Time-Series Ground-Water-Level and Aquifer-System Compaction Data, Edwards Air Force Base, Antelope Valley, California, January 1991 through September 1993

By Lawrence A. Freeman

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS AND ACRONYMS

Conversion Factors

Multiply	By	To obtain
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound per square inch (psi)	703.1	kilograms per square meter
pound per square inch (psi)	2.30667	feet of water at 4.0 degrees Celsius
yard (yd)	.9144	meter
millibar (mbar)	.0336	height of water, in feet

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F=1.8(°C)+32$$

Vertical Datum

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

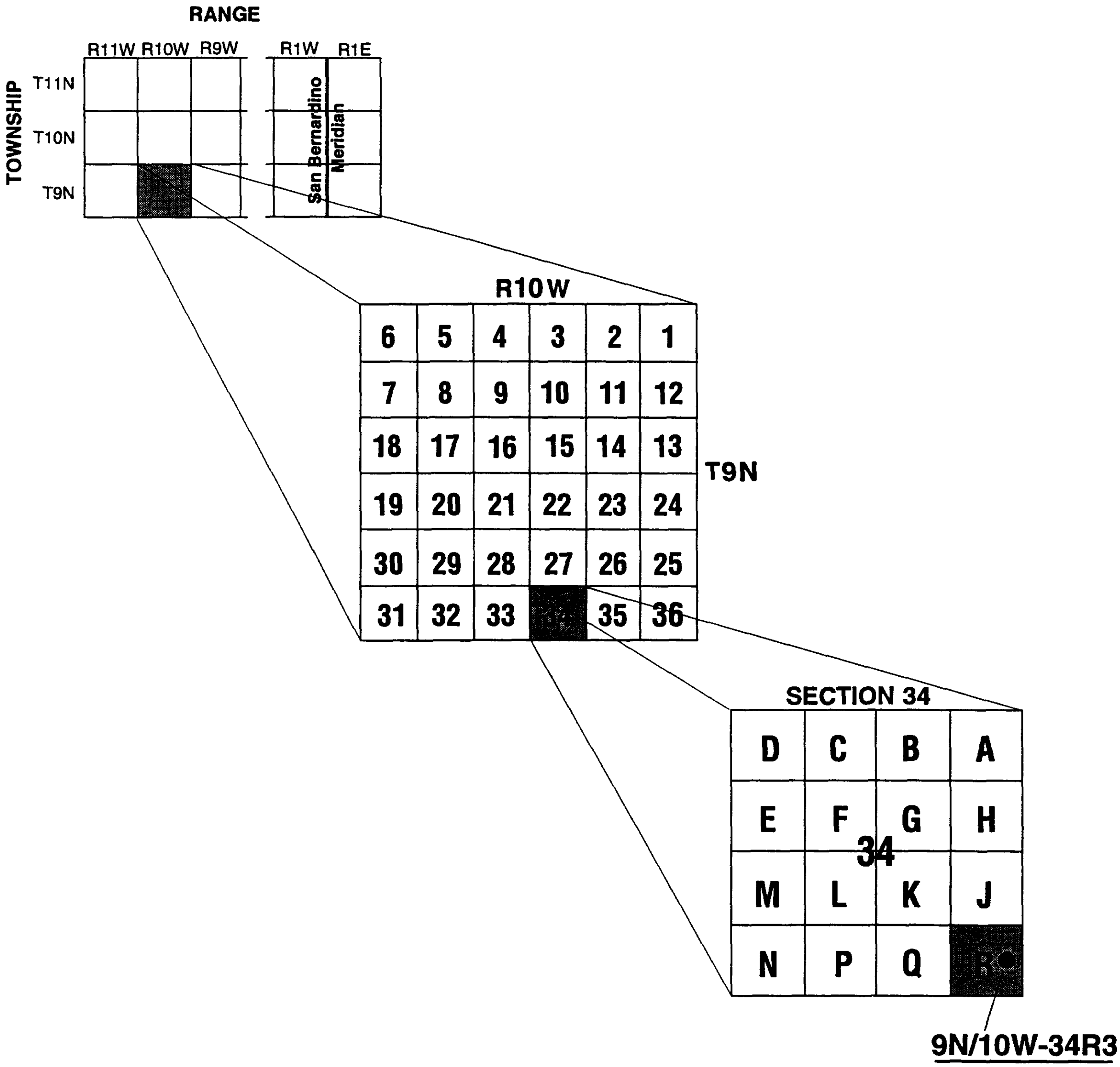
Local barometric pressure: Barometric pressure is shown as recorded without correction to sea level.

Abbreviations and Acronyms

A	Ampere
ADAPS	Automated DAta Processing System
DBLS	Depth to water Below Land Surface
DC	Direct Current
DECODES	DEvice COnversion and DElivery System
GLS	Generalized Least Squares
GPS	Global Positioning System
LVDT	Linear Voltage Displacement Transducer
mbar	Millibar
mV	Millivolt
Mw	Magnitude
NWIS	National Water Information System
PST	Pacific Standard Time
USGS	U.S. Geological Survey
V	Volt
W	Watt

Well-Numbering System

Wells are identified and numbered according to their location in the rectangular system for the subdivision of public lands. Identification consists of the township number, north or south; the range number, east or west; and the section number. Each section is divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with "A" in the northeast corner of the section and progressing in a sinusoidal manner to "R" in the southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. In California, there are three base lines and meridians; Humboldt (H), Mount Diablo (M), and San Bernardino (S). All wells in the study area are referenced to the San Bernardino base line and meridian (S). Well numbers consist of 15 characters and follow the format 009N010W34R003S. In this report, well numbers are abbreviated and written 9N/10W-34R3. Wells in the same township and range are referred to only by their section designation, 34R3. The following diagram shows how the number for well 9N/10W-34R3 is derived.



Time-Series Ground-Water-Level and Aquifer-System Compaction Data, Edwards Air Force Base, Antelope Valley, California, January 1991 through September 1993

By Lawrence A. Freeman

Abstract

As part of a study by the U.S. Geological Survey, a monitoring program was implemented to collect time-series ground-water-level and aquifer-system compaction data at Edwards Air Force Base, California. The data presented in this report were collected from 18 piezometers, 3 extensometers, 1 barometer, and 1 rain gage from January 1991 through September 1993. The piezometers and extensometers are at eight sites in the study area. This report discusses the ground-water-level and aquifer-system compaction monitoring networks, and presents the recorded data in graphs. The data reported are available in the data base of the U.S. Geological Survey.

INTRODUCTION

Long-term withdrawal of ground water at Edwards Air Force Base has resulted in aquifer-system compaction. This has produced three predominant problems:

1. Land-surface deformation resulting in the formation of earth fissures and erosion caused by altered surface-water drainage gradients;
2. Permanent loss of ground-water-storage capacity of the aquifer system (Ikehara and Phillips, 1994); and
3. Structural damage to man-made facilities as a result of land surface subsidence.

Land subsidence has created earth fissures and cracks in the bed of Rogers Lake. The dry lakebed is used by Edwards Air Force Base as a space shuttle landing site and as an emergency landing site for various types of experimental and test aircraft. Earth fissures and cracks are a hazard to airfield activity. Fissures also can create direct pathways for lake water and surficial contaminants to enter shallow aquifers. Land-surface deformation, in the form of a tilt, has occurred because of the uneven distribution of subsidence at the base. This has altered surface-water drainage gradients and caused erosional features that did not exist historically (Blodgett and Williams, 1992). The permanent and continuing loss of ground-water storage capacity due to aquifer-system compaction has made it increasingly difficult to pump equivalent amounts of water during each pumping season. After the pumping season ends, water levels may recover to nearly the same elevation as the previous season. However, the actual amount of water available in storage is reduced due to compaction of the aquifer system. When pumping resumes, ground water levels decline rapidly and return to the previous years' low levels. Ground-water pumps must operate longer, and lift the water greater distances in order to obtain the same amount of water. This results in increased pumping costs (Londquist and others, 1993).

Structural damage as a result of land subsidence commonly includes damage to roads, runways, sewer systems, wells, and water distribution systems (Blodgett and Williams, 1992). Repair or replacement costs can be high. Subsidence has caused structural weaknesses or changes from the original design and has increased the structure's susceptibility to damage from natural disasters, such as floods and earthquakes.

In 1989, the U.S. Geological Survey (USGS), in cooperation with Edwards Air Force Base, began a series of investigations to evaluate geohydrologic factors related to the deformation of the bed of Rogers Lake. The study area is located on Edwards Air Force Base, which is located in Antelope Valley, California (fig. 1). Defining the geohydrologic processes at Edwards Air Force Base that are related to the spatial distribution and rate of land subsidence, as well as the causes and locations of earth fissuring, is the primary objective of the USGS investigations. Land subsidence and surface deformation associated with ground-water withdrawals are problems occurring nationally and globally. Determining ground-water management alternatives that could mitigate aquifer-system compaction at Edwards Air Force Base is a secondary objective.

Purpose and Scope

The purpose of this report is to present data that can be used to determine the relationship of ground-water levels to the land subsidence and aquifer-system compaction that is occurring on, and adjacent to, Edwards Air Force Base. The data reported were collected January 1991 through September 1993 from a ground-water monitoring network at Edwards Air Force Base. Computed hourly data were derived from data collected by specialized instrumentation and automatic recording devices, and include ground-water levels, aquifer-system compaction, barometric pressure, and precipitation. This report also includes a brief discussion of the methods used to collect and process the data.

The data presented in this report are provided graphically, in two sections. Daily mean values for the period of record are included in the section, "Data for periods of record at instrumented sites." Hourly data for periods of selected geohydrologic events are presented in the section, "Data for periods of special interest." Plots for periods of selected geohydrologic events may have two or more types of data on each plot. The purpose of including these plots is to demonstrate the temporal and spatial responses shown by certain data for the selected geohydrologic events and to provide the users of these data with several examples of what can be determined by the use of hourly values.

Previous Studies

The U.S. Geological Survey has completed several reports from studies made in cooperation with Edwards Air Force Base (Moyle, 1960; Weir, 1962, 1963, 1965; Giessner and Robson, 1965; Giessner and Westphal, 1966; Tyley, 1967; and Koehler, 1969). In addition, several recent studies by the USGS have reported on land subsidence, land-surface deformation, and hydrogeology of Edwards Air Force Base and vicinity. Blodgett and Williams (1992) reported measured land subsidence at Edwards Air Force Base that occurred between 1961 and 1989 through 1991, and they reported on features of land-surface deformation affecting the lakebed of Rogers Lake. Ikehara and Phillips (1994) also measured land surface elevation at Edwards Air Force Base in 1992 as part of the larger Antelope Valley study, and recalculated subsidence. Londquist and others (1993) summarized the regional hydrogeologic setting of Antelope Valley and reported on geologic, geophysical, and hydrologic data, including aquifer-system compaction, collected by the USGS from 1989 through 1991. Rewis (1993) reported on additional lithologic, borehole geophysical, and monitoring-well construction data collected by the USGS from 1991 through 1992. Land use and water use in the Antelope Valley was reported on by Templin and others (1995). The 1992 seasonal potentiometric surface maps of the Lancaster and North Muroc ground-water subbasins in the vicinity of Edwards Air Force Base (fig. 2), based on monthly ground-water-level measurements, were shown in Rewis (1995). The extent of USGS hydrogeologic investigations at Edwards Air Force Base and vicinity from 1989 through 1992 is summarized in Prince and others (1995).

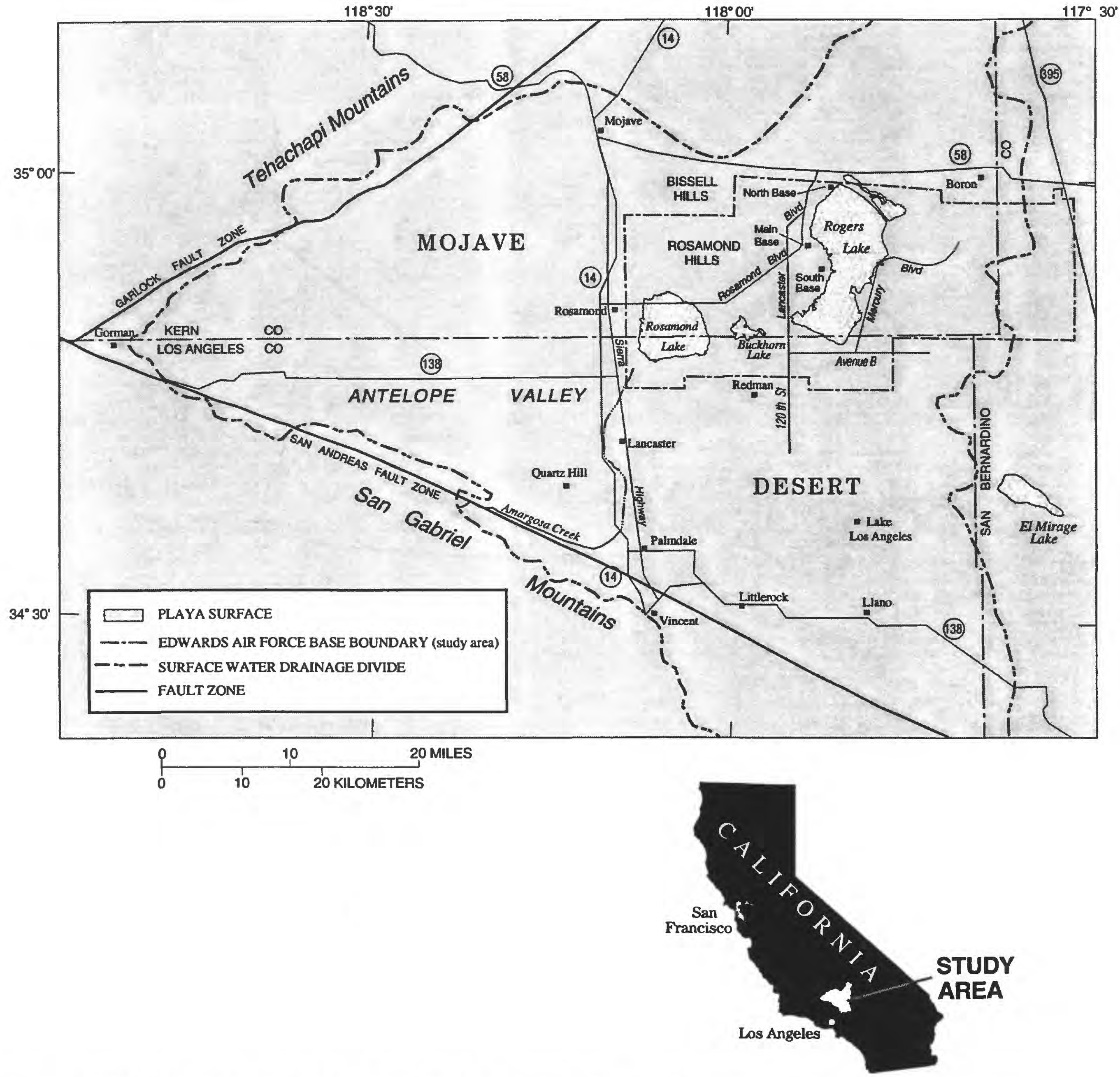


Figure 1. Location of Edwards Air Force Base study area (modified from Londquist and others, 1993).

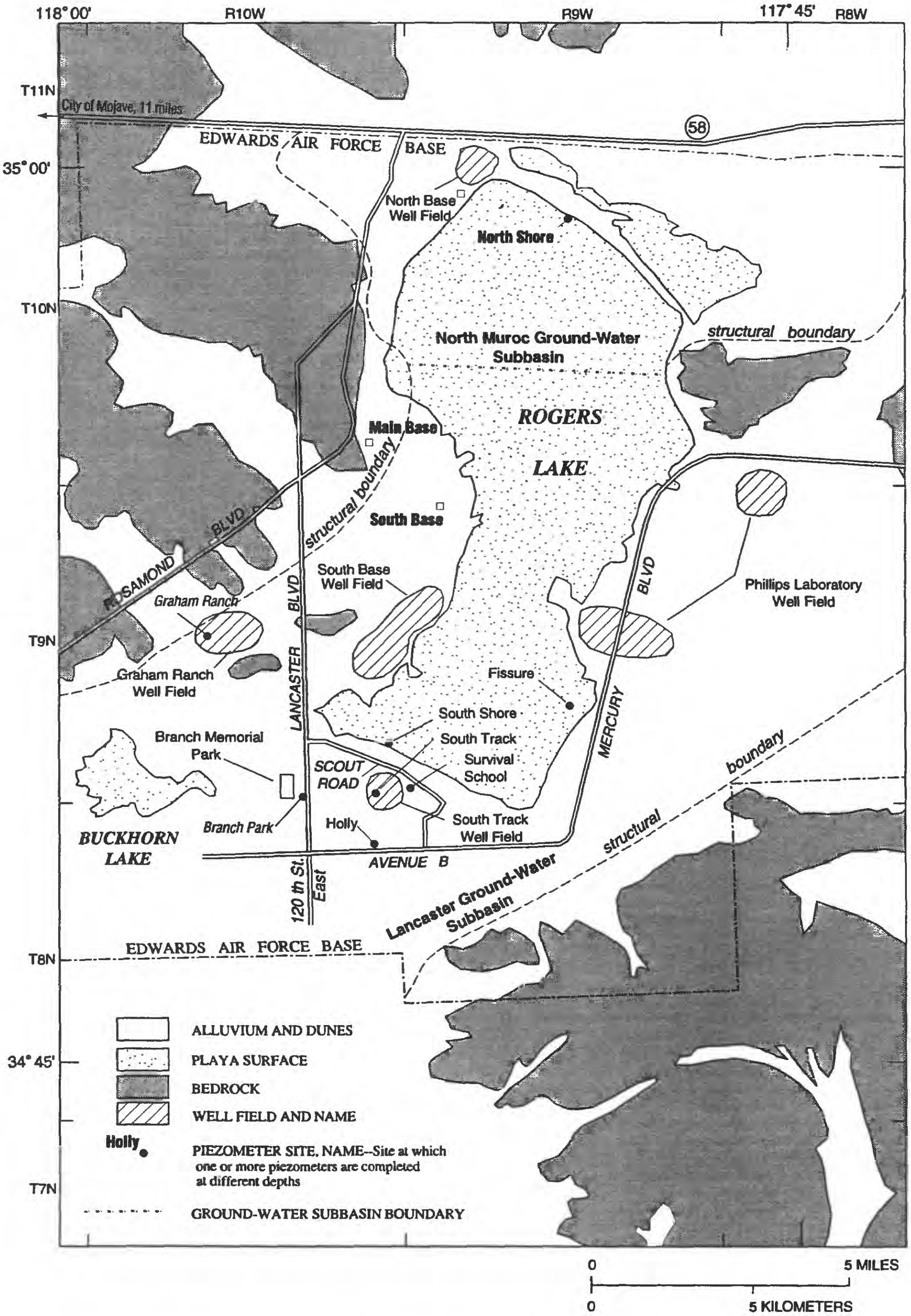


Figure 2. Location of sites on Edwards Air Force Base where time-series records of ground-water-level and aquifer-system compaction data were collected (modified from Rewis, 1993).

Acknowledgments

The author wishes to thank the many individuals and offices at Edwards Air Force Base who have provided area access and logistical support for this study. Special thanks to Phillip Brady, Chief of Plans and Programs; Lawrence Plews, Project Manager; Malcolm Marmet, Air Field Manager; and Herbert Parsons, Assistant Air Field Manager.

GROUND-WATER-LEVEL MONITORING SITES

Ground-water levels were monitored at eight sites in the Edwards Air Force Base study area. The monitored sites were selected from a large network of existing domestic and abandoned wells and the observation wells that were drilled by the USGS. This section of the report discusses criteria for site selection, locations of sites, instrumentation, and data collection.

Site Selection

There were several considerations in determining where to locate the ground-water-level monitoring sites. Monitoring water-level fluctuations in the proximity of the South Track Well Field (fig. 2), and at several distances from this important pumping center, was the primary consideration. This production well field is near the location of maximum measured land subsidence at Edwards Air Force Base (Londquist and others, 1993). Secondly, ground-water-level data were needed at the two extensometer sites, Holly and Fissure, located near the South Track and Phillips Laboratory Well Fields, respectively (fig. 2). In addition, sites were needed to monitor ground-water levels in the principal and deep aquifers (Londquist and others, 1993) over a large representative area in the vicinity of Rogers Lake. Finally, a small unnamed ground-water basin in the Graham Ranch area (fig. 2) was of interest because it offered a possible alternative supply of ground water for Edwards Air Force Base. This ground-water subbasin is isolated from the Lancaster ground-water subbasin, which is the primary water supply for Edwards Air Force Base (Londquist and others, 1993).

A series of exploration wells were drilled by the USGS from 1989 through 1992. The initial purpose for these wells was to obtain geological and geophysical information (Londquist and others, 1993; and Rewis, 1993). These wells were then configured as single or nested piezometers (fig. 3) for the purpose of determining seasonal water-level changes, seasonal potentiometric surfaces, and hydraulic gradients of the different aquifers. A piezometer differs from a well in that it is constructed to determine the water level of a discreet zone or thickness of the aquifer system. A well is typically constructed to withdraw water from more than one aquifer or aquifer zone and, therefore, reflects a composite hydraulic head (Fetter, 1988).

After more than a year of making periodic ground-water-level measurements, enough information had been gathered to determine the best sites for time-series data collection, and which of the individual piezometers at the sites would provide the most useful information.

Site Locations and Operational History

Eight sites were selected for this study and are listed in table 1 and shown in figure 2. Site name, state well number, USGS site-identification number, piezometer number, land surface datum, elevation, and screened interval of each piezometer are listed in table 1.

Table 1. Time-series ground-water-level data-collection sites at Edwards Air Force Base

[USGS, U.S. Geological Survey. ft, feet. Site identification No., as listed in California District National Water Information System (NWIS) site file. Land surface datum elevation and depth of screened interval as listed in California District Ground Water Site Inventory data base]

Local site name	State well No.	USGS site identification No.	Piezometer No.	Land surface datum (ft)	Depth of screened interval (ft)
Holly	8N/10W-1Q1	344835117531301	1	2,301.85	[1]980-1,010
	-1Q2	344835117531302	2	2,301.72	[1]605-635
	-1Q3	344835117531303	3	2,301.72	[1]430-460
	-1Q4	344835117531304	4	2,301.72	[1]85-115
Fissure	9N/9W-28A1	345056117501401	1	2,271.08	[2]735-745
	-28A3	345056117501403	3	2,271.08	[2]320-340
	-28A5	345056117501405	5	2,271.08	[2]40-60
Graham Ranch	9N/10W-16R2	345212117561802	2	2,312.8	[1]494-564
	-16R3	345212117561803	3	2,312.8	[1]300-340
South Track	9N/10W-36P2	344922117543301	1	2,290.90	[2]435-455
	-36P3	344922117543302	2	2,291.21	[2]90-110
Survival School	9N/10W-36J1	344932117525401	1	2,283.00	[2]870-890
	-36J2	344932117525402	2	2,283.00	[2]503-523
Branch Park	9N/10W-34R3	344923117550302	2	2,290.4	[1]480-510
	-34R5	344923117550305	4	2,290.6	[2]60-80
South Shore	9N/10W-25P1	345016117532301	1	2,269.49	[2]450-470
	-25P2	345016117532302	2	2,269.49	[2]100-120
North Shore	10N/9W-10B1	345856117485501	1	2,278.57	[2]282-302

[1]Londquist and others (1993)
[2]Rewis (1993)

The Holly site was the first site where instrumentation was installed for ground-water-level monitoring. Maximum land subsidence on Edwards Air Force Base has been measured near this site (Londquist and others, 1993). The name for this site is derived from the name of a bench mark at the site. Originally, four piezometers were monitored for ground-water-level changes, but because of the failure of the flotation systems installed in June 1990, and the failure of submersible transducers installed in January 1991, little useful information was obtained. Piezometers 1 and 2 were reinstrumented with new transducers in June 1992.

The Fissure site was the second site where instruments were installed for ground-water-level monitoring. The site was given its name because of nearby earth fissures and is located on the playa of Rogers Lake (fig. 2). Transducers in piezometers 1, 3, and 5 were installed during June 1991; the transducers in piezometers 1 and 3 failed, providing little useful data, and were reinstrumented in July 1992.

The Graham Ranch site was the third site where instruments were installed for ground-water-level monitoring. Time-series data have been collected from two of the three piezometers. In June 1991,

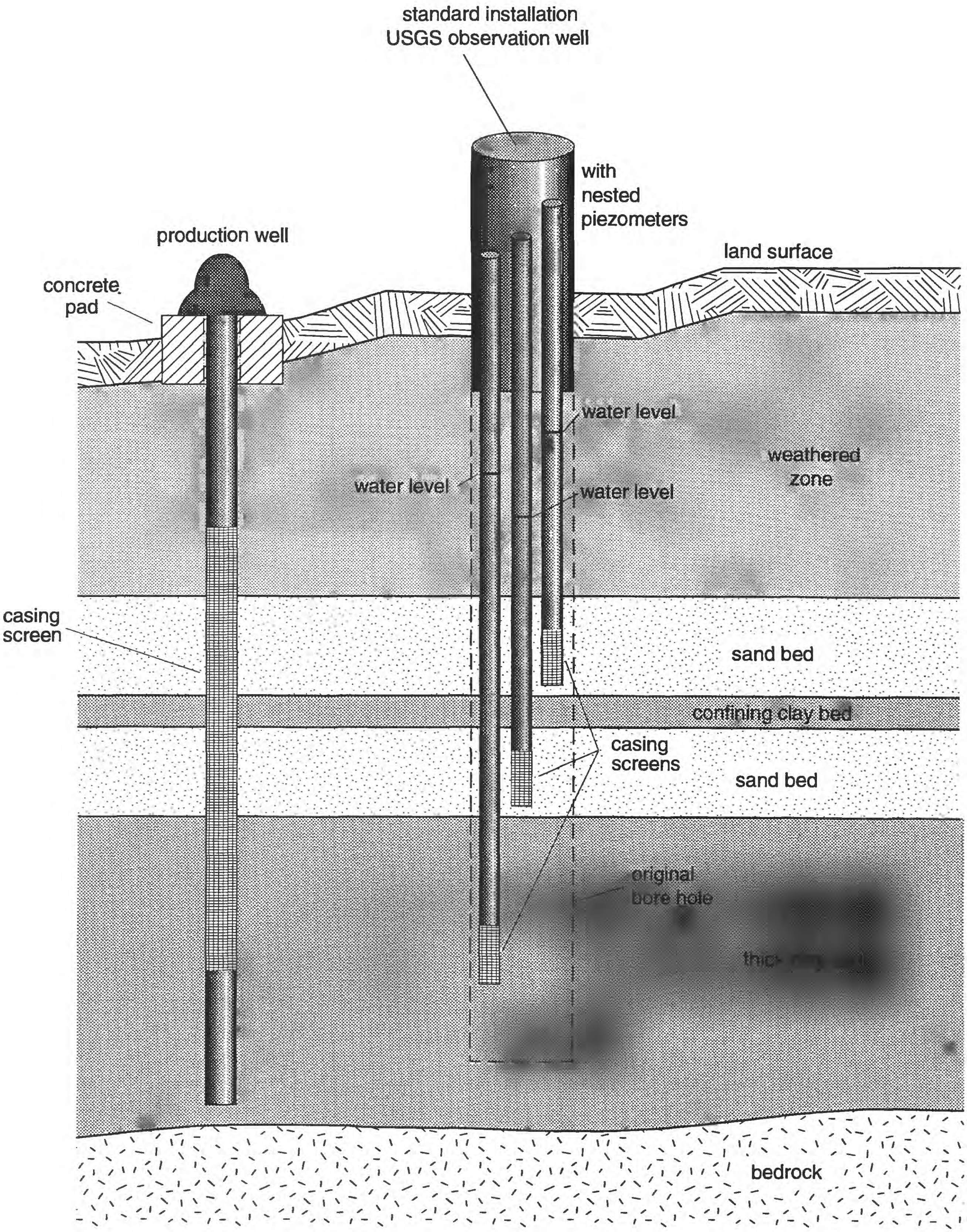


Figure 3. Standard piezometer installation at Edwards Air Force Base, comparing basic configurations of a production well and a USGS observation well.

piezometer 3 was instrumented. Data were collected through January 1992, when the buried instrument shelter was flooded, destroying the data logger and transducer. In June 1992, piezometer 2 was instrumented for ground-water-level monitoring. This site was monitored to determine how daily and seasonal production-well pumping was affecting ground-water levels. There are two production wells within 0.25 mi of the Graham Ranch piezometers.

The South Track site is located adjacent to the production wells that comprise the South Track Well Field. The two piezometers at this site were instrumented for ground-water-level monitoring in July 1992. Piezometer 1 was instrumented to record the large daily changes in the deep aquifer ground-water level caused by pumping from the adjacent production wells. Piezometer 2 was instrumented to monitor ground-water levels in the principal aquifer at this site.

The Survival School site was instrumented for ground-water-level monitoring in July 1992. It is located in a small wash, approximately 150 yds south of the Edwards Air Force Base Survival School training center. The South Track Well Field is about 0.5 mi west of this site (fig. 2). There are four piezometers at this site and transducers are installed in piezometers 1 and 2.

The Branch Park site ground-water-level monitoring instrumentation was installed in September 1992. Of the four piezometers at this site, piezometers 2 and 4 have transducers. This site is located on a small playa at Branch Memorial Park, which is near the south entrance to Edwards Air Force Base. There is a small fishing pond that is located at the park. Water seepage from this pond apparently has an effect on the water level in the shallow piezometer at this site. The ground-water levels collected through September 1993 in both piezometers indicate no daily effects due to pumping at the South Track Well Field. The ground-water levels in piezometer 4 are constantly rising, which is contrary to ground-water-level trends from all other sites in the study area.

Ground-water-level monitoring instrumentation was installed in piezometers 1 and 2 at the South Shore site in September 1992. The site is located at the shoreline of the south end of Rogers Lake (fig. 2), the lowest area of the playa. Although this site has the greatest potential for flooding, it did not flood during the period of this report. During winter storm runoff, surface water drainage floods the normally dry playa. High precipitation years such as the winter of 1992-93, accentuate this flooding, and along with wind-driven waves, cause the water level in the lake to come close to the tops of the piezometers at this site.

The North Shore site is named for its location near the northern-most end of Rogers Lake (fig. 2). The ground-water-level monitoring instrumentation was installed in December 1992. There are two piezometers, but only piezometer 1 has a transducer. Ground-water-level data for North Shore do not show any daily affect from pumping at the North Base Well Field.

Selection and Operation of Instrumentation

The data-collection needs of the study required a sensitive and stable water-level sensor with good longevity in field installations. Submersible pressure transducers were selected to monitor the ground-water levels and needed to function properly over a range of seasonal and daily water-level changes that ranged from a few tenths of a foot to more than 20 ft (Freeman, 1994). There also was the potential for large daily water-level fluctuations at the South Track site due to its proximity to the production wells. All instrumentation used in the study was capable of sensing and recording ground-water-level data to 0.01-ft accuracy, which was required by the USGS for surface-water data (Cobb, 1989).

The transducers selected for measuring ground-water levels are all gage transducers, which means that they are vented to atmospheric pressure. Fourteen of the 18 transducers had an output range of zero to 5 pounds per square inch (psi), which is equivalent to 0 to 11.53 ft of submergence in water. Three other transducers had a millivolt (mV) output with a range and precision, in feet, equivalent to that of the 5 psi transducer. The data loggers were programmed to store data to 0.001 psi resolution. The remaining transducer had a zero to 15 psi range, which is equivalent to zero to 34.60 ft of submergence. The expanded range of this transducer resulted in psi values that could be recorded to 0.003 psi precision. The transducers with psi output are temperature compensated and are accurate for water temperatures from 4.0-50°C (Design Analysis Inc., written commun., 1994). After converting the psi or mV output to depth of submergence, in feet, a resolution of 0.0023 foot for the 5 psi and mV transducers and 0.0069 foot for the 15 psi transducer was achieved. The 15 psi transducer was installed in piezometer 1 at the South Track site, which registered large daily and seasonal changes in water level, due to its proximity to a major production well field. In addition to ground-water levels, aquifer-system compaction, barometric pressure, and precipitation also were recorded at selected sites. All data were recorded to Pacific standard time.

Three different ground-water-level monitoring systems were installed during the investigation. The first system, a Campbell Scientific CR21X data logger (CR21X) with float and shaft encoder did not operate properly because of the depths to water and friction between the float, float tape, and the walls of the 2-in. diameter piezometer casings. The second system used Druck Inc. model PDCR 950 Ti (Druck) submersible transducers and Campbell Scientific CR10 data loggers (CR10). This system had mixed results, but, the transducers generally were not reliable enough for the long-term monitoring needs of the study. The final system used for measuring and recording ground-water levels consisted of Design Analysis Water Log H-300 submersible pressure transducers (H-300) (fig. 4) and CR10 data loggers. In addition to the CR10 memory, data were backed up on a storage module (SM-192). The SM-192 preserves data and programs in the event of CR10 power failure. The CR10 program can be stored on the SM-192 and reloaded to the CR10. This ground-water-level monitoring system has been reliable and was the primary system employed for this study (Freeman, 1994).

The typical system for measuring and recording ground-water-level data consists of one or two H-300s connected to a CR10 (fig. 5). The system is powered by a single 12-V battery with a 10-W solar panel and a 12-V, 1-A regulator. The CR10, battery, SM-192, and regulator typically are sheltered in a small fiberglass environmental box. The dry air system (fig. 6) used to keep the air in the vent tube of the H-300 free of moisture was located in the shelter with the CR10 or in a separate shelter. Then the shelter(s) are mounted to a vertical pole that is attached to a 4-ft-long 6- or 8-in. diameter steel outer casing (fig. 7), which is buried in the ground. The steel casing protects the 2-in. diameter polyvinylchloride piezometer casings. The shelters and the outer casing can be locked to protect against vandalism and environmental damage.

Data were recorded hourly and consisted of instantaneous values of transducer submergence depth as psi or mV and hourly mean values of submergence depth in psi or mV, internal shelter temperature, CR10 temperature, ground-water temperature in degrees centigrade, and battery voltage. The ground-water data presented in this report are based on the instantaneous hourly values. The remaining data were recorded primarily for the purpose of detecting and troubleshooting instrumentation problems. Field visits to all sites were made every 4-6 weeks to collect the data to check the instrumentation operation, and to make manual measurements of ground-water levels with a steel or electric tape.

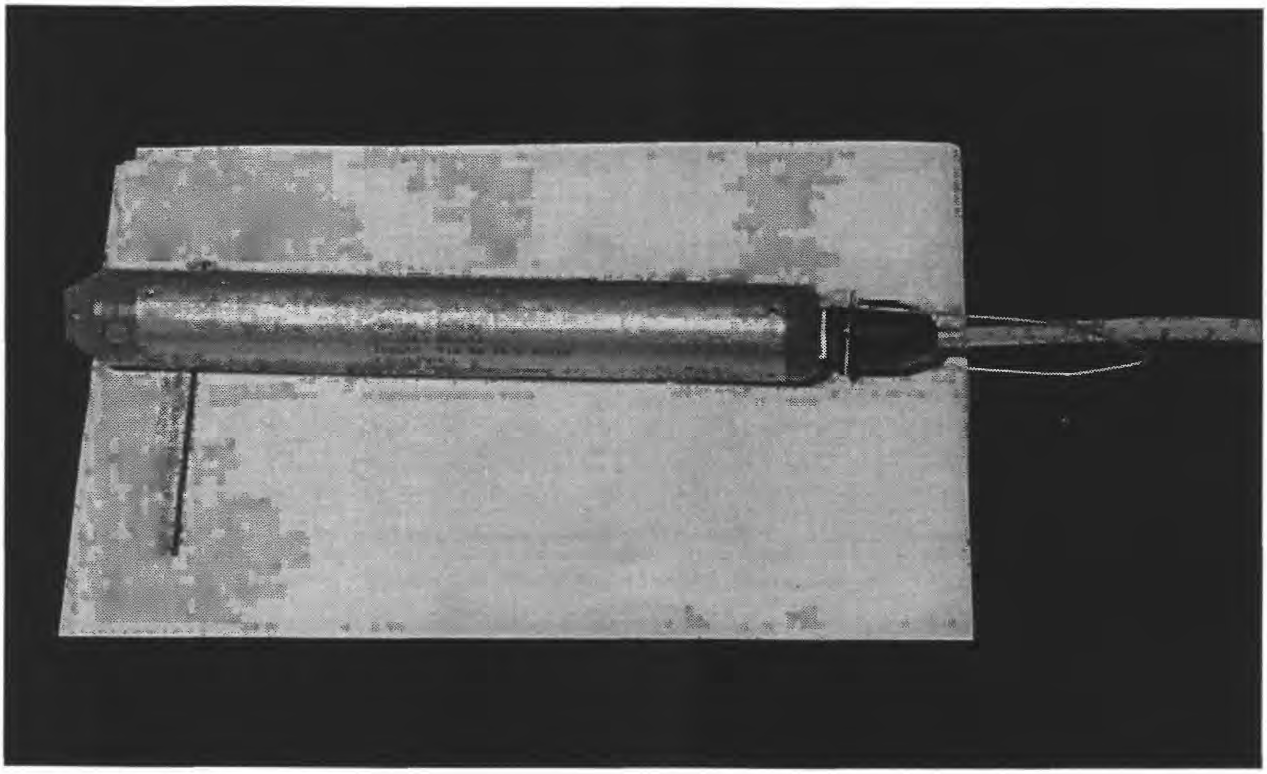


Figure 4. Design Analysis Water Log H-300 submersible pressure transducer and vent tube (reproduced with permission of Design Analysis, Inc.).

Ground-Water-Level Data Collection

Calibration of each transducer was done in the field at the time the transducer was installed in the piezometer. In addition, the calibration was checked each time a transducer was repositioned. Calibration was done by moving the transducer in equal increments through the water column in the piezometer and recording the transducer output and the corresponding distance the transducer was moved. A minimum of four incremental calibration points were used, which spanned the factory calibration range. Three readings were obtained at each calibration point. These data pairs were used to generate a generalized least squares (GLS) regression equation that was used to convert psi or mV to submergence depth of the transducer below water surface. This equation was then combined with an offset, equal to the water level measured by a calibrated tape added to the submergence depth at the time the transducer was installed. The final equation converts the transducer output to depth to water below land surface (DBLS).

During field visits, ground-water-level measurements were made and compared with the values being recorded by the instrumentation. The values of transducer submergence depth, measured and recorded by the CR10 in psi or mV, were converted to DBLS using the appropriate equation. The equation for converting transducer output to DBLS is:

$$DBLS = SP-(psi\ or\ mV)(Sr), \qquad (1)$$

where

DBLS is Depth to water below land surface datum, in feet;

SP	is Set Point Distance, in feet; the measured distance below land surface datum of the pressure transducer at the time of installation;
psi or mV	is the transducer output, in pounds per square inch, or millivolts at a specific time; and
Sr	is the slope of the GLS regression equation, in units/feet.

Land surface datum of each piezometer was determined by surveying elevations from nearby bench marks or global positioning system (GPS) survey markers (Rewis, 1995). Land surface datum elevation for each piezometer is listed in table 1. The level of accuracy of land surface datum elevation listed in table 1 is reflected by the number of digits to the right of the decimal point, and is a result of the level of accuracy of the survey method used to obtain the elevation at the benchmark or GPS marker. Field notes were kept and log sheets were completed for each site visited during routine data collection.

Ground-water-level measurements were made to 0.01-foot accuracy using either a calibrated steel tape, or a calibrated electric tape. Repeat measurements of DBLS were made to reduce the possibility for error in the measurements. When tape measurements for a given piezometer agreed within 0.02-foot, the DBLS was noted and compared with the converted submergence depth values. Differences between measured and converted values of DBLS were then noted and used to adjust the transducer data where necessary during the office computational process.

Data were downloaded from the CR10 recorder to a SM-192 storage module or a portable computer. The portable computer provided the ability to plot and view data while at the site, which was an important capability for timely trouble-shooting of the instrumentation. Viewing plotted data in the field also provides the opportunity to evaluate effects of events, such as ground-water pumping and earthquakes that have occurred since the previous visit.

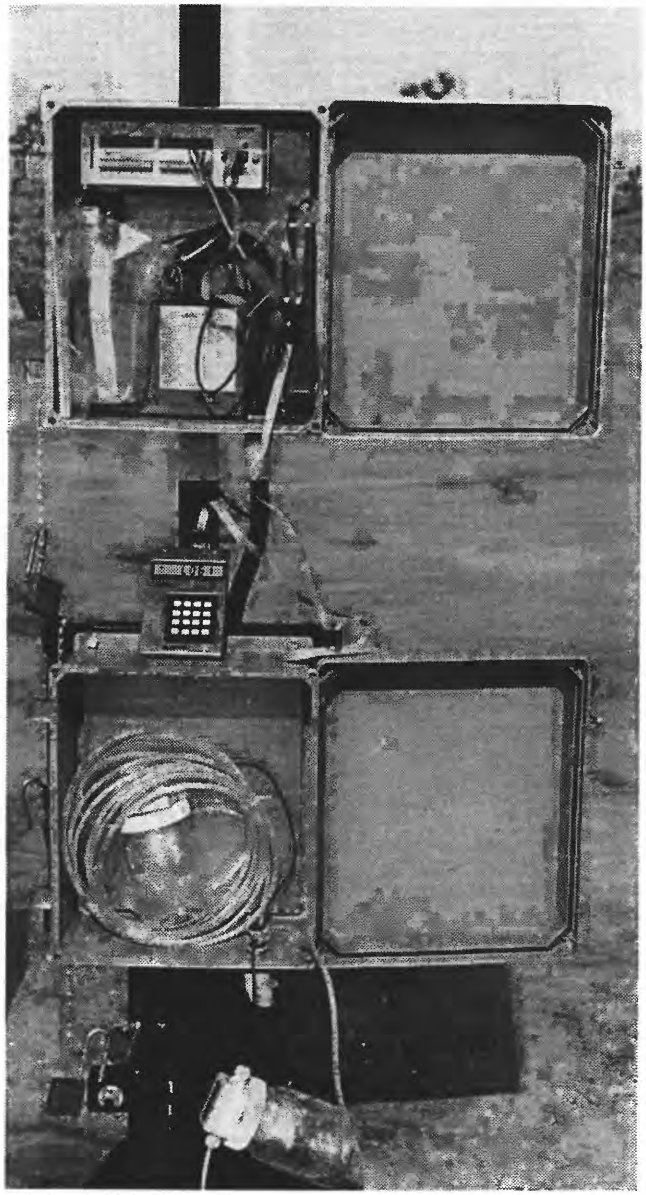


Figure 5. Data logger and transducer system used for recording ground-water levels.

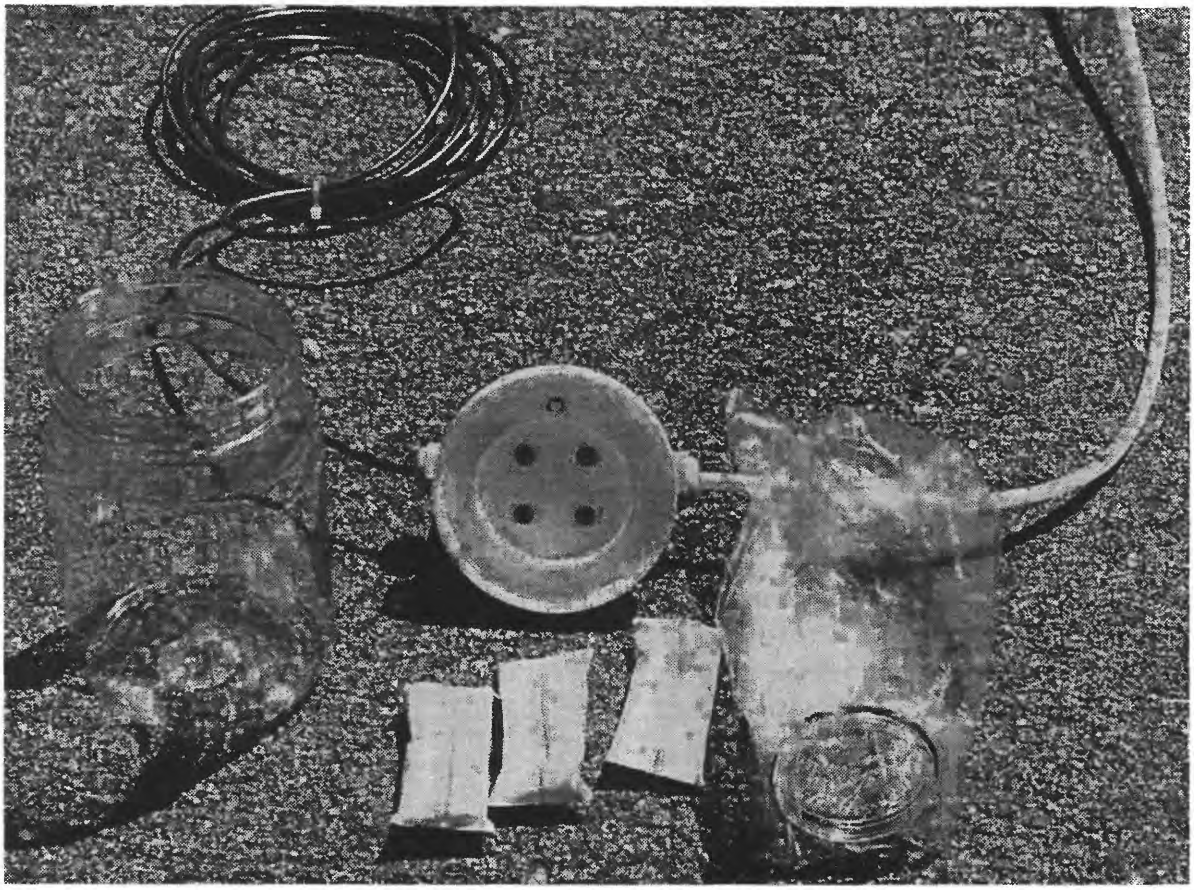


Figure 6. Dry-air system for H-300 submersible pressure transducer (reproduced with permission of Design Analysis, Inc.).

AQUIFER-SYSTEM COMPACTION MONITORING SITES

Aquifer-system compaction was monitored by three extensometers at two sites in the Edwards Air Force Base study area. The sites were selected after reviewing information on rates of land subsidence at locations within the study area. The extensometers were installed by the USGS and operated in conjunction with the ground-water-level recording sites. This section of the report discusses criteria for site selection and location, instrumentation, and field-data collection.

Site Selection and Location

Extensometer sites were selected in order to record aquifer-system compaction for three depth intervals. As previously stated, the Holly site was selected to monitor aquifer-system compaction at the point of maximum measured land-surface subsidence at Edwards Air Force Base (Blodgett and Williams, 1992). A single extensometer was installed at the Holly site. The Holly extensometer measures compaction from land surface to a depth of 840 ft below the aquifer system, where it is anchored in a resisting geologic unit. This

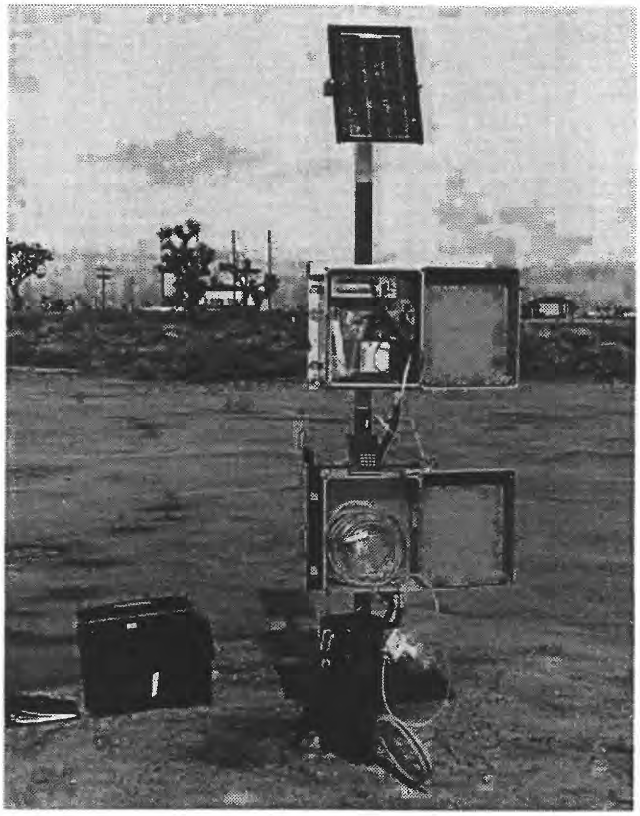


Figure 7. Typical Edwards Air Force Base ground-water level recording site.

extensometer recorded the compaction that occurs over the entire thickness of the aquifer system at this site.

The Fissure site was selected to monitor compaction several miles from the South Track Well Field. The site is on the playa of Rogers Lake (fig. 2). Two extensometers were installed at this site. The deep extensometer registers compaction between 15 and 52 ft below land surface where the lithology is primarily clay, silt, and sand. The shallow extensometer registers compaction between land surface and 15 ft below land surface where the lithology is entirely clay (Rewis, 1993). The clays near the surface expand and contract in response to hydration from precipitation and(or) flooding and desiccation.

Selection and Operation of Instrumentation

The extensometer installations at the Holly and Fissure sites are unique adaptations of a telescoping extensometer design (Poland and Yamamoto, 1984). The Holly extensometer (fig. 8) was installed during June 1990. The extensometer consists of a weighted fulcrum arm, fastened to a concrete pad at land surface. The arm is attached to a 2-in. anchor pipe, which, as previously stated is anchored in concrete at a depth of 840 ft. As the concrete pad moves relative to the anchor pipe, the fulcrum arm changes from its horizontal position. An instrument table is positioned over the extensometer. In order to provide a stable platform for the instrumentation, the two support legs for the instrument table are anchored in concrete at 15 ft below land surface. Because of the anchored depth of the support legs, this extensometer measures compaction from a depth of 15 to 840 ft and it is assumed that compaction between land surface and 15 ft is negligible. More information about the Holly extensometer design and construction are given by Blodgett and Williams (1992).

The time-series record of aquifer-system compaction at the Holly site is obtained by measuring and recording the movement of the instrument table relative to the anchor pipe (fig. 8). The primary recording instrumentation consists of a Campbell Scientific CR21X data logger, and a Trans-Tek model 243 linear voltage displacement transducer (LVDT). The LVDT body is fastened to the instrument table. A small metal rod called the core protrudes from the LVDT and rests on a reference surface attached to the 2-in. anchor pipe. As the land surface moves relative to the reference surface, the LVDT core is displaced causing a change in the

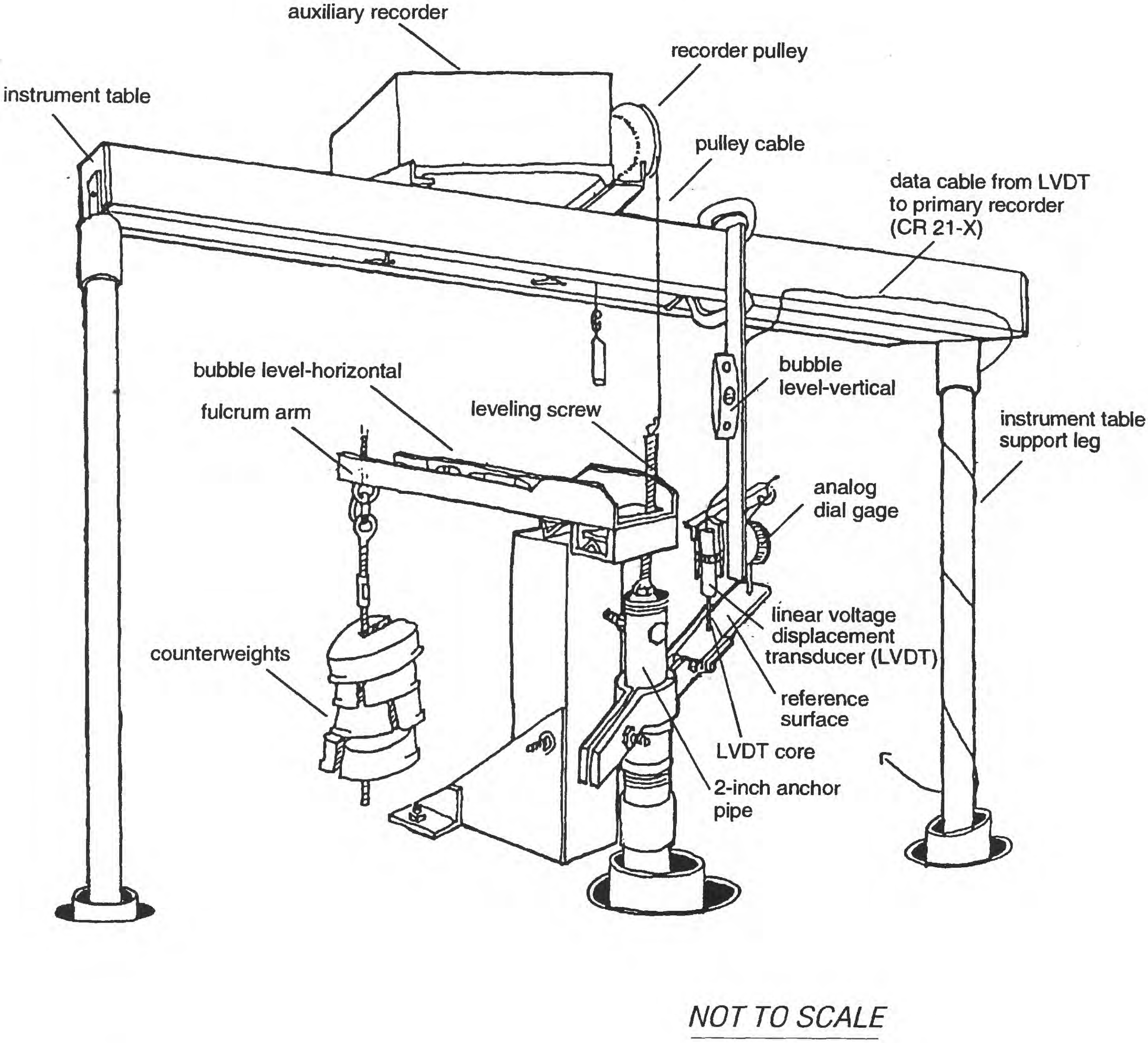


Figure 8. Holly extensometer, above-ground installation.

output voltage of the LVDT, which is then converted to feet. The LVDT has a range of 0.0167 foot. In addition, a sensitive Soil-Test dial gage is fastened to the instrument table next to the LVDT. The LVDT rod and dial gage indicator rest on the same reference surface. Analog dial gage readings are noted for comparison with the changes recorded by the LVDT and CR21X. The analog dial gage can be read to 0.0001 in., and has a range of 2 in. Barometric pressure is measured at the site by a Setra barometer and recorded by the CR21X. A Stevens- Type F analog recorder is used to collect an auxiliary record of compaction in the event of electronic failure of the primary recording system. This auxiliary recorder was fitted with special gears to provide the 0.001-ft precision needed for compaction data.

The LVDT output was calibrated by adding counter weights to the fulcrum arm in fixed increments, and noting the changes in output voltage from the LVDT, and changes in the analog dial gage. The data were used to generate an equation that is used to convert the change in voltage output of the LVDT into a change in feet. The equation was computed by means of GLS regression.

$$AC = Or + (Sr)(mV), \qquad (2)$$

where

AC is computed aquifer compaction, in feet;
Or is the offset (y-intercept), in feet, of the GLS regression equation;
Sr is the slope of the GLS equation, in ft/mV; and
mV is the recorded millivolt output of the LVDT measurement at a specific time.

Successful recording of aquifer-system compaction commenced in January 1991, after an initial period of adjusting and fine tuning the extensometer and its instrumentation. Instrumentation improvements and other refinements were made again in August 1992. The refinements made were: moving and positioning the dial gage so that it was referenced to the same surface as the LVDT; adding more weights to the fulcrum arm, which increased the stability (rigidity) of the anchor pipe; and attaching the pulley cable of the auxiliary recorder directly to the leveling screw of the anchor pipe. The result was data with much less noise (fig. 19, at back of report), and greatly improved consistency in the values measured by the analog dial gage, the auxiliary recorder, and the LVDT/CR10 instruments. The record of hourly compaction has been essentially uninterrupted, except for short periods when these refinements were being made.

The two extensometers at the Fissure site (figs. 9, 10) have a different design than the extensometer at the Holly site. The deep extensometer has an anchor pipe set in concrete 52 ft below land surface and the shallow extensometer has an anchor pipe set in concrete at land surface. Like the Holly site, the instrument table support legs at the Fissure site are set in concrete 15 ft below land surface. The shallow extensometer measures changes between land surface and 15-ft depth, and the deep extensometer measures changes between depths of 15 and 52 ft. The shallow zone is monitored to gain information about the response of the lake bed clays to wet and dry periods and to surface deformation processes such as fissure formation. Two Trans-Tek model 243 LVDTs are mounted on the instrument table. Each LVDT is mounted inside a micrometer chamber that has three leveling legs and is positioned on the instrument table. Each extensometer LVDT core is connected to a separate anchor pipe. The top end of each LVDT core passes through the coil that is attached to the micrometer dial on the top of the micrometer chamber. The micrometer dial is used to raise or lower the LVDT coil inside the micrometer chamber. The vernier scale of the micrometer dial allows direct and precise determination of how much the LVDT is moved during repositioning and calibration checks.

In this report, sediment compaction is considered to be the equivalent of aquifer-system compaction. The time-series record of aquifer-system compaction at the Fissure site is obtained by measuring and recording the relative movements of the land surface and the 52-ft depth anchor pipes relative to the instrument table legs that are fixed at the 15-ft depth (fig. 8). The instrumentation consists of a CR10, SM-192, and the LVDTs. In addition, two analog dial gages are used to provide a check of the recorded changes in sediment compaction. Sediment compaction is the specific name of the parameter under which the data are stored in the USGS data base. The instrumentation is powered by two 12-V DC batteries connected in parallel that are charged by a 10-W solar panel and 12-V, 1-A regulator. This is the same data logger and power supply system used to operate the transducers in the piezometers at this site. The extensometer instrumentation was installed in July 1992. The data recorded for the extensometers are the unadjusted voltage output from the LVDTs. A specialized data logger program was designed for use in the CR10 at this site because of its multiple role of recording the ground-water level, aquifer-system compaction, and precipitation data.

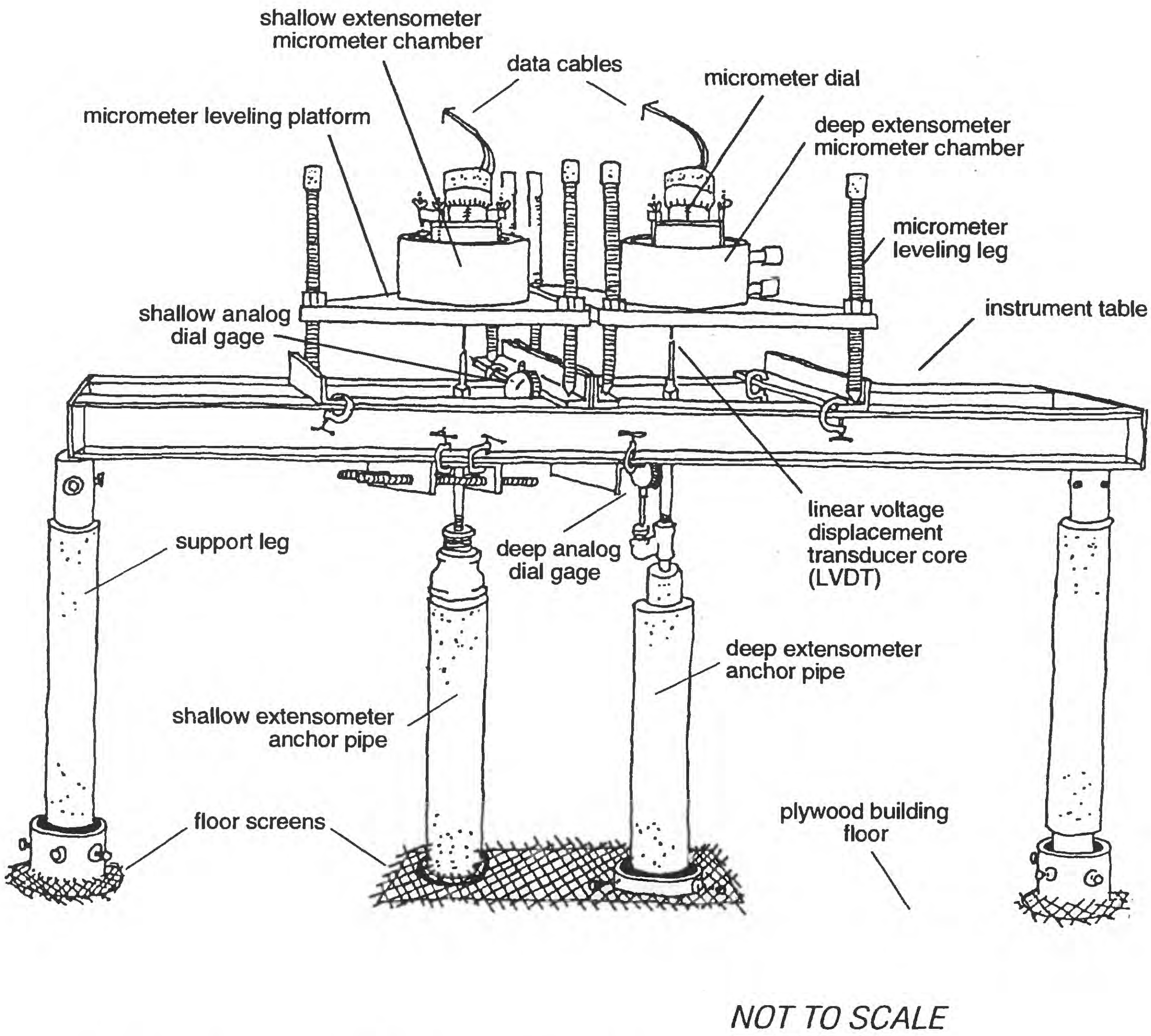


Figure 9. Fissure extensometers, above-ground installation.

The design of the Fissure extensometers, and the instruments used, make calibration of the LVDTs much simpler than at the Holly site. The calibration is done by turning the micrometer dial adjustment knob and comparing the micrometer dial values with the voltage output from each LVDT. The LVDT voltage and the micrometer dial readings are used to calculate a GLS regression equation. The GLS regression equation and conversion from inches to feet (eq. 3) are used to process the data in the USGS time-series data base. On occasion, the LVDTs need to be repositioned when the 0.0333-foot range limit of the LVDT is approached. When they are repositioned, a calibration check is made by using the micrometer dial in the same manner as the original calibration:

$$AC = Or + (Sr)(mV)(0.08333), \qquad (3)$$

where

- AC is computed aquifer compaction in feet;
- Or is the offset (Y-intercept) of the GLS regression equation, in feet;
- Sr is the slope of the GLS equation in/mV; and

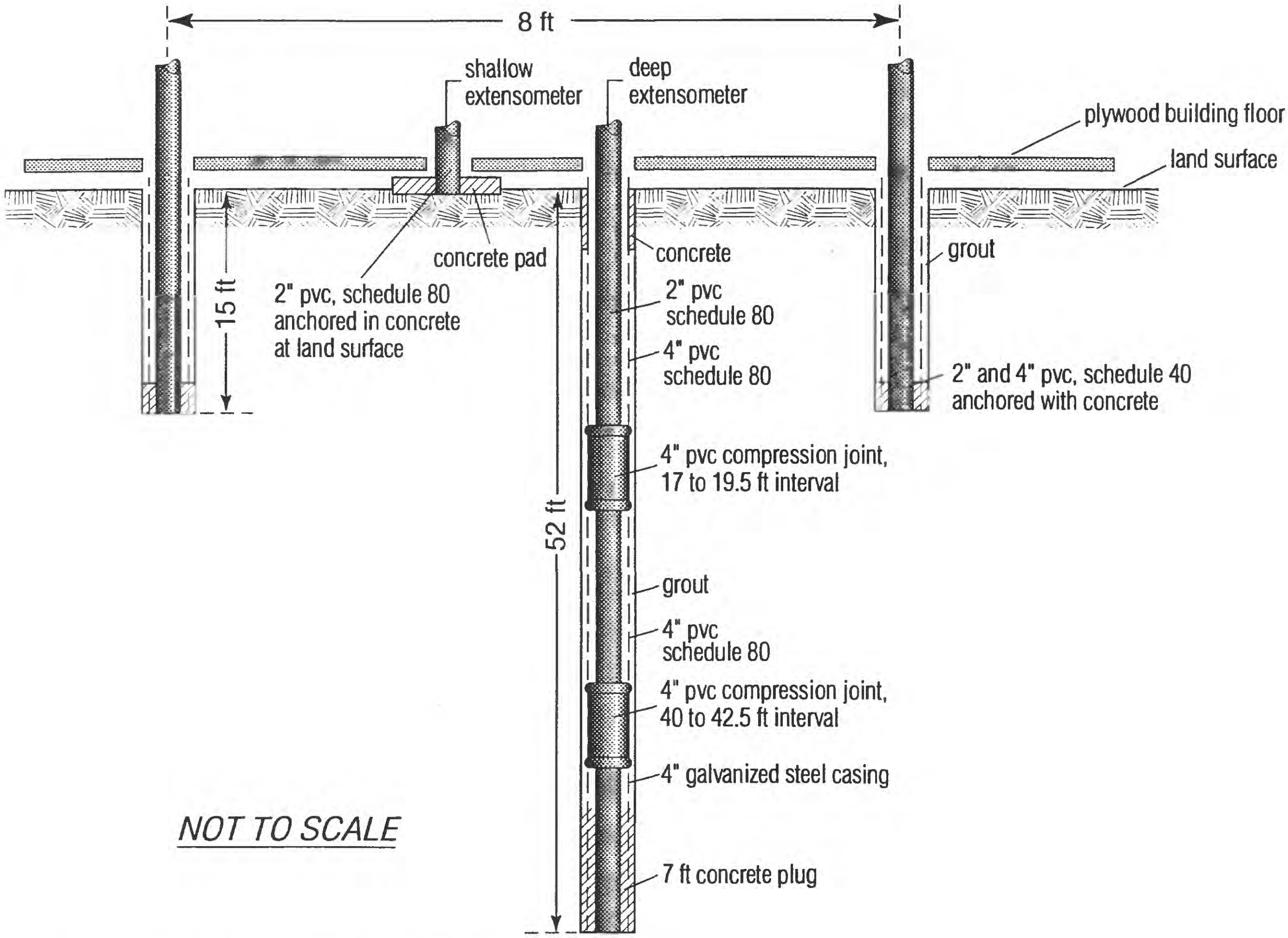


Figure 10. Fissure extensometer, below-ground installation.

mV is the recorded millivolt output of the LVDT at a specific time.

0.08333 is a constant used to convert inches to feet.

Aquifer-System Compaction Data Collection

During visits to the two sites, dial-gage readings are noted and compared with the output from the LVDTs. The amount of change in the dial-gage readings and in the LVDT output that occurs between visits should agree closely. The values of LVDT voltage registered by the data loggers are converted to feet in the field.

At the Holly site, a 48-in. carpenters' level is permanently positioned on the fulcrum arm. If the arm is not level, it is adjusted accordingly. Dial and LVDT readings are noted before and after the leveling procedure in order to define any corrections to the recorded data. The design of the extensometers at the Fissure site does not require re-leveling.

Data for the study are retrieved in the field in the same manner and at the same time as the ground-water-level data for these sites. The use of a portable computer and PFC software is the preferred method. Data are plotted on the screen of the portable computer before leaving the site to ensure that the instrumentation is functioning properly.

DATA PROCESSING

All data presented in this report are stored and processed on a USGS nation-wide computer system in the Automated DAta Processing System (ADAPS) of the National Water Information System (NWIS) data base. Data that are retrieved and stored on a portable computer are transferred to the minicomputer using standard file transfer software. Once in the minicomputer, a backup copy of the data is made for local magnetic tape archival. The data are then converted by the DEvice COnversion and DElivery System (DECODES) into a standard input format for ADAPS. Data generated by DECODES are considered to be the original data for all digital recorders (Hubbard, 1992). All data editing and computations were done within ADAPS.

ADAPS is designed to store and process time-series data. (Dempster, 1990). One advantage of using ADAPS is that there is a permanent, on-line record of the changes and corrections applied to the original, time-series data in the process of computing daily statistics. This computation process is called the primary computation, and as applied to the project's data, consists of four steps:

1. Original data (Edited Unit Values) are converted to the engineering units of the parameter, using a linear conversion equation;
2. Datum corrections are applied to the converted data;
3. These corrected data are stored separately as Computed Unit Values; and
4. Daily statistics (Daily Values) are computed from the Computed Unit Values and stored.

The original time-series data loaded into ADAPS are called edited unit values because they are available to be edited or deleted and may not be identical to the original archived data after editing. Since no data modification was made to these data with DECODES, the edited unit values are the same as data recorded in the field, and usually require some conversion to engineering units. For example, the data presented in this report as "DBLS" are recorded as psi or mV from the transducer. These values are converted during the primary computation to DBLS, in feet (step 1).

Manual measurements, and observations of analog dial gages were made to compare with the recorded values. The difference between the measured or observed value and the recorded value is stored with the date and time of observation in the datum corrections file. In all cases, drift in the instrument was determined to occur linearly over time, so a datum correction can be calculated for each computed value by a linear time proration between datum correction values (step 2). The primary computation calculates these corrections and applies them to each of the converted edited unit values and stores the results separately as computed unit values (step 3). Computed unit values can be created only by the primary computation and cannot be manually created or edited. This process maintains the edited unit values in their original edited form.

Daily statistics also are calculated from the computed unit values by the primary computation (step 4). The daily statistics computed for these data include maximum, minimum, mean, and instantaneous observation at noon. With the exception of daily summations, such as total daily rainfall, ADAPS always considers a day as including all values recorded from 0000 to 2400 hours, with the values at 0000 and 2400 included in all calculations. Rainfall values recorded at midnight are summed for the preceding day.

In addition to the function of the primary computation, ADAPS provides many programs for error screening, editing, manipulation, analysis, and display of the data stored in the data base. One program, PLOTWAT, was used extensively to produce time-series plots of all data, and was used to generate the initial plots presented in this report.

Plots of the edited unit values were used to check the original data for outliers or questionable values and to get a general idea of the activity at each site for that data period. Plotting the computed unit values data also provided the ability to compare sets of data for different sites during the same time period. Plotting the data before and after the primary computation process was a principle quality assurance tool.

GROUND-WATER-LEVEL AND AQUIFER-SYSTEM COMPACTION DATA

The time-series data for this study are presented graphically in the following two sections: "Data for periods of record at instrumented sites" and "Data for periods of special interest."

Data for Periods of Record at Instrumented Sites

The four types of data presented in this section are the daily values for the individual periods of record of ground-water-level, aquifer-system-compaction, barometric pressure, and rainfall data.

Ground-Water Levels

The ground-water-level data recorded during the Edwards Air Force Base study are presented in figures 11-18 (at back of report). Daily noon values of DBLS in feet, periodic water-level measurements, or both, were previously published for the 1992 and 1993 water years (October 1 through September 30) for most of the sites (Johnson and Fong-Frydendal, 1993; Johnson, 1994). Graphs of daily mean DBLS, in feet, for the period of record for each instrumented piezometer are shown in figures 11-18. Gaps in the record are the result of long-term removal of instrumentation, or short-term instrument malfunction. Long-term breaks in the data that were caused by instrument removal, are listed in table 2 as having separate periods of record. However, for purposes of data presentation, all data for each piezometer are shown on individual plots for the period covered by this report. As the ground-water level in a given piezometer falls further below land surface, the numerical value for DBLS increases. The vertical scale for DBLS increases from top to bottom, therefore, a downward trend represents a lowering of ground-water level.

Aquifer-System Compaction

The aquifer-system compaction data collected during this study are presented in figures 19 and 20 (at back of report). Daily mean sediment compaction for each extensometer is presented. Sediment compaction is the parameter name used in ADAPS, and for this report is equivalent to aquifer-system compaction. Gaps in the record were caused by either instrument modification or range exceedence of the LVDTs. The periods of record for the individual extensometers are shown on the figures and in table 2. By convention, increasing aquifer-system compaction is expressed by an increasing numerical value. Decreasing aquifer-system compaction is expressed by a decreasing numerical value. The vertical scale of aquifer system compaction increases from top to bottom, so a downward trend represents a lowering of the land surface. The first daily mean value for these data is not necessarily equal to zero because of compaction that occurred between the time the instrumentation was set to zero and the end of the first full day of record.

Barometric Pressure and Precipitation

Supplemental data were collected for the purpose of analyzing barometric and precipitation influences on the ground-water-level and aquifer-system compaction record. Local barometric pressure was recorded at the Holly site (fig. 21, at back of report) and precipitation was recorded at the Fissure site (fig. 22, at back of report). The barometer data are presented as daily mean barometric

Table 2. Periods of record for time-series data collected at Edwards Air Force Base sites

[DBLS, Depth to Water Below Land Surface; mbars, millibars]

Local site name	Installation type	Type of data	Period of record
Holly	Piezometer 1	DBLS, in feet	1/11/91-6/18/91 6/10/92-9/30/93
	Piezometer 2	DBLS, in feet	1/11/91-7/19/91 6/11/92-9/30/93
	Piezometer 3	DBLS, in feet	1/11/91-6/30/91
	Piezometer 4	DBLS, in feet	1/14/91-4/24/91 8/21/91-12/2/91
	Extensometer	Aquifer-system compaction, in feet	1/11/91-9/30/93
	Barometer	Barometric pressure, in mbars	1/11/91-9/30/93
Fissure	Piezometer 1	DBLS, in feet	7/30/92-9/30/93
	Piezometer 3	DBLS, in feet	7/30/92-9/30/93
	Piezometer 5	DBLS, in feet	2/21/92-9/30/93
	Deep Extensometer	Aquifer-system compaction, in feet	7/31/92-9/30/93
	Shallow Extensometer	Aquifer-system compaction, in feet	7/31/92-9/30/93
	Rain gage	Precipitation, in inches	12/19/91-9/30/93
Graham Ranch	Piezometer 2	DBLS, in feet	6/12/92-9/30/93
	Piezometer 3	DBLS, in feet	6/25/91-1/28/92
South Track	Piezometer 1	DBLS, in feet	7/16/92-9/30/93
	Piezometer 2	DBLS, in feet	7/16/92-9/30/93
Survival School	Piezometer 1	DBLS, in feet	7/16/92-9/30/93
	Piezometer 2	DBLS, in feet	7/16/92-9/30/93
Branch Park	Piezometer 2	DBLS, in feet	9/17/92-9/30/93
	Piezometer 4	DBLS, in feet	9/17/92-9/30/93
South Shore	Piezometer 1	DBLS, in feet	9/18/92-9/06/93
	Piezometer 2	DBLS, in feet	9/18/92-9/30/93
North Shore	Piezometer 1	DBLS, in feet	12/17/92-9/30/93

pressure, in millibars, and the precipitation data are presented as daily sum rainfall, in inches. Barometric pressure can be used to remove the response of water levels for changes of atmospheric loading. The data in this report have not been adjusted in this way. The rainfall data are useful in explaining some of the events recorded at the Fissure site by the shallow extensometer.

Data for Periods of Special Interest

Three selected data presentations (figs. 23-25, at back of report) have been included in this report. Hourly ground-water-level response to changing barometric pressure is presented in figure 23. This figure depicts the inverse relation between the change in barometric pressure and the change in ground-water level measured in a piezometer open to atmospheric pressure. The response of ground-water levels to the June 28, 1992, Landers earthquake (Mw [magnitude] = 7.3, 34°12' north, 116° 26' west, 0357 hours PST) (Galloway, 1993), in three piezometers at three sites is shown in figure 24. The greatest response was in piezometer 2 at the Graham Ranch site where the recorded change was 1.39 ft. Responses at the Holly and Fissure site piezometers, were less than at the Graham Ranch site but were still measurable. The relation of changes in ground-water levels and aquifer-system compaction at the Fissure site, as the result of the formation of a new fissure about 100 yds west of the site, are shown in figure 25. As can be seen from the figure, the changes occurred as follows:

1. The shallow extensometer records sudden extension of the aquifer system, followed by a more consistent rate of extension, simultaneously;
2. The deep extensometer records sudden compaction, which doesn't recover, approximately 6 hours later;
3. Ground-water level in piezometer 5, rises quickly and begins a slow downward recovery over the next several days; and
4. Ground-water level in piezometer 1 falls quickly and rises to its original level.

SUMMARY

As part of a study by the U.S. Geological Survey, a monitoring program was implemented to measure time-series ground-water-level and aquifer-system compaction data at Edwards Air Force Base, California. The purpose for collecting these data was to study the relation of ground-water-level fluctuations and aquifer-system compaction as they related to pumping of ground water from several Edwards Air Force Base production wells.

Time-series data were collected for 18 piezometers, 3 extensometers, 1 barometer and 1 rain gage at 8 sites on Edwards Air Force Base, California, from January 1991 through September 1993. Ground-water levels were recorded for the North Muroc ground-water subbasin, the principal and deep aquifers of the Lancaster subbasin, and a small subbasin in the Graham Ranch area of Edwards Air Force Base. Aquifer-system-compaction data were recorded for three zones at two extensometer sites.

A description of the ground-water-level and aquifer-system compaction monitoring sites, site selection and site locations, instrumentation selection and operation, data collection and processing, illustrations of the instruments, and graphic presentations of the data are included in this report. The data reported were recorded hourly, with the exception of the rainfall data, and are stored in the ADAPS data base of the U.S. Geological Survey.

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FIGURES 11-25

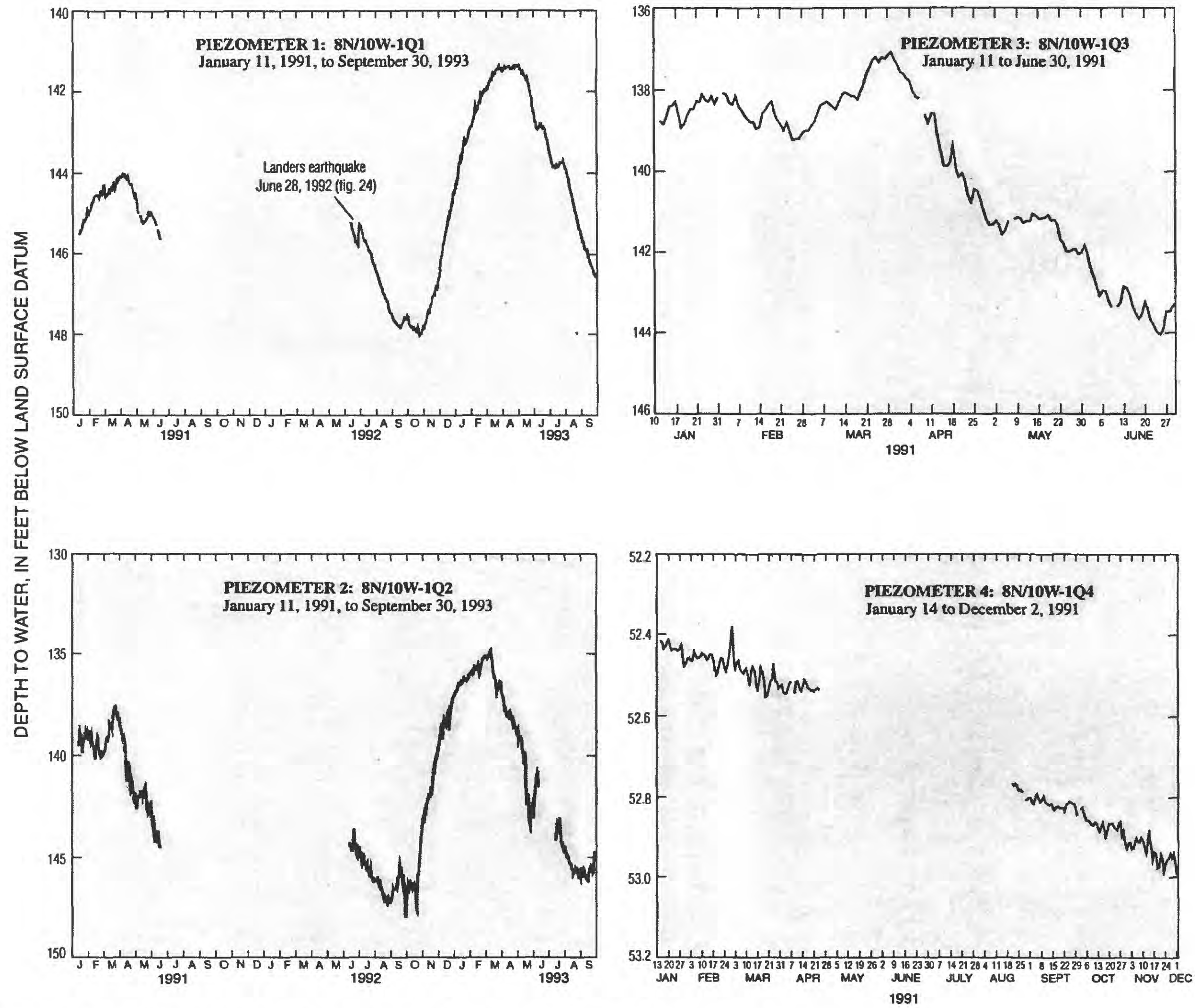


Figure 11. Daily mean of hourly ground-water levels for Holly site piezometers 1-4.

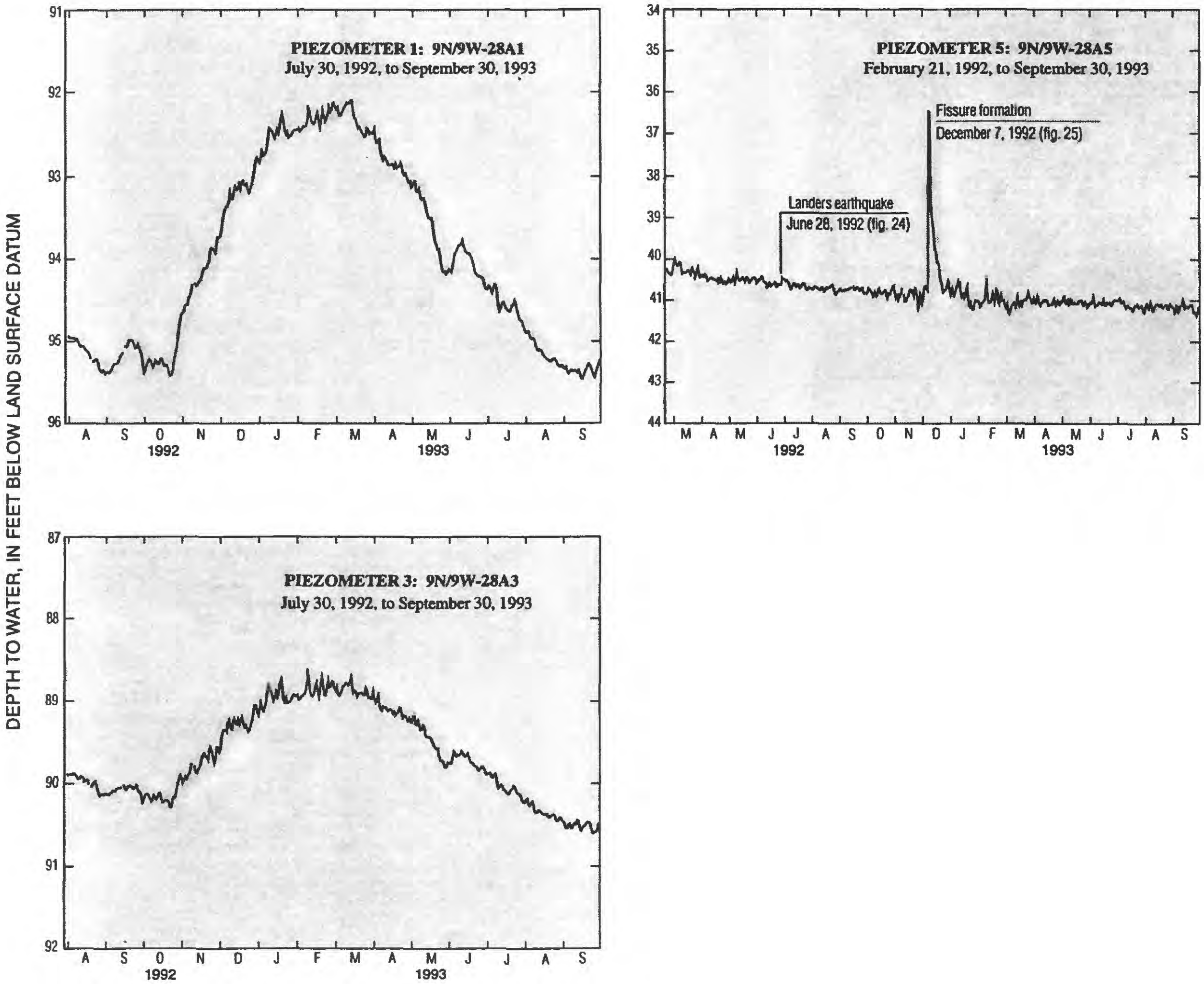


Figure 12. Daily mean of hourly ground-water levels for Fissure site piezometers 1, 3, and 5.

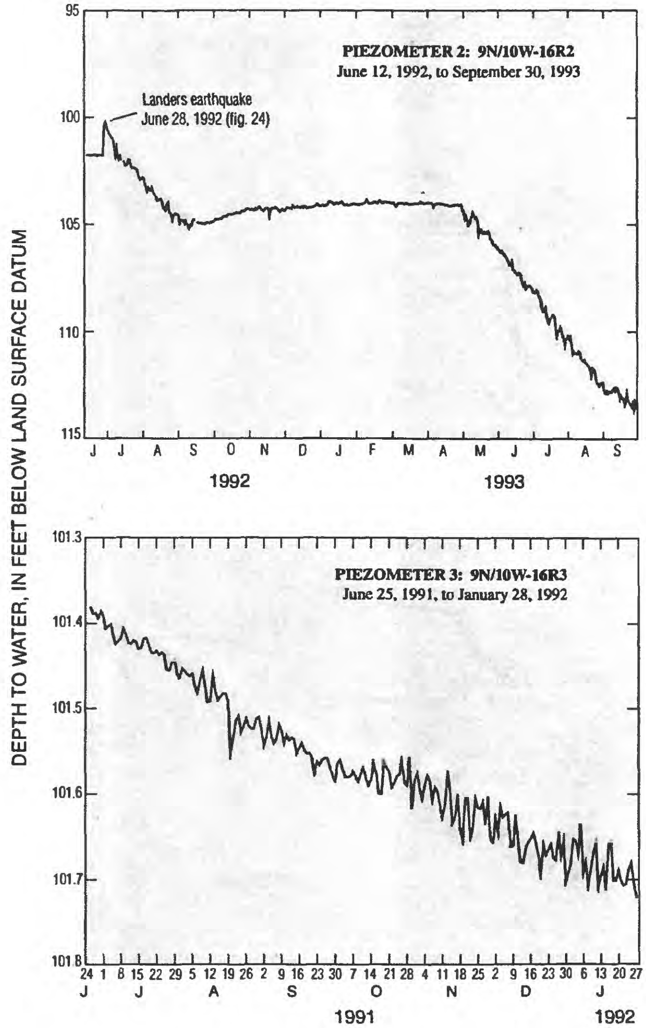


Figure 13. Daily mean of hourly ground-water levels for Graham Ranch site piezometers 2 and 3.

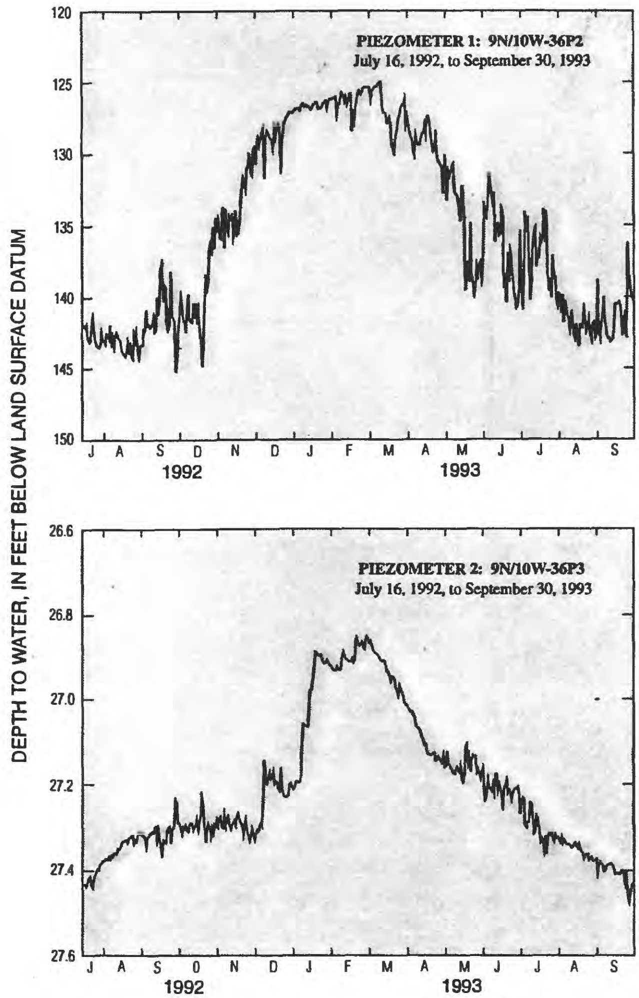


Figure 14. Daily mean of hourly ground-water levels for South Track site piezometers 1 and 2.

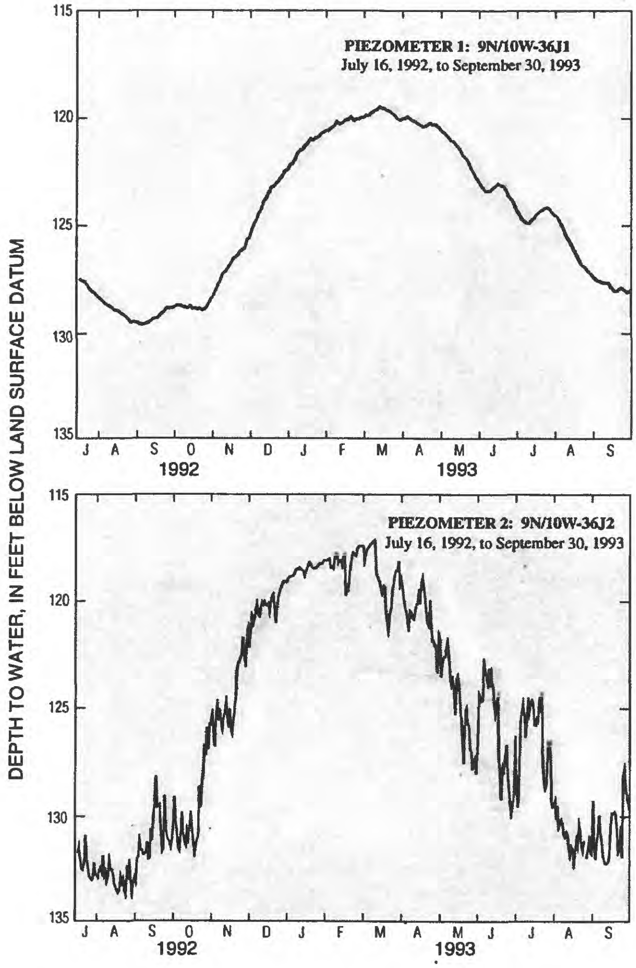


Figure 15. Daily mean of hourly ground-water levels for Survival School site piezometers 1 and 2.

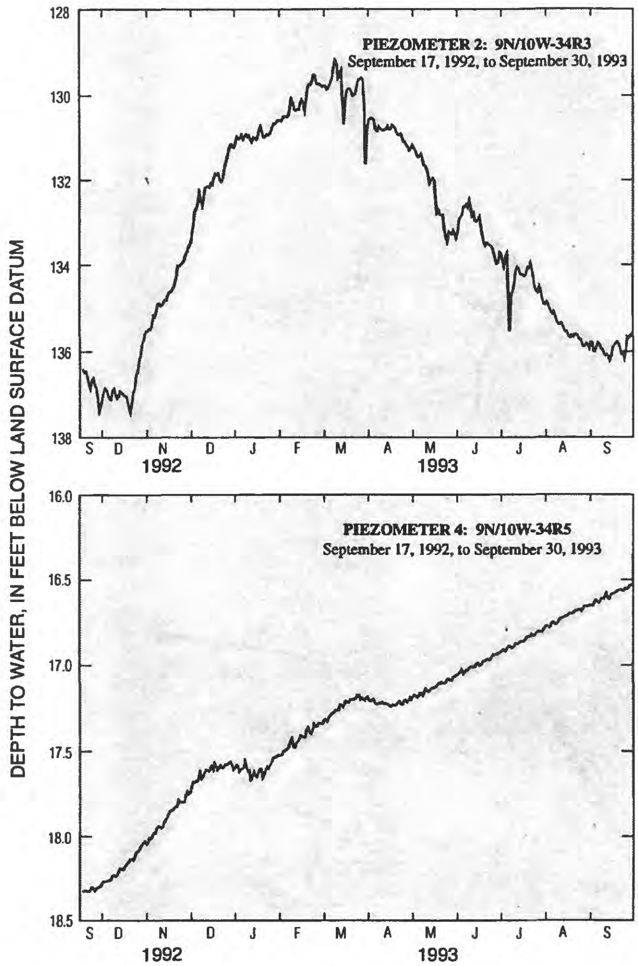


Figure 16. Daily mean of hourly ground-water levels for Branch Park site piezometers 2 and 4.

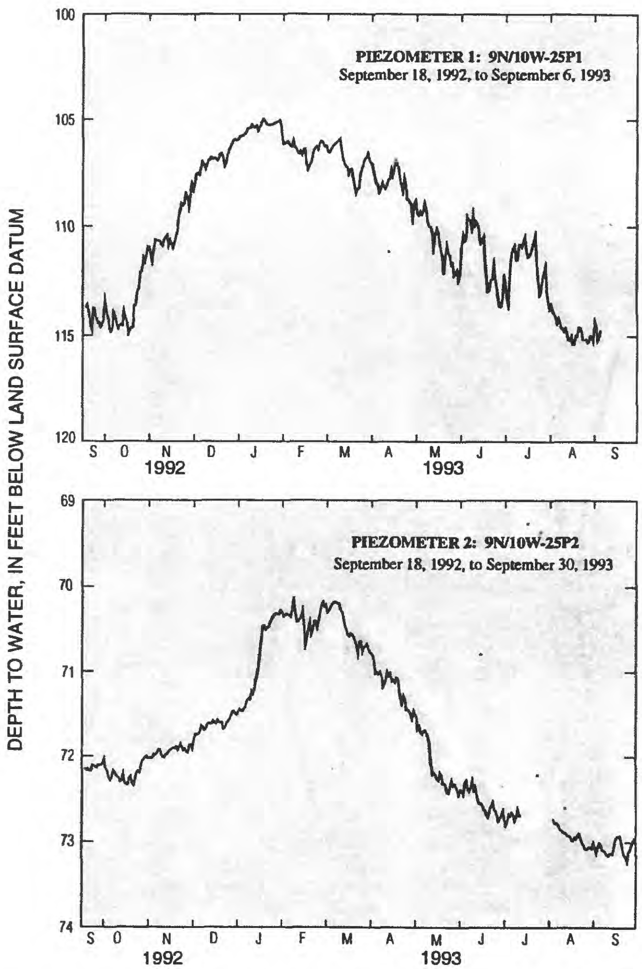


Figure 17. Daily mean of hourly ground-water levels for South Shore site piezometers 1 and 2.

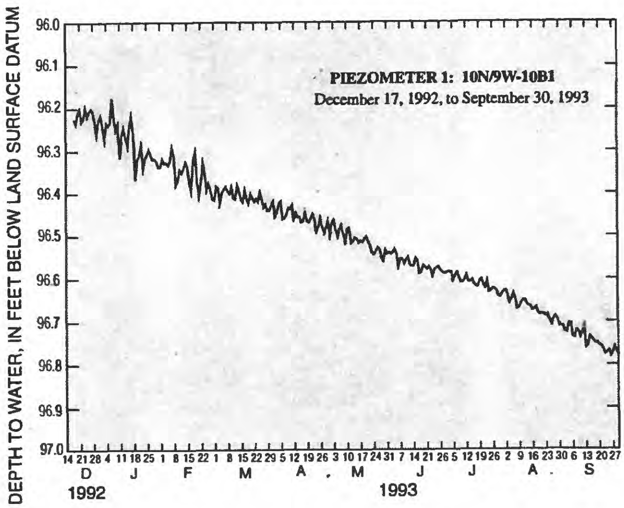


Figure 18. Daily mean of hourly ground-water levels for North Shore site piezometer 1.

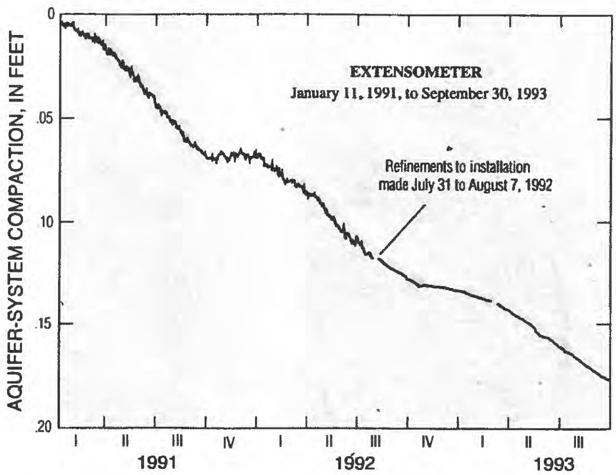


Figure 19. Daily mean of hourly aquifer-system compaction for Holly site extensometer.

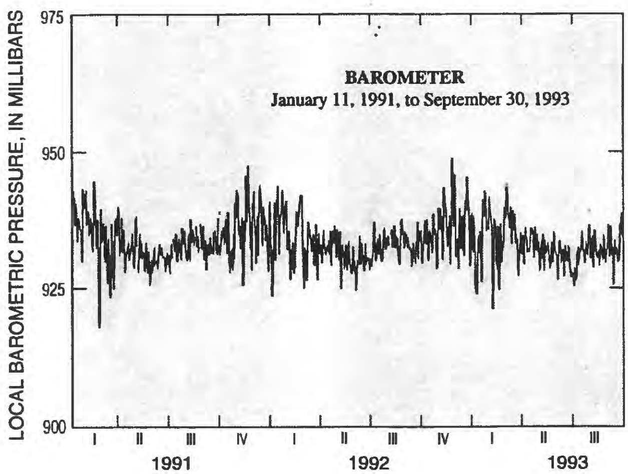


Figure 21. Daily mean of hourly local barometric pressure at the Holly site.

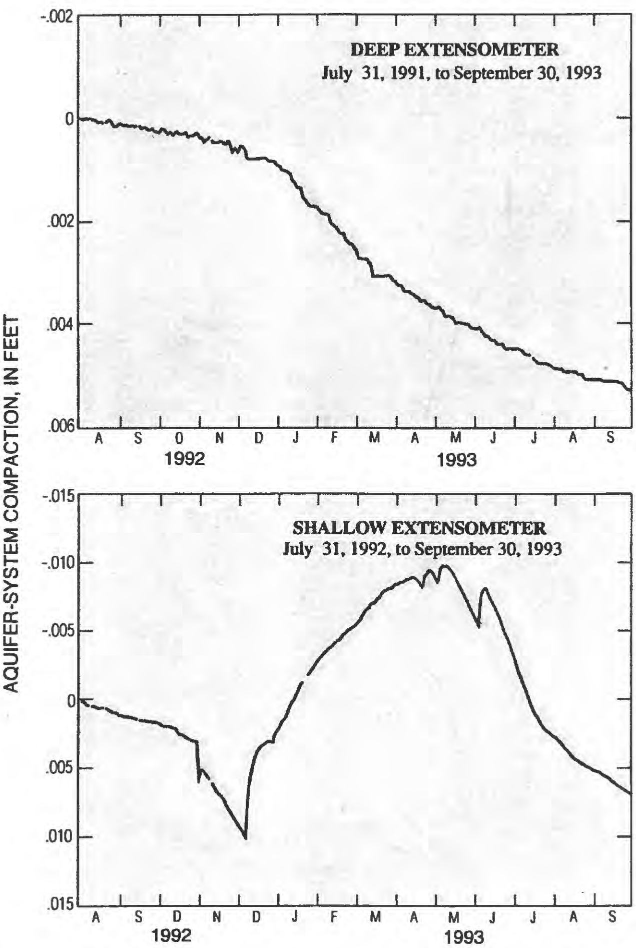


Figure 20. Daily mean of hourly aquifer-system compaction for Fissure site Deep and Shallow extensometers.

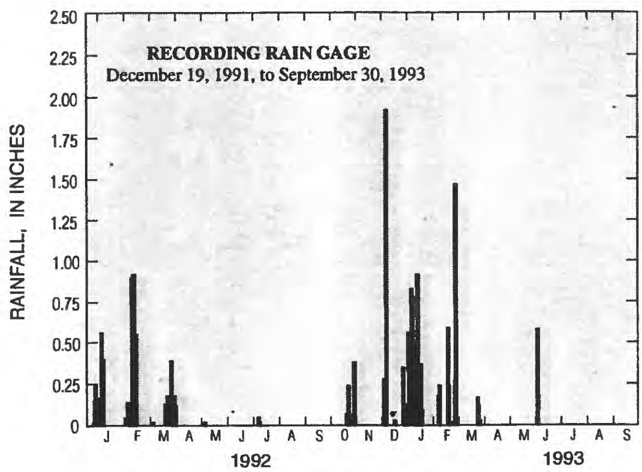
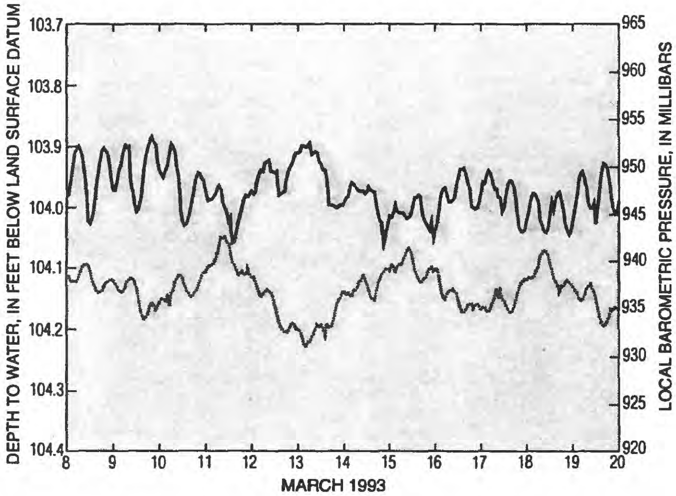


Figure 22. Daily precipitation at the Fissure site.



EXPLANATION

— **GRAHAM RANCH SITE, PIEZOMETER 2** Water level, hourly values

— **HOLLY SITE BAROMETER** - Local barometric pressure, hourly values

Figure 23. Hourly ground-water-level response of Graham Ranch site piezometer 2 to changes in hourly local barometric pressure at Holly site, March 1993.

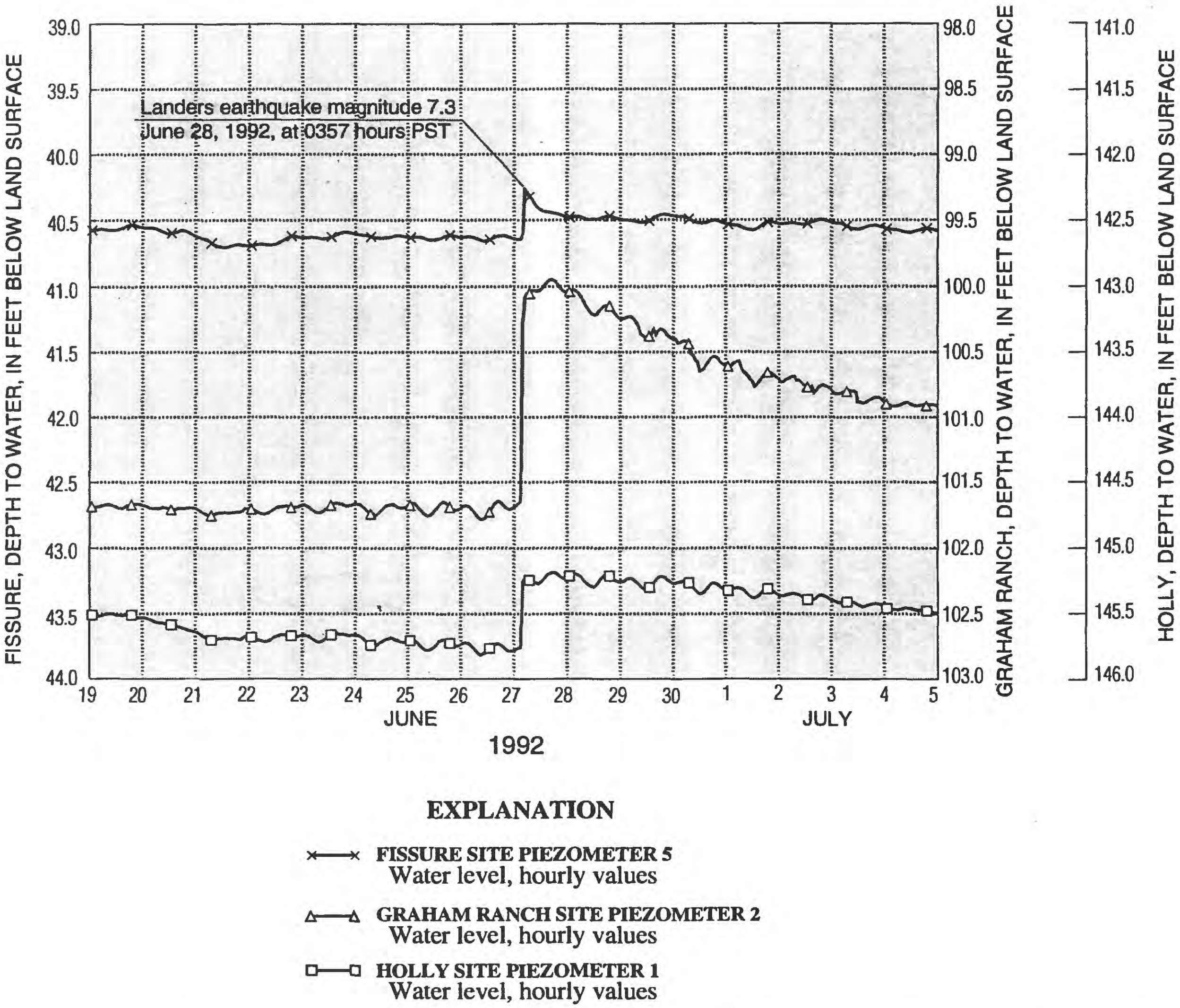


Figure 24. Change of hourly ground-water levels in response to the June 28, 1992, Landers earthquake for Fissure site piezometer 5, Graham Ranch site piezometer 2, and Holly site piezometer 1, June 19-July 5, 1992.

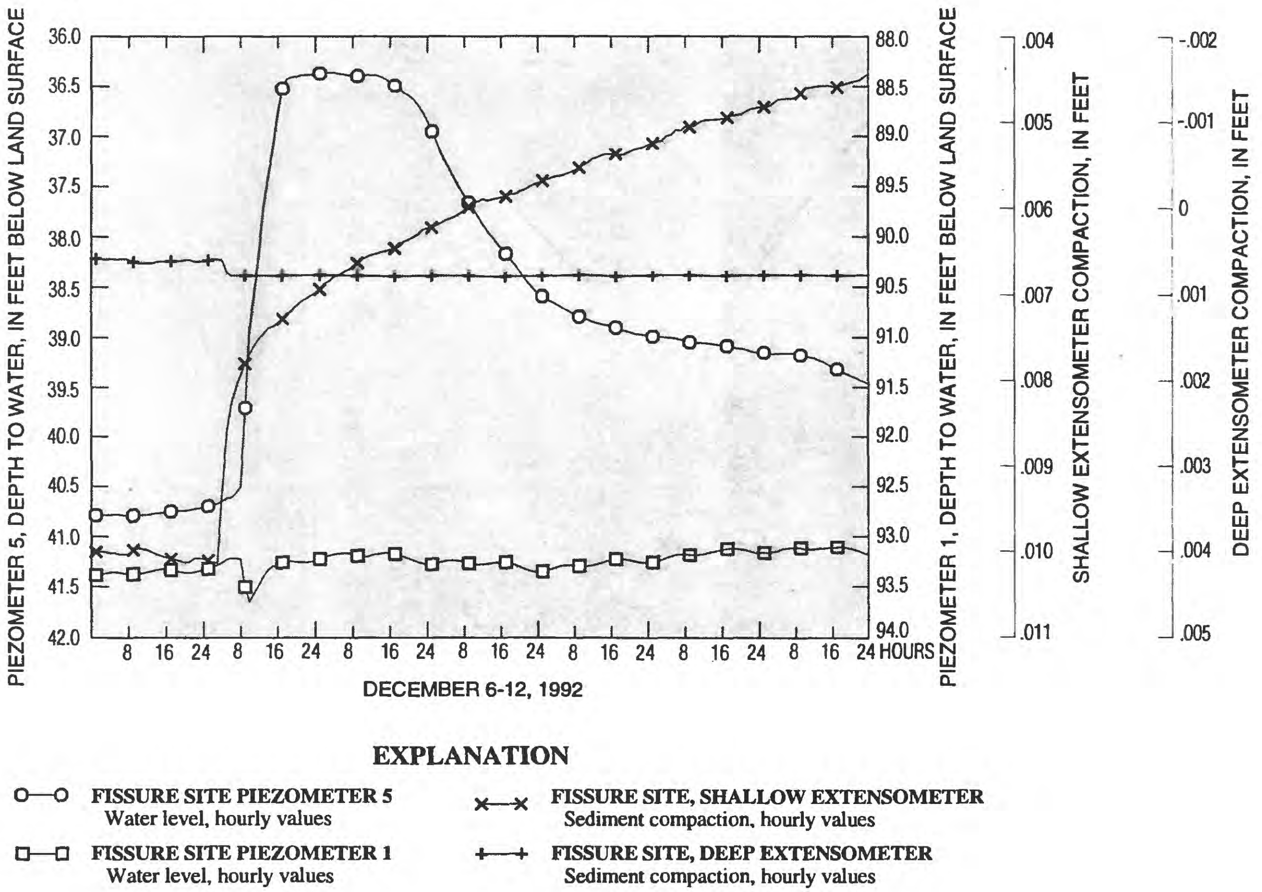


Figure 25. Hourly ground-water-level response and aquifer-system compaction to the formation of a fissure in the lakebed about 300 feet west of the Fissure site on December 7, 1992, for piezometers 5 and 1, and Shallow and Deep extensometers for the period December 6-12, 1992.