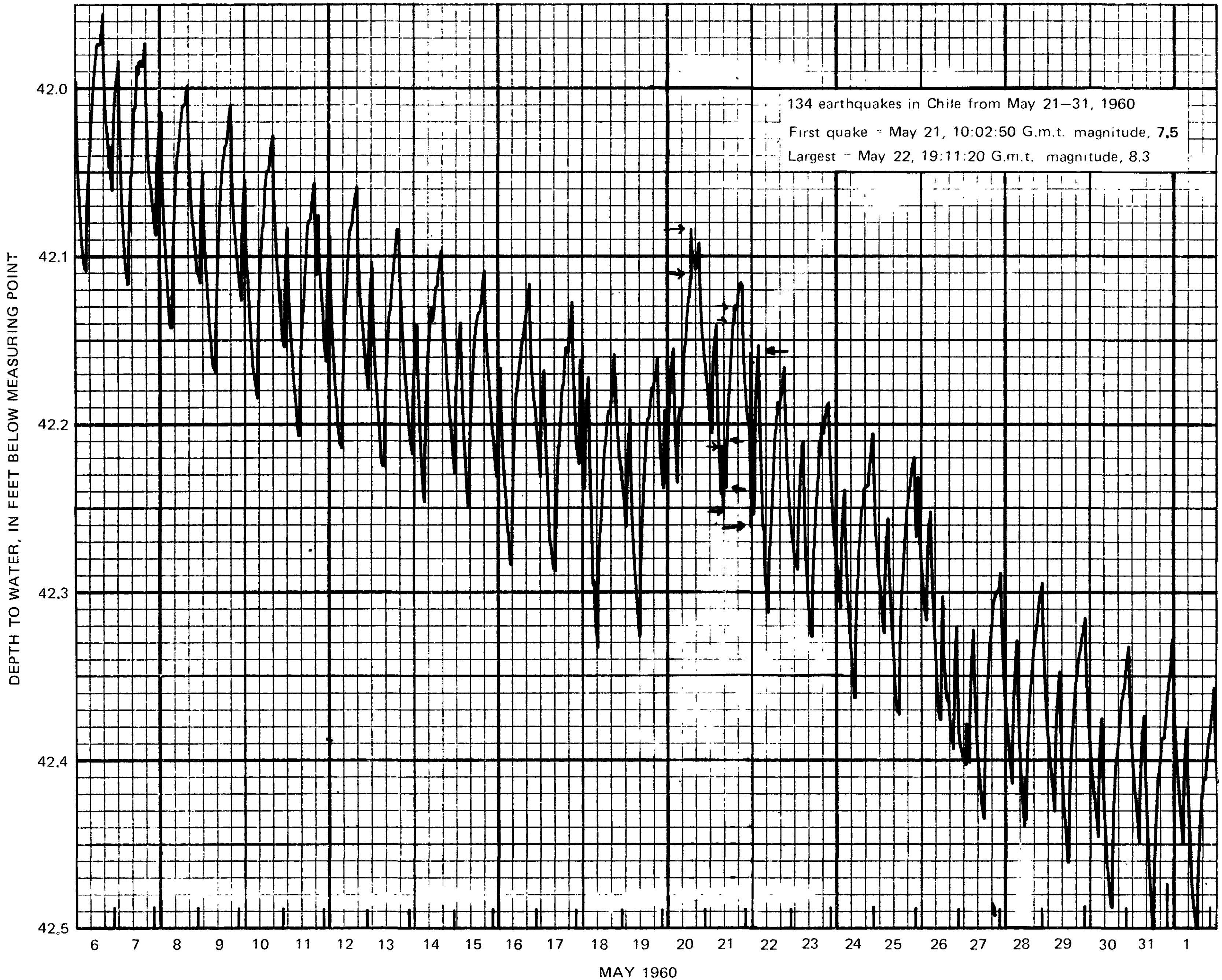



FIGURE 18.--Water-level recorder chart for well 2N/7E-2C1, showing response to Chilean earthquakes in May 1960. Arrows show fluctuations caused by earthquakes.

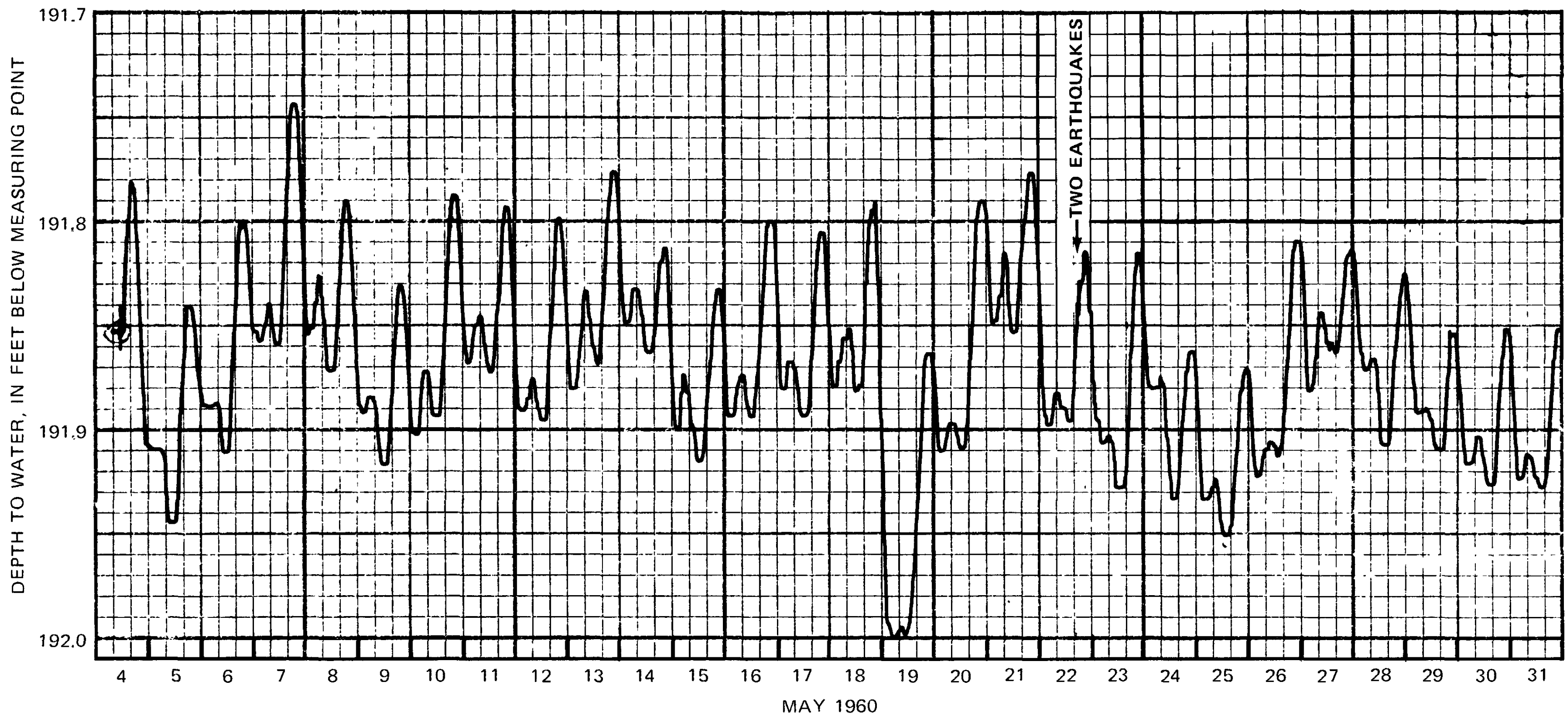



FIGURE 19.--Water-level recorder chart for well 2N/7E-4H1, showing response to Chilean earthquakes in May 1960.

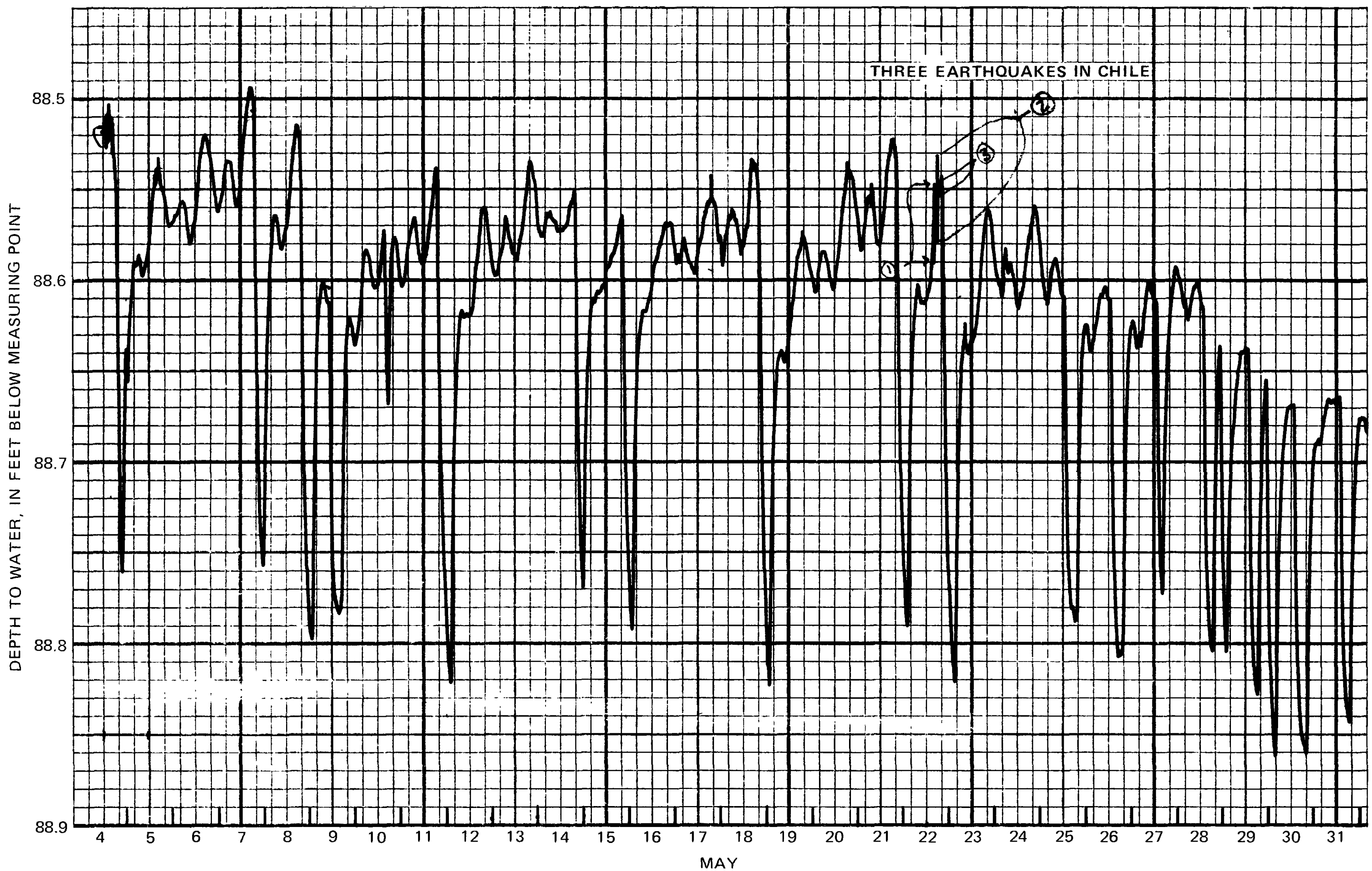



FIGURE 20.--Water-level recorder chart for well 3N/8E-29C1, showing response to Chilean earthquakes in May 1960.

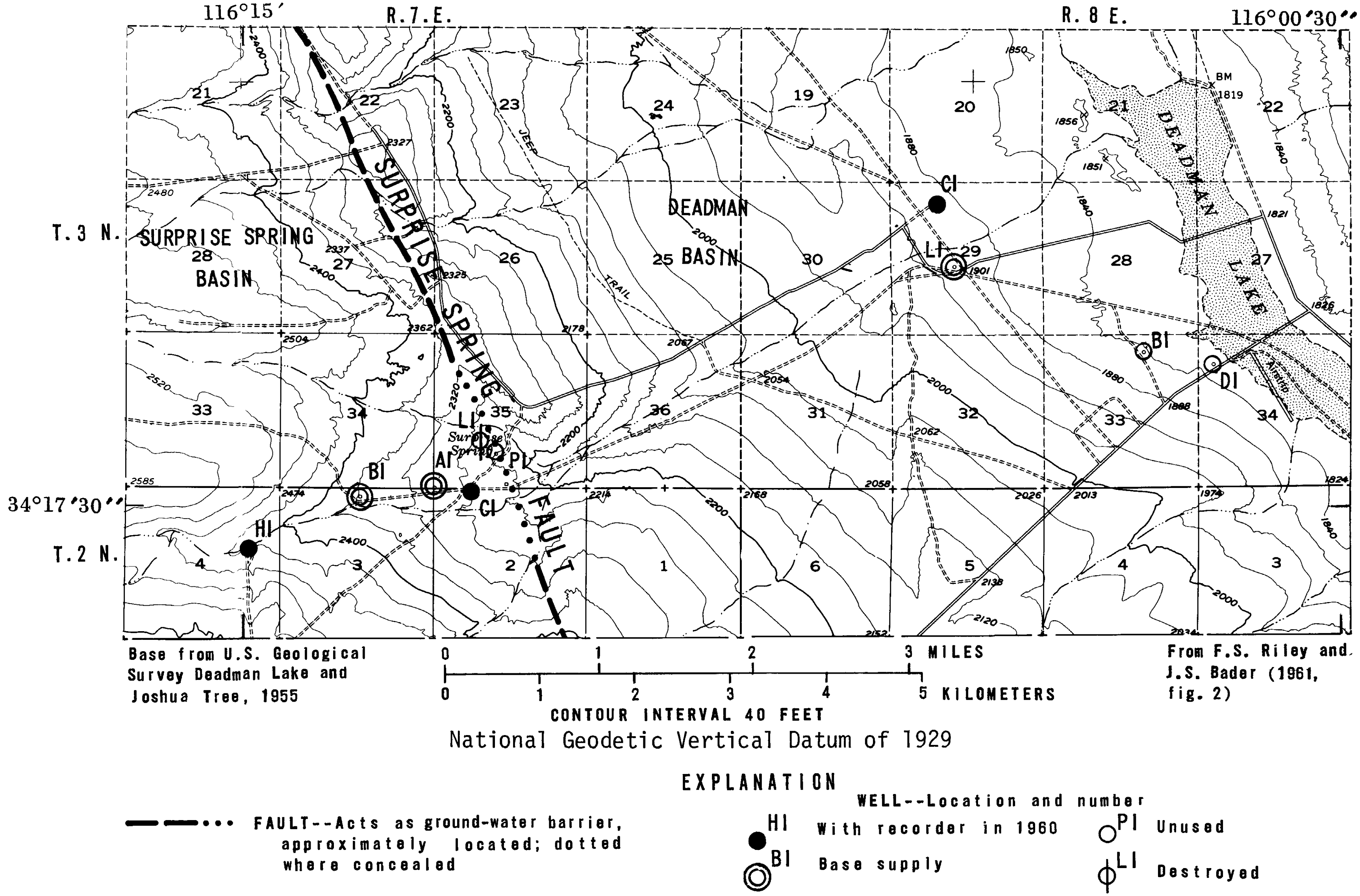



FIGURE 21.--Part of the U.S. Marine Corps Base, Twentynine Palms, Calif., showing the location of wells and the Surprise Spring fault.

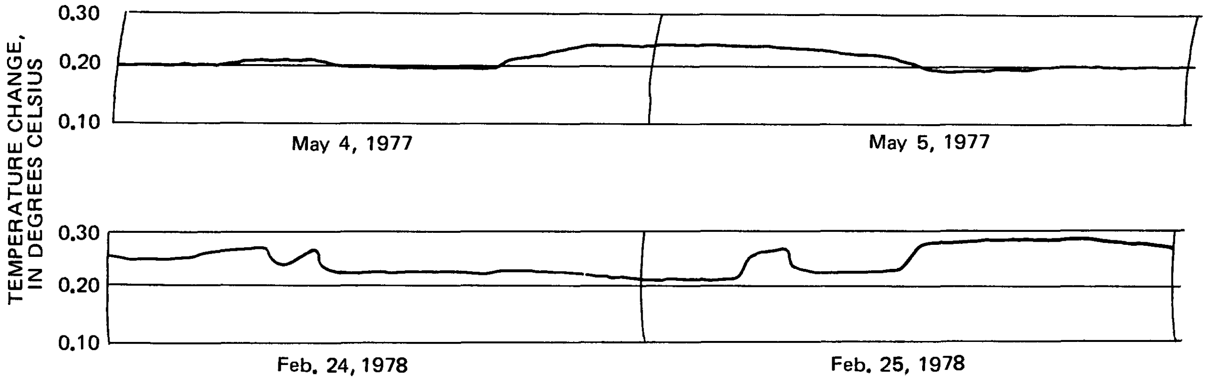
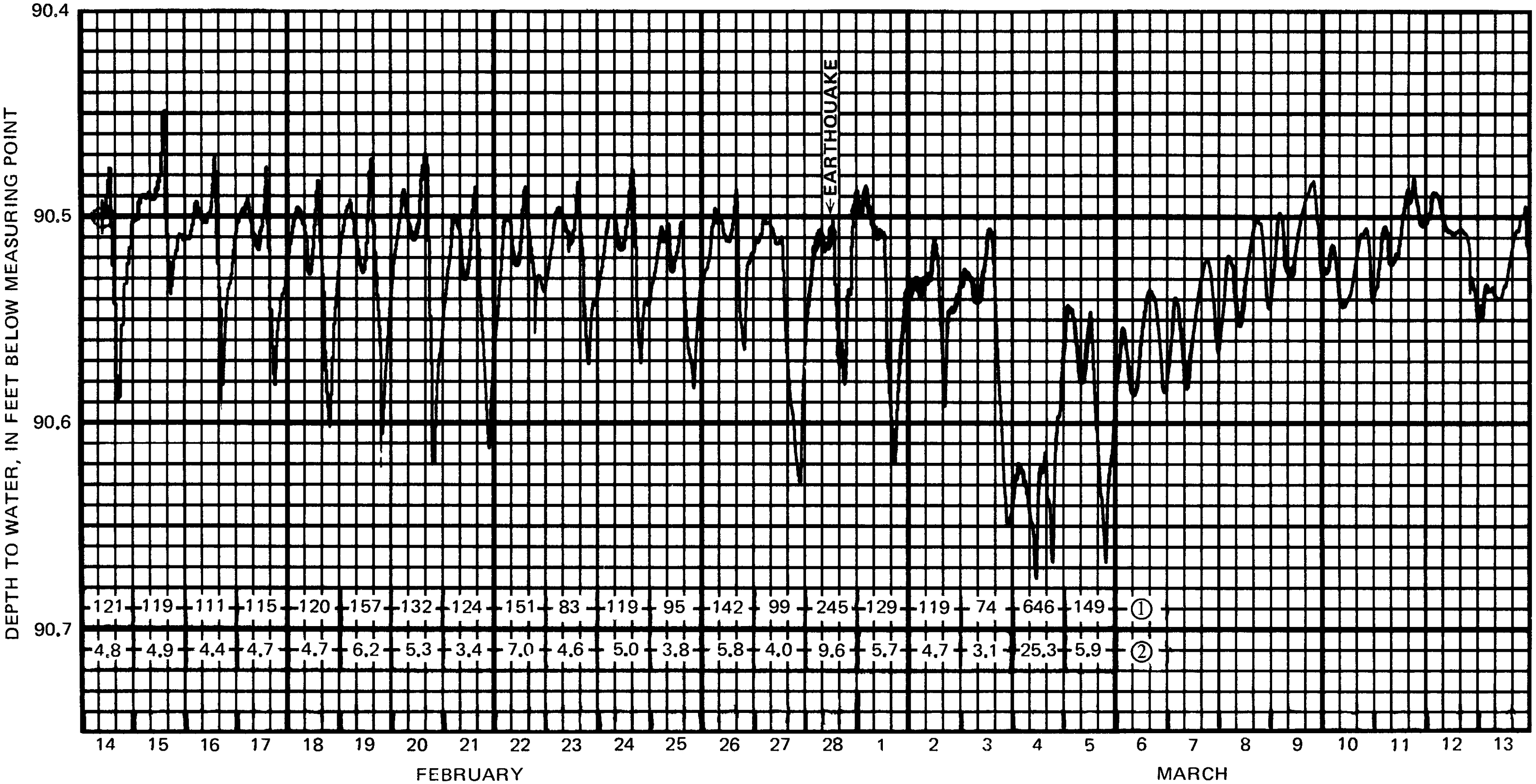



FIGURE 22.--Temperature change in well 6N/13W-8Ol.




① Thousands of gallons per day, pumped from well 3N/8E-29L1, 2300 ft from recorder

② Hours pumped

FIGURE 23.--Water-level recorder chart for well 3N/8E-29C1, showing effects of nearby pumping during parts of February and March 1978.

TABLES

47 (p. 49 follows)

TABLE 1. - Description

| State well number | Date of observation | Owner or user | Year completed | Depth of well (ft) | Type and diameter (in.) |
|---|---|---|---|---|---|
| 30S/37E-13C1M | 03-09-78 | Frank Arciero Ranch | 1974 | 334 | R 16 |
| 1N/7E-23A1S | 03-14-78 | San Bernardino County | 1970 | 368.5 | C 10 |
| 2N/7E-2C1S | 11-09-60 | U.S. Marine Corps | 1952 | 400 | C 10 |
| 2N/7E-3A1S | 11-09-60 | U.S. Marine Corps | 1953 | 560 | R 16 |
| 2N/7E-3B1S | 11-09-60 | U.S. Marine Corps | 1952 | 700 | R 16 |
| 2N/7E-4H1S | 11-09-60 | U.S. Marine Corps | 1952 | 500 | C 10 |
| 3N/8E-29C1S | 11-10-77 | U.S. Marine Corps | 1952 | 202.5 | C 10 |
| 3N/8E-29L1S | 11-09-60 | U.S. Marine Corps | 1952 | 600 | R 16 |
| 4N/15W-22H1S | 03-18-77 | Santa Clarita Water Co. | | 105.5 | 14 |
| 4N/15W-22H2S | 08-22-77 | Santa Clarita Water Co. | 1976 | 401 | R 16 |
| 4N/16W-27H1S | 03-01-78 | Santa Clarita Water Co. | 1952 | 335.0 | 12 |
| 5N/11W-7G2S | 09-15-76 | Palmdale Water District | | 96.4 | 8 |
| 5N/11W-24G1S | 09-16-76 | J. P. Crawford | | 439.5 | 8 |
| 5N/12W-2K5S | 09-15-76 | Palmdale Water District | | | 8½ |
| 6N/12W-33G1S | 09-15-76 | Charles Kindshita | | 137.5 | C 6¼ |
| 6N/13W-8Q1S | 09-16-76 | Marion Fisher | 1972 | 380 | R 8 |
| 2S/1E-25J1S | 01-26-79 | Morongo Indian Reservation | 1978 | 433 | R 14 |
| 15S/14E-18C1S | 02-13-78 | Imperial Irrigation District | 1958 | 383.0 | R 8 |

[1]Not known

## EXPLANATION OF WELL TABLE

State well number is the number given the well and described in "Well-Numbering System."

Date of observation is the date the well was visited and the data were collected.

Owner or user is listed for the date the well was canvassed.

Year completed is the year the well was drilled.

Depth listed is the depth measured at the time of well canvass or the depth reported by the driller or owner.

Type is the method used to drill the well: C, cable tool, or R, rotary. The diameter is the casing size, in inches.

Type of pump is: N, none; S, submersible, or T, turbine. The type of power is E, electric; or N, none.

Yield tells the rate of pumping from the well during a pumping test. The value given is not necessarily the maximum amount of water the well can produce; the yield is limited by the size of the pump.

Use of the well is: Or, recording observation well; Ot, taped observation well; Ps, public supply well.

Measuring point is: Tap, top of access pipe; Tc, top of casing; Trf, top of recorder shelter floor; or Trs, top of recorder shelter.

Altitude given is that of land-surface datum (lsd) at the well. A minus (-) is shown if the altitude is below National Geodetic Vertical Datum of 1929.

Water level is given in feet below land-surface datum.

Other data are: C, chemical analysis; D, driller's log; E, electric log; G, gamma log; P, pumping test; T, temperature measurement; W, additional water levels.

of wells

| Type of pump and power | Yield (gal/min) | Use | Measuring point | | Altitude of lsd, in feet above or below(-) NGVD of 1929 | Water level below lsd (ft) | Other data |
|---|---|---|---|---|---|---|---|
| | | | Description | Distance above lsd (ft) | | | |
| N N | 50 | Or | Trf | 2.5 | 2,150 | 140.81 | C,D,G,P,W |
| N N | | Or | Trf | .9 | 2,376 | 210.60 | C,D,W |
| (1) | 346 | Ot | Tc | 2.2 | 2,272.1 | 43.19 | C,L,P,W |
| T E | 1,800 | Ps | Tap | 1.7 | 2,300.9 | 75.53 | C,L,P,W |
| T E | 1,540 | Ps | Tap | 1.5 | 2,355.3 | 117.76 | C,L,P,W |
| (1) | 267 | Ot | Tc | 2.6 | 2,442.2 | 192.19 | C,L,P,W |
| N N | 250 | Or | Tc | 2.2 | 1,890.9 | 88.60 | C,D,L,P,W |
| (1) | 2,000 | Ps | Tap | 1.7 | 1,905.7 | 103.30 | C,L,P,W |
| N N | | Or | Tc | 3.9 | 1,485 | 70.39 | W |
| T E | 630 | Ps | | | 1,485 | | D,P |
| N N | 900 | Or | Tap | 2.35 | 1,184.6 | 92.32 | D,P,W |
| N N | | Or | Tc | 1.0 | 2,869 | 27.35 | C,W |
| N N | | Or | Tap | 2.25 | 3,065 | 63.28 | C,W |
| S E | | Or | Tc | .6 | 2,815 | 17.22 | W |
| N N | | Or | Tc | 1.4 | 2,875 | 9.71 | W |
| N N | | Or | Tc | 1.3 | 3,195 | 20.25 | C,D,T,W |
| N N | 2,000 | Or | Tc | 1.0 | 2,760 | 15.52 | D,E,P,W |
| N N | 89 | Or | Trs | 4.0 | -65.0 | 7.57 | C,D,P,T,W |

analyses of water

per liter (μg/L). Laboratory: B, Babcock Laboratories; D, California Department of Water Resources; Geological Survey]

| | | | | | | | Dissolved solids | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Potassium | Bicarbonate | Carbonate | Sulfate | Chloride | Fluoride | Silica | Residue on evaporation at 180°C | Sum of determined constituents | Nitrogen | Boron (μg/L) | Iron (μg/L) | Laboratory and number |
| 6.3 | 320 | 0 | 690 | 250 | 9.3 | 19 | | 1,750 | 0.03 | 30 | 0 | U-70047 |
| 5 | 88 | 6 | 14 | 9 | 1.2 | | 204 | | 0 | | | B-690130-F |
| | 92 | 0 | 300 | 150 | 4 | 14 | 780 | | | 900 | 0 | N-1491 |
| | 85 | 0 | 320 | 130 | 5 | 10 | 700 | | | 700 | 0 | N-1493 |
| | 88 | 0 | 300 | 150 | 3.6 | 10 | 750 | | | 540 | 0 | N-1502 |
| | 88 | 0 | 320 | 170 | 5 | 14 | 820 | | | 630 | 0 | N-1501 |
| | 92 | 0 | 300 | 160 | 3.2 | 10 | 780 | | | 50 | 0 | N-1503 |
| | 110 | 3.6 | 300 | 170 | 3.0 | 8 | 800 | | | | 0 | N-1511 |
| | 46 | 0 | 360 | 200 | 4.3 | 14 | 1,080 | | | | 0 | N-1512 |
| | 61 | 0 | 340 | 190 | 4 | 10 | 1,030 | | | | 0 | N-1513 |
| | 92 | 0 | 300 | 200 | 1.5 | 18 | 860 | | | 700 | 0 | N-1515 |
| | 90 | 0 | 300 | 200 | 1.5 | 18 | | 854 | | 700 | 0 | N |
| | | | | | 1.4 | | | | | | | B |
| 2.9 | 580 | 0 | 320 | 150 | .6 | 20 | | 1,190 | .11 | 390 | 20 | U-304131 |
| .7 | 200 | 0 | 19 | 15 | .6 | 9.3 | | 222 | .06 | 60 | 20 | U-304129 |
| 3.2 | 280 | 0 | 130 | 41 | .7 | 11 | | 501 | 1.5 | 90 | 10 | U-304130 |
| 59 | 280 | 0 | 450 | 6,000 | .3 | 22 | 10,250 | 10,480 | .03 | 2,200 | | D-T1874 |

TABLE 2. - Chemical

[Constituents and properties in milligrams per liter (mg/L) except for boron and iron, which are in micrograms
N, U.S. Navy; U, U.S.

| Well No. | Date | Depth (ft) | Specific conductance (µmho/cm) | pH | Temperature (°C) | Hardness as $CaCO_3$ | Noncarbonate hardness | Calcium | Magnesium | Sodium | Percent sodium |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30S/37E-13C1M | 02-04-76 | 334 | 2,540 | 7.8 | | 210 | 0 | 69 | 9.9 | 510 | 83 |
| 1N/7E-23A1S | 01-29-70 | 370 | 220 | 8.8 | | 28 | | 10 | 1 | 36 | 63 |
| 3N/8E-29C1S | 04-09-52 | 163 | | 7.9 | 23.3 | 112 | | 41 | 2.4 | | |
| | 04-15-52 | 252 | | 7.9 | 25.3 | 82 | | 31 | 1.0 | | |
| | 04-25-52 | 472 | | 8.0 | 23.9 | 80 | | 27 | 2.9 | | |
| | 04-25-52 | 474 | | 8.0 | 26.7 | 130 | | 42 | 4.9 | | |
| | 04-25-52 | 564 | | 8.1 | 27.9 | 74 | | 25 | 2.9 | | |
| | 05-06-52 | 653 | | 8.2 | 31.1 | 58 | | 18 | 2.9 | | |
| | 05-14-52 | 794 | | 7.5 | 31.1 | 100 | | 34 | 3.9 | | |
| | 05-15-52 | 800 | | 7.9 | 31.7 | 80 | | 28 | 2.4 | | |
| | 05-28-52 | ([1]) | | 8.0 | | 100 | | 33 | 4.9 | | |
| | 06-12-52 | | | 8.0 | 29.4 | 103 | | 33 | 5 | [2]258 | |
| | 06-26-52 | | | | | | | | | | |
| 5N/11W-7G2S | 10-26-76 | | 1,600 | 7.6 | 18.5 | 250 | 0 | 12 | 53 | 340 | 75 |
| 5N/11W-24G1S | 10-26-76 | | 310 | 7.0 | 21.2 | 81 | 0 | 20 | 7.6 | 53 | 58 |
| 6N/13W-8Q1S | 10-26-76 | | 750 | 7.0 | 20.0 | 160 | 0 | 32 | 19 | 120 | 62 |
| 15S/14E-18C1S | 05-08-58 | 500 | | 7.7 | 30.0 | 1,900 | | 420 | 120 | 3,320 | 79 |

[1]Sample collected from pump discharge after 8 hours of pumping.
[2]Includes potassium.

TABLE 3. - Drillers' logs of wells

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 30S/37E-13C1M. Altitude: 2,150 ft. Casing diameter: 16 inches, 0-336 ft, 12-inch open hole 336 to 650 ft. Perforated: 90-336 ft. | | |
| Sand, medium to coarse, with small rocks and boulders------- | 120 | 120 |
| Sand, coarse, with large gravel and small boulders---------- | 30 | 150 |
| Sand, medium to coarse, hard packed, with some boulders----- | 30 | 180 |
| Sand, medium to coarse, hard packed, with streaks of clay--- | 30 | 210 |
| Sand, medium to coarse, hard packed------------------------- | 30 | 240 |
| Sand, coarse and gravel, with streaks of clay--------------- | 30 | 270 |
| Sand, medium to coarse-------------------------------------- | 60 | 330 |
| Clay, blue-gray--------------------------------------------- | 320 | 650 |
| 1N/7E-23A1S. Altitude: 2,376 ft. Casing diameter: 10 inches, 0-380 ft. Perforated 360-370 ft. | | |
| Sand, fine, with some silt and small boulders to 5 inches--- | 13 | 13 |
| Clay, adobe with small boulders to 10 inches---------------- | 42 | 55 |
| Sand, fine and silt, with some small boulders--------------- | 20 | 75 |
| Silt with boulders and sharp pea gravel of mixed color of granite and basalt---------------------------------------- | 8 | 83 |
| Boulders and sharp pea gravel of mixed color---------------- | 40 | 123 |
| Boulders, sand, gravel, with some silt---------------------- | 20 | 143 |
| Boulders and gravel of mixed color-------------------------- | 23 | 166 |
| Boulders, sharp gravel, and silt---------------------------- | 9 | 175 |
| Boulders, sand, and silt------------------------------------ | 29 | 204 |
| Boulders, sand, and a large amount of silt------------------ | 16 | 220 |
| Boulders and a large amount of silt------------------------- | 10 | 230 |
| Boulders, silt and pea gravel------------------------------- | 5 | 235 |
| Clay, silt, sand, gravel, and boulders---------------------- | 7 | 242 |
| Sand, fine, and boulders------------------------------------ | 28 | 270 |
| Clay, silty and fine sand----------------------------------- | 6 | 276 |
| Sand, fine, and some boulders and silty clay---------------- | 9 | 285 |
| Boulders, sand, and gravel compress in fine sand------------ | 25 | 310 |
| Sand, fine, silt, boulders, with some silty clay pellets---- | 15 | 325 |
| Silt, fine sand, gravel, and boulders. Boulders get bigger and harder with depth----------------------------------- | 55 | 380 |

TABLE 3. - Drillers' logs of wells--Continued

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 3N/8E-29C1S. Altitude: 1,890.93 ft. Casing diameter: 10 inches, 0-800 ft. Perforated: 500-523, 540-565, 584-605, 640-646, and 660-684 ft. | | |
| Soil, sandy to silty, buff-brown, hard near bottom---------- | 12 | 12 |
| Sand, very fine to coarse; some silt; and a few cobbles; calcareous, light brown, soft---------------------------- | 12 | 24 |
| Sand, fine to very coarse, slightly silty; and some fine gravel; some iron stain, buff-brown, soft, dry. Less gravel and cleaner with depth---------------------------- | 14 | 38 |
| Sand, very fine to coarse, and silt; clayey, micaceous, light brown, fairly hard; in hard and soft layers below 54 ft---------------------------------------------------- | 45 | 83 |
| Silt, clayey, and some fine sand, calcareous, micaceous, gray-brown, fairly hard------------------------------------ | 16 | 99 |
| very fine to very coarse, poorly sorted; and some gravel and cobbles up to 5 inches; micaceous, gray-brown, very hard, dry----------------------------------------- | 12 | 111 |
| Sand, fine to medium, some coarse, micaceous, gray-brown, soft, dry--------------------------------------------- | 5 | 116 |
| Sand, coarse and some fine; and fine gravel; brown, hard---- | 1 | 117 |
| Sand, very fine to very coarse, poorly sorted; and some gravel and cobbles to 5 inches; gray-brown, soft, water-bearing. Water rose to 88 ft overnight------------------ | 21 | 138 |
| Sand, very fine to very coarse, poorly sorted; some very large cobbles up to 6 inches; gray-brown to buff, very hard, water-bearing------------------------------------- | 6 | 144 |
| Sand, fine to coarse, poorly sorted, micaceous; and silt gray-brown, moderately hard, slightly water-bearing------- | 6 | 150 |
| Sand, very fine to very coarse, poorly sorted; some silt and fine gravel; micaceous, gray-brown, soft, slightly water-bearing---------------------------------------------- | 8 | 158 |
| Sand, very fine to very coarse, poorly sorted; occasionally silty; and some gravel and cobbles up to 4 inches; gray to gray-brown, soft to occasionally hard, largely water-bearing---------------------------------------------- | 46 | 204 |
| Clay, silty, laminated, considerably iron-stained, olive-gray to gray, some thin dark chocolate-brown layers, hard------ | 2 | 206 |
| Sand, very fine to medium and some coarse, micaceous; and silt; olive-gray to brown-gray, soft, occasional layers of clay ¼-inch thick, moderately water-bearing---------------- | 9 | 215 |
| Sand, very fine to very coarse, poorly sorted, micaceous; some silt; gravel; and cobbles up to 6 inches; gray-brown, hard, moderately water-bearing---------------------------- | 5 | 220 |
| Sand, mostly very coarse, some fine and medium; occasionally silty; and considerable gravel and cobbles; gray, soft. The percentage of coarse sand, gravel, and cobbles decreases gradually with depth; largely water-bearing----- | 13 | 233 |

TABLE 3. - Drillers' logs of wells--Continued

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 3N/8E-29C1S.--Continued | | |
| Sand, fine to medium, micaceous; and silt; calcareous cemented, gray-brown to gray, very hard. Considerable gravel and cobbles 236 to 237 and 245 to 247 ft; slightly water-bearing | 14 | 247 |
| Sand, very fine to very coarse, micaceous; some gravel; and cobbles up to 5 inches; gray-brown, moderately soft, largely water-bearing | 13 | 260 |
| Sand, mostly coarse, some fine to medium; gravel, mostly coarse, some fine; and cobbles up to 7 inches; gray to gray-brown, soft, highly water-bearing | 30 | 290 |
| Sand, fine to coarse, poorly sorted, some concretions, strongly cemented, calcareous and siliceous (?) cement, light gray to gray, very hard | 2 | 292 |
| Sand, very fine to very coarse, mostly fine to medium, poorly sorted, micaceous; some silt; and some gravel and cobbles; gray to gray-brown, soft, water-bearing | 48 | 340 |
| Sand, fine to medium; silt; and some gravel; gray-brown, cemented, very hard, slightly water-bearing | 17 | 357 |
| Sand, very fine to very coarse, mostly medium and coarse, micaceous; and some gravel; gray-brown to buff, soft, water-bearing | 38 | 395 |
| Sand, fine to very coarse, mostly coarse; and gravel, fine to medium, some coarse; and few cobbles; partially cemented, gray to brownish-gray, hard to soft, moderately water-bearing. Sandy below 403 ft | 12 | 407 |
| Sand, fine to medium, some coarse, clayey, micaceous; silt; gravel, fine to medium with some coarse; and some cobbles up to 5 inches; gray to brownish-gray, partially cemented, hard, slightly water-bearing. Less silt and more coarse sand with depth | 12 | 419 |
| Clay, silty, sandy, considerably iron stained, light to medium brown, hard | 1 | 420 |
| Sand, fine to very coarse, mostly medium and coarse, concretionary; and gravel, fine to very coarse; and some cobbles up to 10 inches; calcareous, partially cemented, gray to brownish-gray, hard to moderately hard, moderately water-bearing. Cemented 420 to 427 ft | 39 | 459 |
| Sand, fine to coarse; and gravel, mostly fine to medium; gray-brown, some cementation, moderately hard, water-bearing | 4 | 463 |
| Sand, fine to very coarse, mostly medium and coarse; gravel, mostly fine and medium, some coarse; and a few cobbles up to 5 inches; gray-brown, fairly soft, largely water-bearing. Occasional hard lenses of cemented sand and gravel. Somewhat finer grained 487 to 500 ft | 60 | 523 |
| Clay, silty to sandy; and few gravel; light to dark gray, banded, hard | 2 | 525 |

TABLE 3. - Drillers' logs of wells--Continued

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 3N/8E-29C1S.--Continued | | |
| Sand, mostly fine to medium, some coarse; silt; considerable gravel; and some clay; light to dark gray, calcareous, moderate cementation, hard, moderately water-bearing------ | 13 | 538 |
| Sand, very fine to very coarse; gravel, mostly fine; and some cobbles up to 4 inches; brownish-gray, fairly soft, water-bearing. Hard to moderately hard sand and gravel beds below 542 feet, in part water-bearing---------------- | 41 | 579 |
| Sand, fine to coarse, mostly fine to medium; and some fine gravel 579 to 589 and 599 to 601 ft; calcareous, partially cemented, light to medium gray, moderately hard, moderately water-bearing---------------------------------- | 22 | 601 |
| Sand, very fine to coarse; and some silt; calcareous, cemented, light to medium gray, extremely hard------------ | 10 | 611 |
| Clay, silty to sandy, dark brown, considerably iron-stained, hard------------------------------------------------------ | 5 | 616 |
| Sand, fine to coarse; silt; and occasional thin lenses of clay; calcareous, partially cemented, buff to tan, moderately hard, slightly water-bearing------------------ | 13 | 629 |
| Clay, micaceous, silty to sandy, dark brownish gray, moderately hard------------------------------------------- | 3 | 632 |
| Sand, fine to medium silt; and some gravel 642 to 643 ft; clayey, cemented, calcareous, brown to buff, hard, slightly water-bearing--------------------------------------------- | 11 | 643 |
| Sand, fine to coarse; some silt; and fine to some coarse gravel; calcareous, partially cemented, buff to light gray, moderately hard, moderately water-bearing----------------- | 30 | 673 |
| Sand, fine to very coarse; and gravel, mostly fine to medium; some coarse; occasionally silty, brown to gray-brown, soft, water-bearing. Partially cemented below 682 ft----------- | 13 | 686 |
| Clay, silty to sandy, considerable biotite mica and iron-stained, calcareous, generally dark grayish-brown, hard, occasionally sticky (plastic). Occasional lenses of gray, cemented, fine sand; and occasional thin layers of laminated, dark chocolate brown, non-calcareous clay------ | 62 | 748 |
| Silt, clay, and considerable fine sand, micaceous, dark grayish-brown, soft. Considerably less dense and compact than clay above. Occasional thin lenses of cemented sand------------------------------------------------------ | 10 | 758 |
| Clay, silty, occasionally sandy, considerable biotite mica, color varies from buff to gray, but generally grayish-brown, occasionally calcareous, hard. Some thin layers of laminated non-calcareous clay, various shades of gray and brown. Occasional thin layers of clayey silt with fine sand; also thin lenses of gray, cemented, clayey, fine sand------------------------------------------------- | 31 | 789 |
| Sand, fine to medium, some coarse, micaceous, medium brown, soft, moderately water-bearing--------------------------- | 3 | 792 |

TABLE 3. - Drillers' logs of wells--Continued

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 3N/8E-29C1S.--Continued | | |
| Clay, silty, occasionally sandy, micaceous, slightly calcareous, medium to dark brown, hard | 6 | 798 |
| Sand, fine to medium, highly micaceous, moderately cemented, calcareous, light to medium gray, moderately hard | 2 | 800 |
| 6N/13W-8Q1S. Altitude: 3,195 ft. Casing diameter: 8 inches, 0-160 ft, open hole 160-380 ft. Perforated 60-160 ft. | | |
| Sand, coarse | 60 | 60 |
| Sand, coarse and gravel | 30 | 90 |
| Sand, coarse and gravel with blue clay | 30 | 120 |
| Sand, coarse, gravel 25 percent, and blue clay 10 percent | 32 | 152 |
| Clay, blue 55 percent, coarse, sand 25 percent, gravel 10 percent, and limestone 10 percent | 30 | 182 |
| Clay, blue 75 percent and limestone 25 percent | 30 | 212 |
| Clay, blue and sand | 61 | 273 |
| Clay, blue and rock | 31 | 304 |
| Clay, blue, rock and sand | 76 | 380 |
| 2S/1E-25J1S. Altitude: 2,760 ft. Casing diameter: 14 inches, 0-433 ft, open hole 433 to 437 ft. Perforated: 170-533 ft. | | |
| Sand | 30 | 30 |
| Silt and sand | 20 | 50 |
| Sand, coarse and gravel with some cobbles | 34 | 84 |
| Sand and decomposed granite | 21 | 105 |
| Silt, brown, cobbles and coarse gravel | 3 | 108 |
| Sand, brown silt, and clay | 1 | 109 |
| Sand, fine and clay | 5 | 114 |
| Gravel with some sand | 14 | 128 |
| Sand and large gravel | 1 | 129 |
| Cobbles and gravel | 9 | 138 |
| Cobbles, gravel and coarse sand | 47 | 185 |
| Gravel, large, sand, cobbles with decomposed granite | 10 | 195 |
| Gravel, small, and sand | 25 | 220 |
| Sand, coarse, gravel and cobbles | 88 | 308 |
| Sand, coarse and gravel | 33 | 341 |
| Sand, coarse and gravel with cobbles | 56 | 397 |
| Sand, tight and gravel with cobbles | 11 | 408 |
| Sand, coarse and gravel with small boulders | 27 | 435 |
| Granite, fractured | 2 | 437 |

TABLE 3. - Drillers' logs of wells--Continued

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| 15S/14E-18C1S. Altitude: 64.97 ft. Casing diameter: 8 inches to 500 ft. Perforated 140 to 440 ft. | | |
| Sand, very fine to medium, brown with clay stringers. Fine carbonaceous particles and gastropods to 2 mm throughout interval and are common to total depth-------- | 30 | 30 |
| Sand, very fine to medium, brown with thin stringers of silty clay. About 5 percent of cutting contains granite to ¼ inch------------------------------------------------ | 20 | 50 |
| Sand, very fine to medium, brown, dominantly medium and composed primarily of quartz with subordinate amounts of feldspars and heavy minerals. Abundance of gastropods from 80-90 ft------------------------------------------ | 53 | 103 |
| Sand, fine to medium, brown and dark-gray clay------------- | 27 | 130 |
| Sand, fine to medium, brown, with some coarse sand and stringers of brown and gray clay. Abundance of gastropods---------------------------------------------- | 35 | 165 |
| Sand, fine to medium, brown and clay with some coarse sand and carbonaceous particles 59.3 mm. Abundant gastropods to 5 mm, 165 to 175 ft. Brown clay rather hard and contains little moisture---------------------------------- | 75 | 240 |
| Clay, light-gray with streaks of rather hard brown clay and stringers of very fine to medium sand-------------------- | 100 | 340 |
| Sand, fine to medium brown, and light gray clay------------ | 70 | 410 |
| Sand, fine to coarse, brownish-gray with stringers of gray clay--------------------------------------------------- | 30 | 440 |
| Sand, fine to coarse, brownish-gray and gray clay. Very few gastropods and carbonaceous particles-------------------- | 35 | 475 |
| Clay, gray, with stringers of fine to medium sand---------- | 25 | 500 |

TABLE 4. - Individual shock records of the Chilean earthquakes, 1960

[From Saint-Amand, 1961, p. 33]

[Locations and times are from the U.S. Coast and Geodetic Survey; magnitudes are from Pasadena, Calif., and Santiago, Chile]

| Date | Greenwich mean time | | | Lat., °S | Long., °W | Mag. |
|---|---|---|---|---|---|---|
| | Hour | Minute | Second | | | |
| May 21, 1960 | 10 | 2 | 50 | 37.5 | 73.5 | 7.5 |
| | 10 | 53 | 51 | 37.5 | 72.5 | ...... |
| | 12 | 21 | 16 | 37.5 | 73 | ...... |
| | 12 | 59 | 58 | 37.5 | 72.5 | ...... |
| | 13 | 59 | 17 | 37.5 | 72.5 | ...... |
| | 14 | 31 | 55 | 37.5 | 72.5 | ...... |
| | 15 | 8 | 45 | 37.5 | 73 | ...... |
| | 19 | 6 | 21 | ...... | ...... | ...... |
| May 22, 1960 | 3 | 46 | 22 | 37.5 | 73 | ...... |
| | 6 | 1 | 36 | 38 | 73.5 | ...... |
| | 8 | 10 | 53 | 37.5 | 73 | ...... |
| | 10 | 30 | 39 | 38 | 73.5 | 6.5 |
| | 10 | 32 | 43 | 37.5 | 73 | 7.5 |
| | 12 | 16 | 43 | 38 | 73 | ...... |
| | 18 | 55 | 57 | 38 | 73.5 | 7.8 |
| | 19 | 10 | 47 | 38 | 73.5 | 7.5 |
| | 19 | 11 | 20 | 38 | 73.5 | 8.4 |
| | 23 | 29 | 18 | 39.5 | 72 | ...... |
| May 23, 1960 | 0 | 25 | 44 | 38.5 | 75 | ...... |
| | 0 | 51 | 12 | 37.5 | 72 | ...... |
| | 1 | 34 | 53 | 39.5 | 74 | ...... |
| | 2 | 46 | 30 | 41.5 | 73.5 | ...... |
| | 2 | 56 | 17 | 43 | 75.5 | ...... |
| | 5 | 13 | 35 | 38 | 73.5 | ...... |
| | 7 | 9 | 17 | 48 | 77 | ...... |
| | 8 | 13 | 15 | 40.5 | 75.5 | ...... |
| | 9 | 52 | 20 | 37.5 | 73 | ...... |
| | 10 | 37 | 59 | 43.5 | 73.5 | ...... |
| | 14 | 1 | 50 | ...... | ...... | ...... |
| May 24, 1960 | 20 | 32 | 43 | 50.5 | 74 | 5.5 |
| May 25, 1960 | 4 | 44 | 6 | ...... | ...... | 5.7 |
| | 8 | 34 | 33 | 45 | 76 | 6.8 |
| | 19 | 21 | 48 | 40 | 75.5 | 4.4 |
| May 27, 1960 | 3 | 17 | 21 | 41 | 76 | 4.5 |
| | 20 | 49 | 12 | ...... | ...... | ...... |
| | 23 | 6 | 55 | 45 | 77 | ...... |
| May 28, 1960 | 3 | 5 | 53 | 39.5 | 74.5 | 5.5 |
| | 11 | 5 | 40 | 38 | 73 | 6 |
| May 29, 1960 | 7 | 39 | 29 | 38 | 72.5 | 6.5 |
| | 8 | 34 | 20 | 37.5 | 73 | 5.8 |
| | 14 | 5 | 25 | 37.5 | 73 | 5.5 |
| | 21 | 23 | 54 | ...... | ...... | 5.8 |
| May 31, 1960 | 2 | 40 | 0 | 39.5 | 75 | 6.5 |