GEOHYDROLOGY OF THE HIGH ENERGY LASER SYSTEM TEST FACILITY SITE, WHITE SANDS MISSILE RANGE, TULAROSA BASIN, SOUTH-CENTRAL NEW MEXICO

By George T. Basabilvazo, Robert G. Myers, and
Edward L. Nickerson

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 93-4192

Prepared in cooperation with the
U.S. DEPARTMENT OF THE ARMY,
WHITE SANDS MISSILE RANGE

Albuquerque, New Mexico
1994

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.40	millimeter
inch	0.02540	meter
foot	0.3048	meter
mile	1.609	kilometer
acre	4,047	square meter
acre	0.4047	square hectometer
acre	0.004047	square kilometer
square mile	2.590	square kilometer
foot per day	0.3048	meter per day
foot per mile	0.1894	meter per kilometer
foot squared per day	0.09290	meter squared per day
cubic foot per day	0.02832	cubic meter per day
gallon per minute	0.06309	liter per second
gallon per minute	0.06309	cubic decimeter per second
gallon per minute	0.00006309	cubic meter per second

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

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

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ABSTRACT

The High Energy Laser System Test Facility is located at White Sands Missile Range in south-central New Mexico. The soils at the study area consist of Yesum-Holloman and Gypsum land (hummocky), and represent eolian deposits from recently desiccated lacustrine and deposits from the ancestral Lake Otero. The upper 15 to 20 feet of the subsurface consists of varved gypsiferous clay and silt of lacustrine origin. Below the upper 15 to 20 feet the lithology consists of interbedded clay units, silty-clay units, and fine- to medium-grained quartz arenite units that occur in continuous and discontinuous horizons. The clay horizons can cause perched water zones. Analyses of selected clay samples indicate that the clay units are composed primarily of kaolinite and mixed-layer illite/smectite clays.

The aquifer in the study area is a leaky-confined aquifer. Transmissivity was estimated from aquifer-test data to be 780 feet squared per day. The storage coefficient was estimated to be 3.1 x 10^{-3}, and hydraulic conductivity was estimated to be 6.0 feet per day. The direction of ground-water flow is to the south and southwest and the hydraulic gradient was estimated to be 5.3 feet per mile.

The aquifer in the bolson-fill deposits contains water that is brackish to brine, and salinity increases with depth. Analyses of water samples indicate that ground water at the site is brackish to slightly saline at the top of the main aquifer. The dissolved-solids concentration of water near the top of the aquifer ranges from 5,940 to 11,800 milligrams per liter. Predominant ions near the top of the aquifer are sodium and sulfate. At 815 feet below land surface the dissolved-solids concentration is approximately 111,000 milligrams per liter. Predominant ions at 815 feet below land surface are sodium and chloride.

INTRODUCTION

The U.S. Army's High Energy Laser System Test Facility (HELSTF) is located within the White Sands Missile Range, about 29 miles southwest of the city of Alamogordo in the Tularosa Basin, south-central New Mexico (fig. 1). The HELSTF was developed to provide a location for research, development, testing, and evaluation of the Department of Defense High Laser System. Prior to development of the HELSTF, the area was used for the Multifunction Array Radar (MAR) site.

Most potable water used at HELSTF is piped in from two supply wells completed in the alluvial-fan deposits located west of the site. These supply wells are referred to as the MAR supply wells (fig. 1). Nonpotable saline ground water from fine-grained bolson-fill deposits at the facility is used occasionally in construction activities.

The U.S. Army requires an understanding of the movement and quality of ground water in the vicinity of the HELSTF so that they can manage and protect this saline-water resource. To meet this need, a study was conducted by the U.S. Geological Survey in cooperation with the U.S. Department of the Army, White Sands Missile Range.

Purpose and Scope

This report presents a summary of the geohydrologic conditions in the vicinity of HELSTF. Water-quality, geological, geophysical, and hydrological data were compiled from published reports. Water-level measurements were collected in July 1990 from two test wells constructed during this study (HELSTF-1 and HELSTF-2), two preexisting observation wells (Lucero Ranch and Baird South), and six preexisting boreholes (B-28, B-30, B-31, B-34, B-38, and B-39). In 1971, 57 boreholes were drilled by the U.S. Geological Survey on White Sands Missile Range (Kelly, 1973). These boreholes were drilled to furnish additional information for mapping the water table (Kelly, 1973). New data were derived from three HELSTF test wells recently constructed by the U.S. Geological Survey and two preexisting test wells (MAR-CW and MAR-CW2). The new data include borehole-geophysical logs, lithologic logs, and water-quality sampling and analysis for the HELSTF test wells, and data acquired from an aquifer test performed on the HELSTF wells in June and July 1990. The new data also include borehole-geophysical logs for the MAR-CW and MAR-CW2 test wells and water-quality sampling and analysis for the MAR-CW test well.

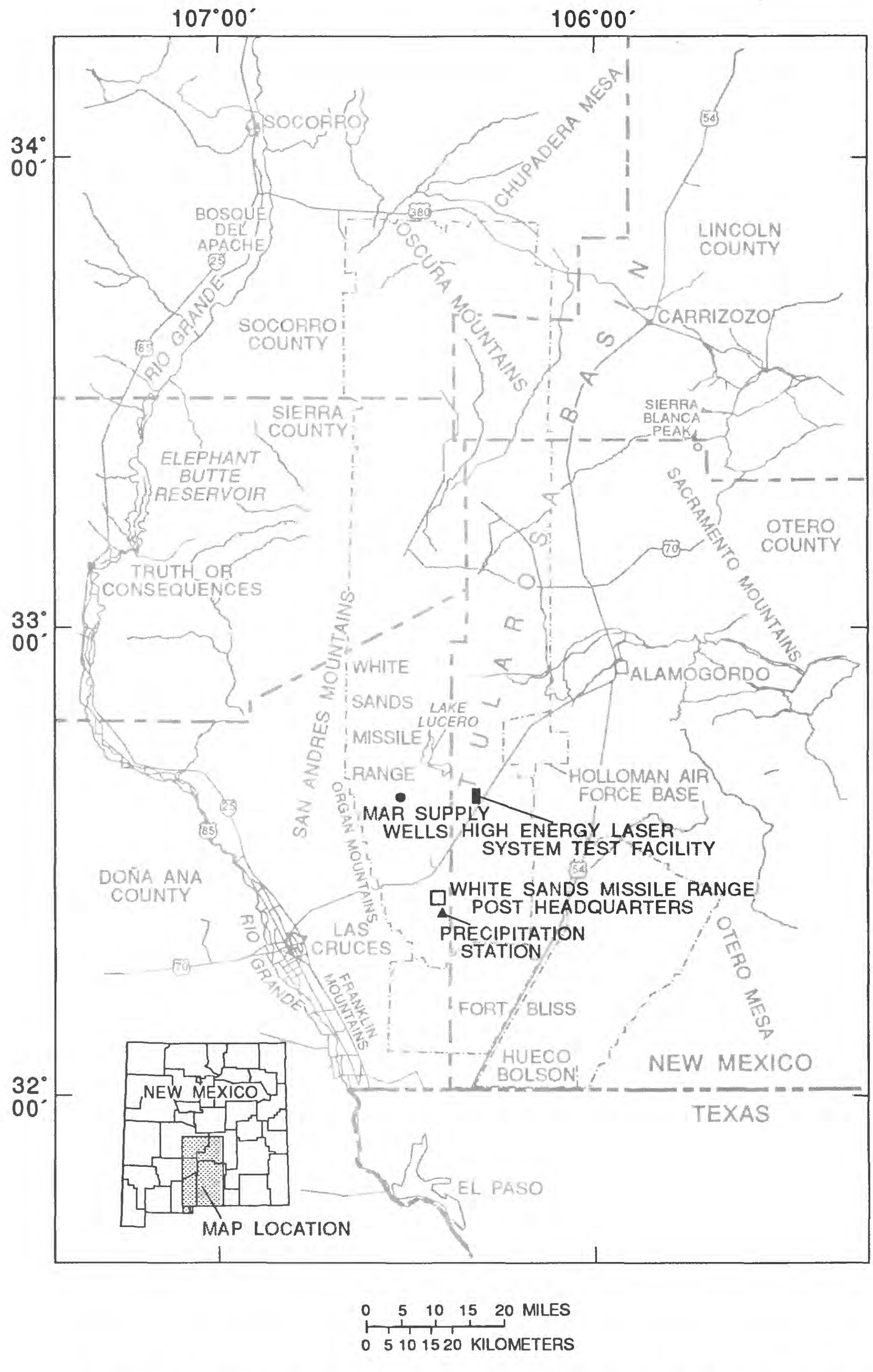


Figure 1.--Location of the High Energy Laser System Test Facility site and surrounding area, south-central New Mexico.

Well-Numbering System

Wells are located according to the system of common subdivision of sectionized land used throughout the State by the U.S. Geological Survey. The number of each well consists of four segments separated by periods and locates the well's position to the nearest 10-acre tract of land (fig. 2). The segments denote, respectively, the township south of the New Mexico base line, the range east of the New Mexico principal meridian, the section, and the particular 10-acre tract within the section.

The fourth segment of the number consists of three digits denoting, respectively, the quarter section or approximate 160-acre tract, the quadrant (approximately 40 acres in size) of the quarter section, and the quadrant (approximately 10 acres in size) of the 40-acre tract in which the well is located. For example, well 19S.06E.21.321 is located in the NW1/4 of the NE1/4 of the SW1/4, section 21, Township 19 South, Range 6 East. If more than one well within the 10-acre tract has the same location number, the letter "A" is assigned to the second well, the letter "B" to the third well, and so on.

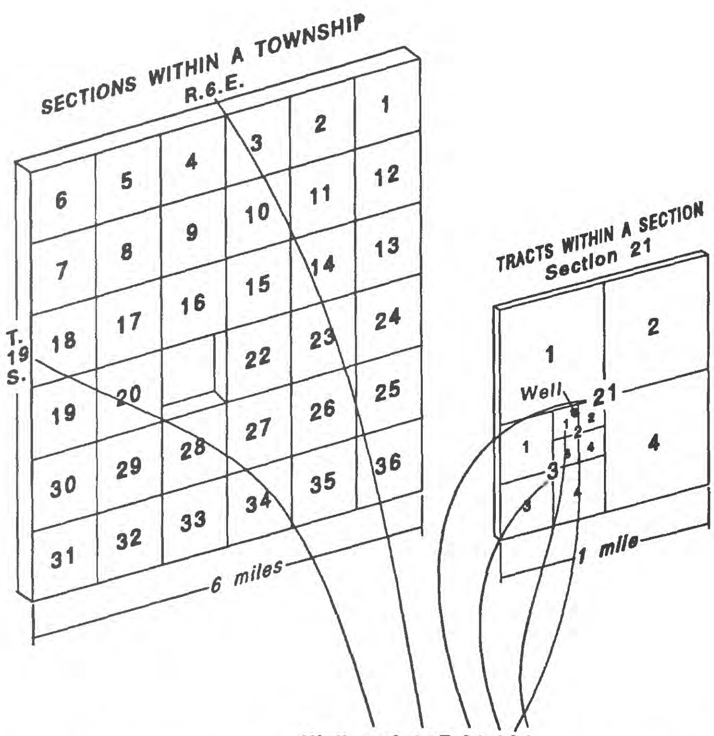


Figure 2.--System of numbering wells in New Mexico.

Description of Study Area

The Tularosa Basin is a north-trending intermontane basin that encompasses an area of approximately 6,500 square miles (fig. 1). The basin is bounded on the west by the Franklin, Organ, and San Andres Mountains and on the east by the Sacramento Mountains and Otero Mesa. The northern boundary is Chupadera Mesa; the southern boundary is a subtle topographic rise south of White Sands Missile Range Post Headquarters that separates the Tularosa Basin from the Hueco Bolson.

The climate in the Tularosa Basin is typical of an arid southwestern basin and is representative of the HELSTF site. Annual precipitation ranges from about 7 inches in the center of the basin to about 25 inches on the higher mountain slopes (Houghton, 1976). Most precipitation falls in the middle to late summer. Table 1 is a record of monthly and annual precipitation at White Sands Missile Range from 1950 through 1987. The intensity and frequency of precipitation are variable throughout the basin and throughout the year because of the localized distribution of summer thunderstorms.

The land surface of the Tularosa Basin contains playas and depressions that have no external drainage. Thus, during rainy periods ephemeral lakes form that eventually evaporate and develop into "alkali flats."

Most surficial deposits at the HELSTF site were described by Seager and others (1987) as eolian dunes composed of gypsite having well-developed gypcrete crusts. Small exposures of older gypsiferous basin-floor and gypsiferous lacustrine clay and silt deposits are present throughout the area (Seager and others, 1987) (fig. 3). According to the Soil Survey Manual of White Sands Missile Range (Neher and Bailey, 1976), soils in the immediate area of the HELSTF site are classified as Yesum-Holloman and Gypsum land (hummocky). As defined by Neher and Bailey (1976), the Yesum-Holloman association is a mapping unit that consists of about 35 percent Yesum (very fine sandy loam), 30 percent Holloman (very fine sandy loam), and 20 percent Gypsum land (hummocky). Yesum soil represents undulating wind deposits and Holloman soil represents level to gently sloping deposits from ancestral lake basins. Gypsum land consists of deposits of gypsum crystals from the ancestral Lake Otero. Gypsum soil consists of gently undulating gypsum dunes (Neher and Bailey, 1976). The colors and accompanying codes in the following lithologic descriptions refer to the colors from the Rock-Color Chart (National Research Council, 1948). The upper 15 to 20 feet of the soil profile, as determined in this study, consists of varved white (N 9) to light-greenish-gray (5 GY 8/1) gypsiferous clay and silt. These deposits are interpreted to be of lacustrine origin.

Below the upper soil profile, the clay, silt, and sand deposits occur in interbedded lenses and layers that complicate the interpretation of the lateral continuity of the subsurface lithologies and hydrologic characteristics. The subsurface lithology at the site was defined to a greater extent by drilling test wells at selected sites.

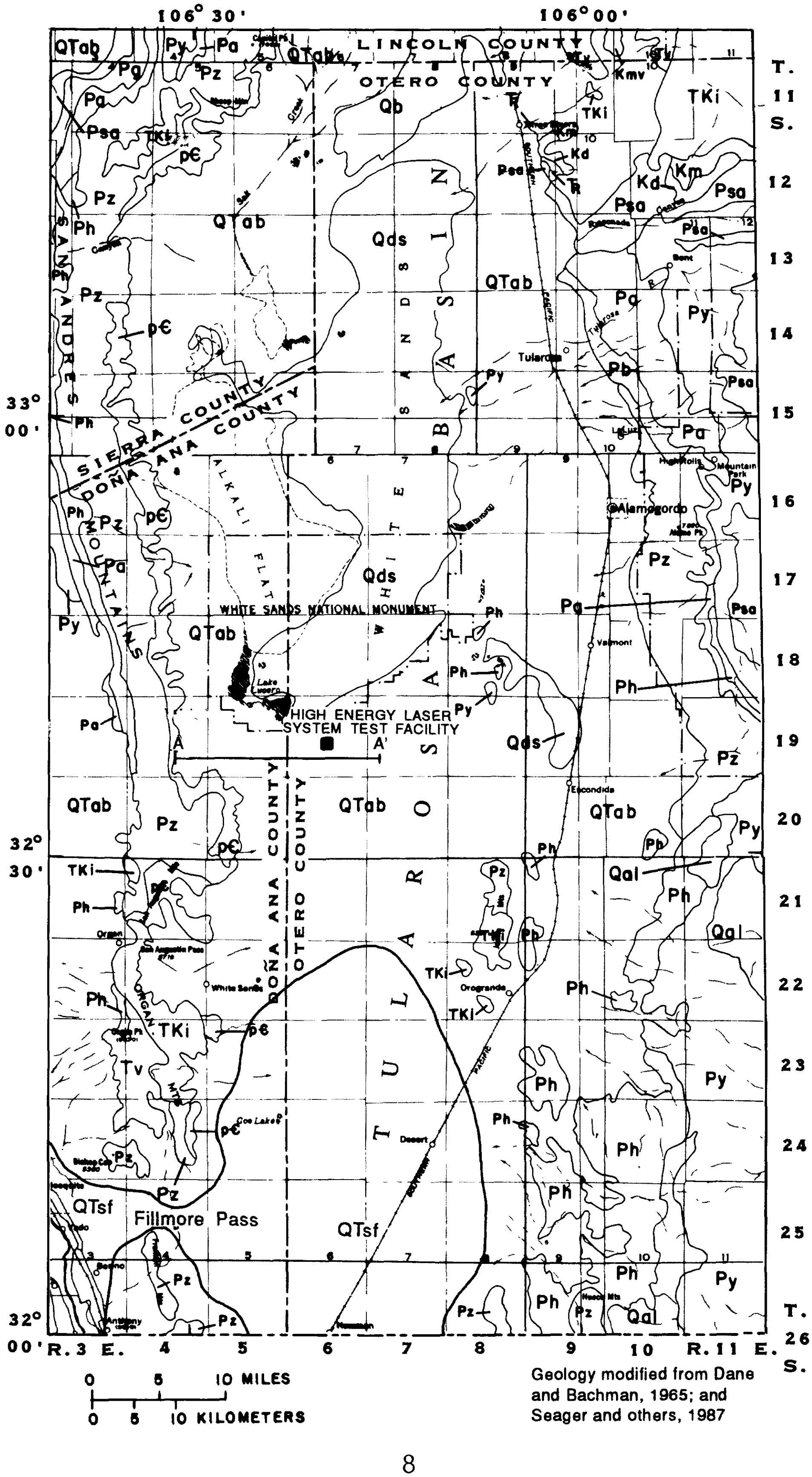
Table 1.--Precipitation data from White Sands Missile Range, New Mexico, 1950-87

[Data from U.S. Army. Values are in inches. T, trace]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1950	0.06	0.28	T	T	0.25	0.11	3.46	0.01	1.20	1.04	0.00	T	6.41
1951	0.14	0.36	0.28	0.80	0.10	T	0.04	2.68	0.04	0.67	0.19	1.78	7.08
1952	0.40	1.21	1.34	1.37	0.49	0.65	1.42	1.48	0.26	0.00	0.32	0.38	9.32
1953	0.00	1.28	0.09	0.48	0.17	0.60	1.35	0.24	0.14	0.70	0.02	0.23	5.30
1954	0.08	T	0.31	T	0.27	0.15	1.21	1.28	1.18	1.38	0.00	0.05	5.91
1955	0.91	0.03	0.62	T	0.04	0.14	3.55	0.80	0.14	2.99	0.05	0.00	9.27
1956	0.15	0.22	0.00	T	0.00	0.63	0.70	1.18	0.00	0.40	T	0.64	3.92
1957	0.40	1.44	0.57	0.02	0.61	T	1.65	2.20	0.32	2.98	0.18	T	10.37
1958	1.26	0.89	3.00	0.28	0.40	1.21	1.85	2.13	5.76	2.84	4.00	T	23.62
1959	0.14	0.85	0.12	T	0.95	0.67	1.22	6.32	T	0.64	0.05	0.49	11.45
1960	1.50	0.54	0.39	T	0.21	0.81	3.46	1.40	0.03	1.46	0.01	1.44	11.25
1961	0.69	T	0.72	T	0.00	1.79	3.20	0.97	1.47	0.04	2.40	1.34	12.62
1962	1.19	0.43	0.60	0.39	T	0.07	5.63	0.24	2.70	1.11	0.51	1.20	14.07
1963	0.13	0.62	T	0.17	T	0.05	1.14	2.45	2.06	0.44	0.59	T	7.65
1964	0.21	0.20	1.40	0.06	0.23	T	0.69	1.83	3.44	0.03	0.03	1.10	9.22
1965	0.93	1.05	0.21	0.25	0.34	1.32	1.05	1.82	2.01	0.58	0.41	2.43	12.40
1966	0.38	0.51	0.09	1.15	0.09	7.42	1.20	2.51	2.35	0.22	0.52	0.19	16.63
1967	0.00	0.51	0.28	0.01	0.10	0.81	0.77	1.88	3.10	0.01	0.81	1.84	10.12
1968	0.61	0.94	1.06	0.06	0.01	0.58	5.05	1.80	0.31	0.31	1.42	0.84	12.99
1969	0.20	0.10	0.10	0.01	0.67	1.20	3.16	3.68	1.26	1.59	0.26	1.30	13.53
1970	0.02	0.35	0.71	T	0.17	0.69	3.87	1.52	0.27	0.43	0.00	0.38	8.41
1971	0.24	0.21	0.00	0.28	0.05	0.52	2.58	0.45	0.46	1.95	1.02	0.97	8.73
1972	0.85	T	T	0.00	0.03	1.83	1.09	4.36	2.20	3.65	0.58	1.60	16.19
1973	1.07	1.74	0.70	T	0.36	0.07	5.67	1.50	0.14	T	0.23	0.00	11.48
1974	1.03	0.02	0.36	0.16	T	0.22	2.26	1.80	4.81	3.84	0.14	1.12	15.76
1975	0.95	0.53	0.40	0.08	0.22	T	1.03	1.24	3.23	0.19	0.74	0.53	9.14
1976	0.57	0.63	0.17	0.51	1.01	0.67	2.59	1.38	0.95	1.81	1.11	0.02	11.42
1977	0.77	T	0.23	0.79	0.16	1.25	3.10	2.34	0.71	0.96	0.07	0.26	10.64
1978	0.86	0.63	0.69	0.03	0.78	1.16	0.56	1.68	3.42	3.40	1.65	0.93	15.79
1979	1.02	0.32	0.01	0.09	0.40	0.10	3.57	3.17	0.96	0.00	0.01	0.25	9.90
1980	0.70	0.94	0.11	0.31	1.35	T	0.67	2.23	4.46	1.00	0.27	0.01	12.05
1981	1.13	0.11	0.50	1.27	0.62	0.58	0.19	2.16	0.75	0.51	0.47	T	8.29
1982	0.67	0.41	T	0.03	0.25	0.15	1.25	0.89	4.34	0.12	0.53	3.24	11.88
1983	0.17	0.74	0.19	1.09	0.07	0.09	0.42	0.99	0.42	2.22	0.56	0.28	7.24
1984	0.41	0.00	0.06	0.02	0.71	2.51	0.66	5.86	0.30	3.96	0.44	2.03	16.96
1985	1.68	0.53	0.70	1.17	0.34	0.74	1.72	1.52	2.93	3.44	0.19	0.05	15.01

Table 1.--Precipitation data from White Sands Missile Range, New Mexico, 1950-87--Concluded

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1986	0.08	0.41	0.52	T	0.53	3.86	1.58	3.02	1.26	1.30	2.74	2.10	17.40
1987	0.49	0.77	0.54	0.63	0.72	1.39	0.40	4.82	0.75	0.13	0.58	3.17	14.39
Mean	0.58	0.52	0.45	0.30	0.33	0.90	1.97	2.05	1.58	1.27	0.61	0.85	11.42
Maximum	1.68	1.74	3.00	1.37	1.35	7.42	5.67	6.32	5.76	3.96	4.00	3.24	23.62
Year	1985	1973	1958	1952	1980	1966	1973	1959	1958	1984	1958	1982	1958
Minimum	0.00	0.00	0.00	0.00	0.00	0.05	0.04	0.01	0.00	0.00	0.00	0.00	3.92
Year	1953, 1967	1984	1956, 1971	1972	1956, 1961	1963	1951	1950	1956	1952, 1979	1950, 1954, 1970	1955, 1973	1956



Geology modified from Dane and Bachman, 1965; and Seager and others, 1987

EXPLANATION

CENOZOIC	QUATERNARY	Qal	ALLUVIUM--Channel-fill sand, gravel, and clay; less than 100 feet thick
		Qds	DUNE DEPOSITS--Predominantly gypsum sand; less than 100 feet thick
		Qb	BASALT
	QUATERNARY AND TERTIARY	QTab	BOLSON DEPOSITS--Gravel, sand, silt, and clay with older gypsiferous lacustrine clay and silt deposits; as much as 8,000 feet thick
		QTsf	SANTA FE GROUP--Composed of ancestral Rio Grande deposits of the Camp Rice Formation. Sand, gravel, silt, clay, and caliche. Thickness not estimated
	TERTIARY	Tv	VOLCANIC DEPOSITS
		TKi	INTRUSIVE IGNEOUS ROCKS
MESOZOIC	CRETACEOUS	Kmv	MESAVERDE GROUP--Sandstone, shale, and coal deposits; as much as 1,000 feet thick
		Km	MANCOS SHALE--Mainly shale; as much as 1,200 feet thick
		Kd	DAKOTA SANDSTONE--Sandstone and shale; about 100 feet thick
	TRIASSIC	T̄R	DOCKUM GROUP--Sandstone, shale, and limestone; about 500 feet thick
PALEOZOIC	PERMIAN	Psa	SAN ANDRES LIMESTONE--Limestone and dolomite; 300 to 600 feet thick
		Py	YESO FORMATION--Sandstone, gypsum, halite, and limestone; 320 to 4,200 feet thick
		Ph	HUECO LIMESTONE--Limestone; 420 to 1,500 feet thick
		Pa	ABO FORMATION--Mudstone, arkose, conglomerate, and limestone; 200 to 1,500 feet thick
		Pb	BURSUM FORMATION--Shale, sandstone, and limestone; 300 to 400 feet thick
	PERMIAN TO CAMBRIAN	Pz	PALEOZOIC ROCKS UNDIVIDED--Sandstone, shale, limestone, and dolomite; 1,740 to 5,000 feet thick
	PRECAMBRIAN	p€	GRANITIC AND METAMORPHIC ROCKS

A |———| A' LINE OF SECTION

Figure 3.--Generalized surficial geology of the High Energy Laser System Facility site and adjacent areas, south-central New Mexico, and line of section A-A'.

Development of the Tularosa Basin coincided with crustal extension associated with development of the Rio Grande Rift and the Basin and Range physiographic province in the late Tertiary age (Seager and Morgan, 1979). Normal faults that developed during the late Tertiary age (Seager and Morgan, 1979) are responsible for the present topography. The basin fill predominantly consists of clay, silt, sand, and gravel with some older gypsiferous lacustrine clay and silt deposits (fig. 3). The deposits of Quaternary age exposed north of White Sands Missile Range Post Headquarters in the Tularosa Basin consist of inactive gypsum dunes, gypsiferous basin-floor deposits, and older lacustrine deposits (Seager and others, 1987).

Ancestral Rio Grande deposits of the Santa Fe Group of Tertiary and Quaternary age are exposed in the southern part of the Tularosa Basin (fig. 3; Seager and others, 1987). The Camp Rice Formation, which is the upper unit of the Santa Fe Group, is present throughout the southern part of the Tularosa Basin and varies in age from late Tertiary to early Quaternary age (Gile and others, 1981; Seager and others, 1987). The Camp Rice Formation consists of alluvial, fluvial, and lacustrine facies. The fluvial facies occurs south of the HELSTF site where the ancestral Rio Grande flowed through Fillmore Pass and into the Tularosa Basin (Seager, 1981). The fluvial facies consists of interbedded clay, silt, and sand and underlies a thin cover of Quaternary eolian facies (Seager and others, 1987). This eolian facies developed in part because of the warmer and drier climatic conditions since about 10,000 years ago and the diversion of the ancestral Rio Grande to its present course west of the Tularosa Basin (fig. 1). The subsequent entrenchment by the Rio Grande stopped flow through Fillmore Pass and into the Tularosa Basin. Lake Otero (Herrick, 1904) apparently existed approximately 10,000 years ago, when the ancestral Rio Grande flowed into the Tularosa Basin (Strain, 1970; Seager, 1981).

Acknowledgments

This study was conducted in cooperation with the U.S. Department of the Army at White Sands Missile Range; their assistance is greatly appreciated. The authors express appreciation to the New Mexico Bureau of Mines and Mineral Resources for x-ray diffraction analysis and to the well drillers from the U.S. Geological Survey, Branch of Coal Geology, for their cooperation and assistance.

GEOHYDROLOGY

The following description of the geohydrology of the HELSTF area is based on previous reports and analysis of well records, geologic maps, geophysical logs, lithologic descriptions, water-quality information, and aquifer tests. The maximum thickness of the basin-fill deposits in the study area is about 5,700 feet (Healey and others, 1978). The basin fill, which forms the main aquifer in the area, consists of interbedded clay, silt, and fine- to medium-grained sand (McLean, 1970).

Test Wells

Three test wells--HELSTF-1, HELSTF-2, and HELSTF-3--were drilled for this study by the U.S. Geological Survey, Branch of Coal Geology, using the hydraulic-rotary method and bentonite-based drilling fluid. Two existing test wells, MAR-CW and MAR-CW2, were logged and sampled to obtain water-quality information. The locations of the test wells are shown in figure 4. Immediately after the HELSTF wells were drilled, borehole-geophysical data were collected in the uncased holes (figs. 5-7). The geophysical logs included resistivity (long-short normal), natural gamma, neutron, and caliper. Natural gamma, neutron, gamma-gamma (fig. 8), and color video (TV) logs were collected in both MAR-CW test wells. Construction data and geophysical logs available for the five test wells at the HELSTF site are presented in table 2.

All three HELSTF test wells were completed using the same techniques and similar materials (figs. 9-11). The bottom of the borehole was sealed with three-eighths-inch gravel, thickened bentonite drilling mud, and bentonite chips or bentonite pellets. The sand pack consisted of 8/12 mesh silica sand placed adjacent to and approximately 2 feet above and below the screened interval. A 4-foot bentonite plug was installed above the sand pack, which consists of bentonite pellets that were slurried down the annular spacing via a tremmie pipe. The annular space (about 2 inches) was sealed above the bentonite plug by slurring down a combination of bentonite chips and a bentonite-based expansive sealant. The annular space at the top of the borehole was cemented with quick drying cement.

Test well HELSTF-1 was completed May 14, 1990 (fig. 9). The well was developed by bailing for 2 1/2 hours until the water was clear and the specific conductance of the water stabilized. Water samples were collected at the completion of the bailing.

Test well HELSTF-2 was completed June 21, 1990. The well was developed by jetting with compressed air for 4 hours. Development was halted after no silt was observed in the discharge water and the specific conductance of the water stabilized.

Test well HELSTF-3 was completed at a location 70 feet east of HELSTF-2 on June 27, 1990. This well was completed and developed in the same manner as HELSTF-2, except that the PVC casing was 6 inches in diameter rather than 4 inches (fig. 11).

Drill cuttings from the three HELSTF test wells consisted of clay, silt, and very fine to fine-grained quartz arenites (see tables 8, 9, and 10: in supplemental information in the back of the report). Correlation of the lithology between HELSTF-2 and HELSTF-3, as interpreted from borehole-geophysical logs (figs. 5-7) and drill cuttings, indicates that the clayey units are interbedded with silty and sandy units. These units occur in intertonguing layers (fig. 12) that may be discontinuous. Clay samples from selected intervals were collected for x-ray diffraction analysis and analyzed at the New Mexico Bureau of Mines and Mineral Resources in Socorro. The clays sampled are predominantly kaolinitic in composition (table 3). Additional clays, determined in decreasing order of occurrence, include Kaolinite, illite/smectite (mixed layer), illite, and smectite. Clays are predominantly light brown (5 YR 6/4) to moderate brown (5 YR 4/4); however, moderate-reddish-brown (10 R 4/6) and light-greenish-gray (5 G 8/1) clays also were observed (table 3). The sand observed in the HELSTF cuttings is well rounded, generally well sorted, and very fine to fine grained, and is composed of approximately 90 to 95 percent quartz.

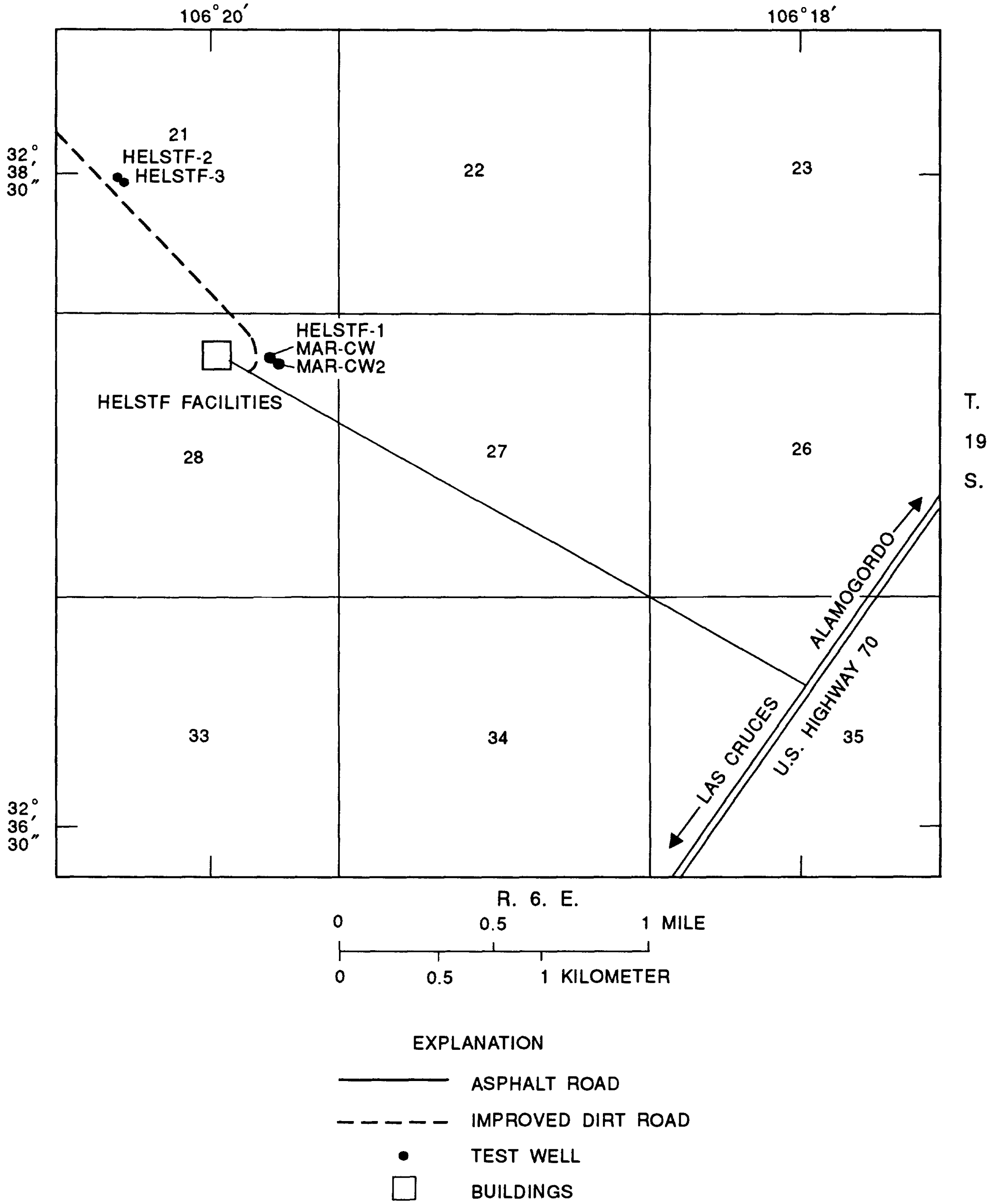
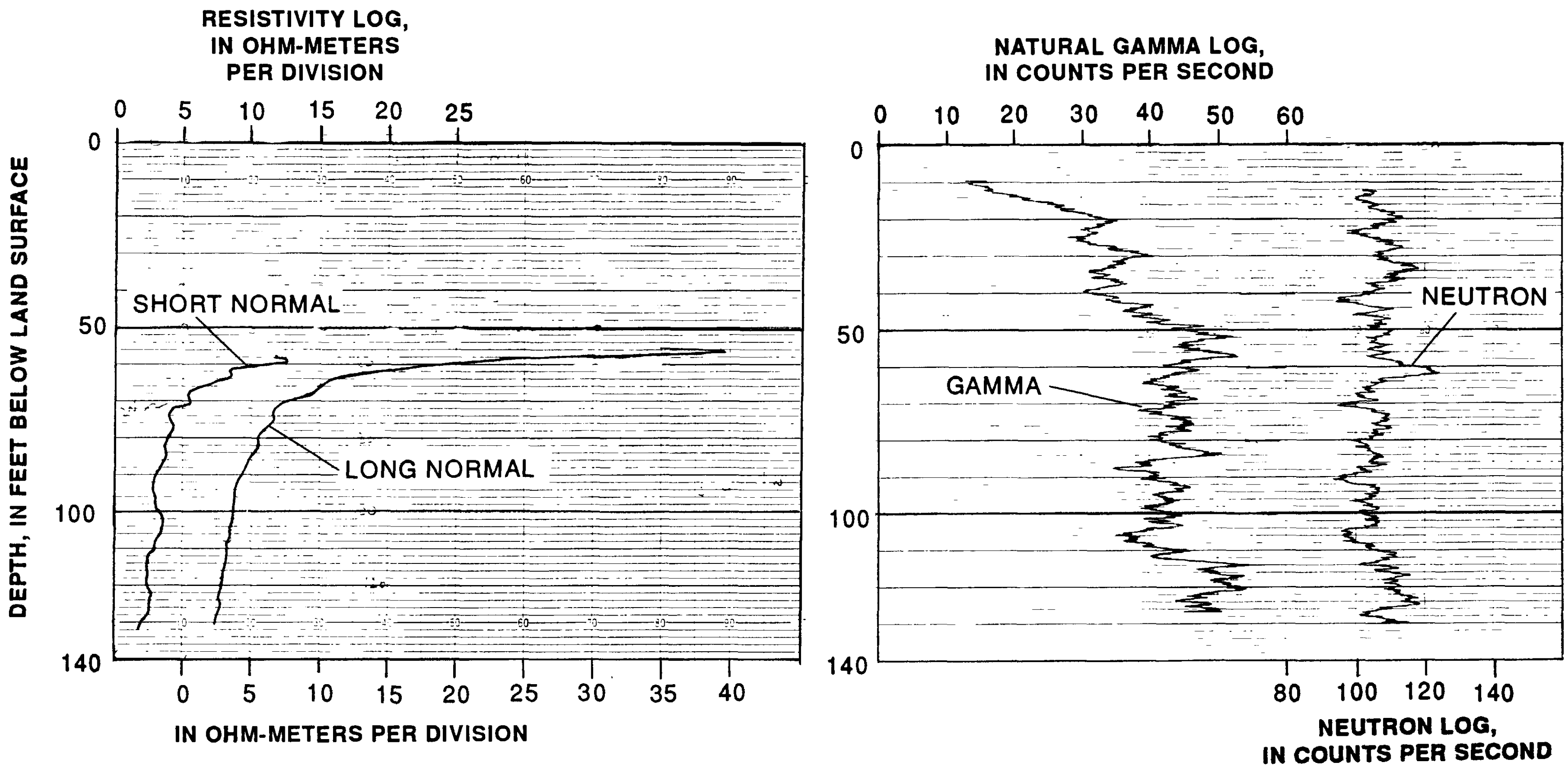
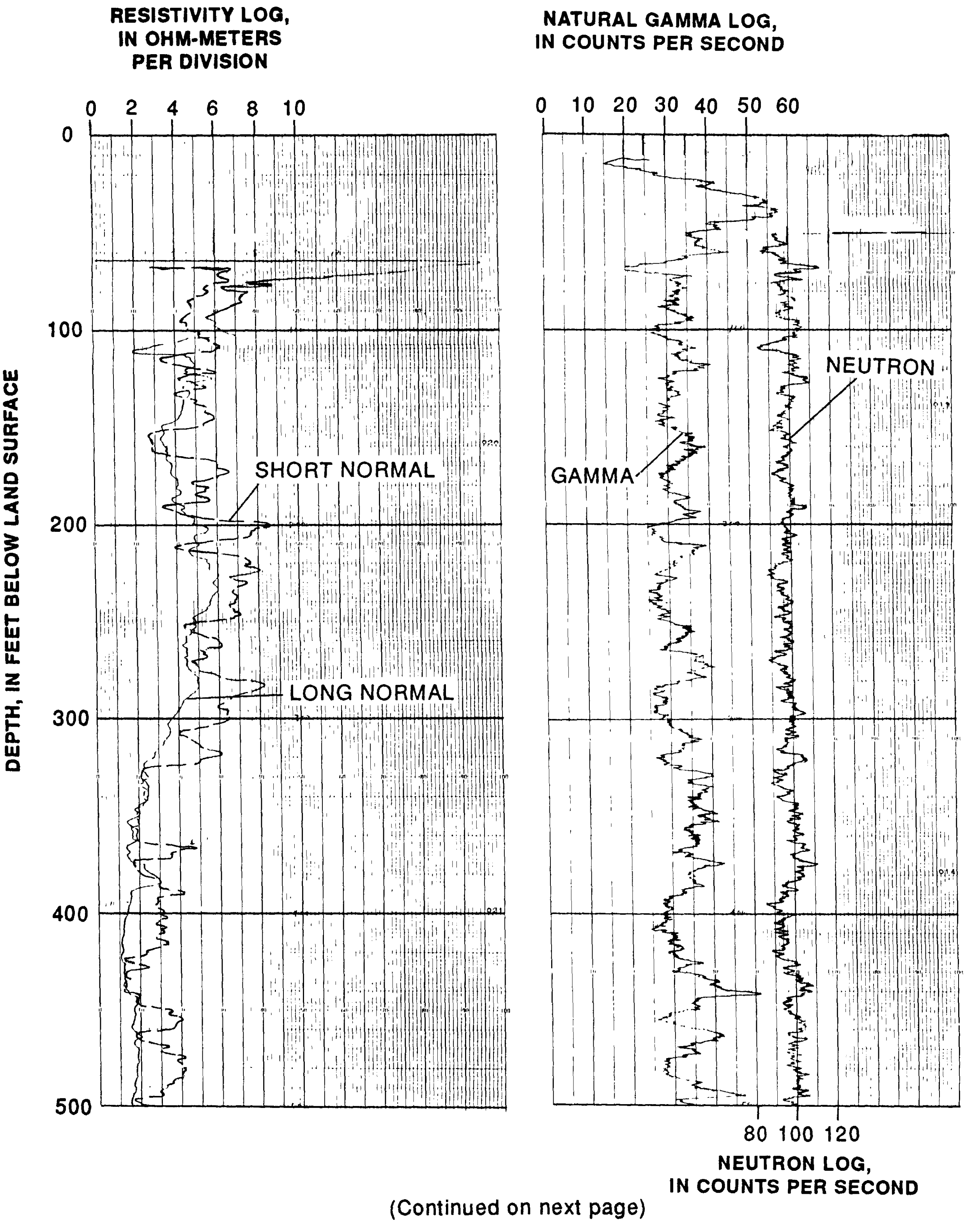


Figure 4.--Location of test wells in the area of the High Energy Laser System Test Facility, White Sands Missile Range, New Mexico.



*NOTE: ALL LOGS WERE MADE IN UNCASED DRILL HOLES FILLED WITH DRILLING FLUID.

Figure 5.--Borehole-geophysical logs for test well HELSTF-1 (19S.06E.28.221A), White Sands Missile Range, New Mexico. See figure 4 for test well location.



(Continued on next page)

Figure 6.--Borehole-geophysical logs for test well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico. See figure 4 for test well location.

(Continued from previous page)

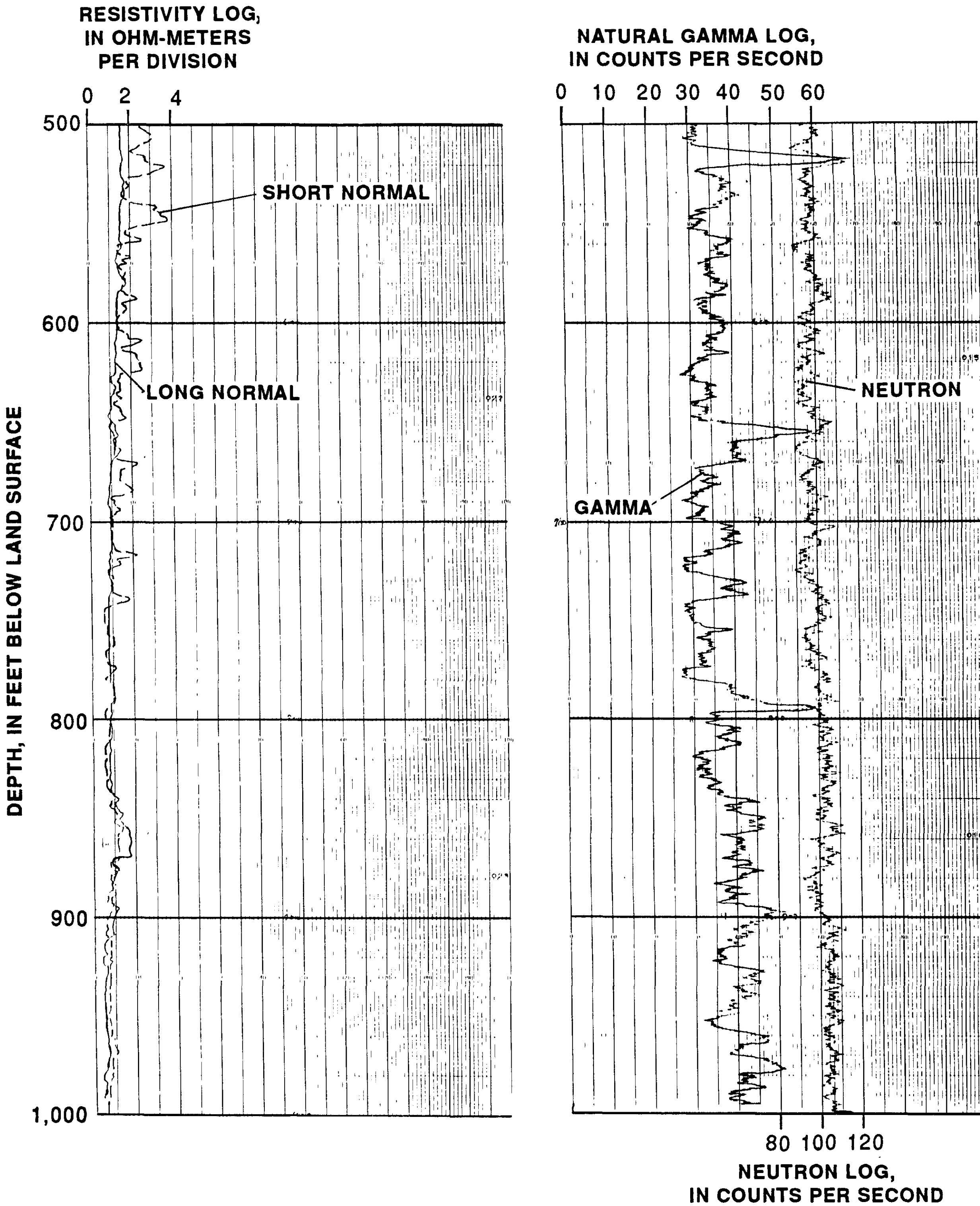


Figure 6.--Borehole-geophysical logs for test well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico-Continued.

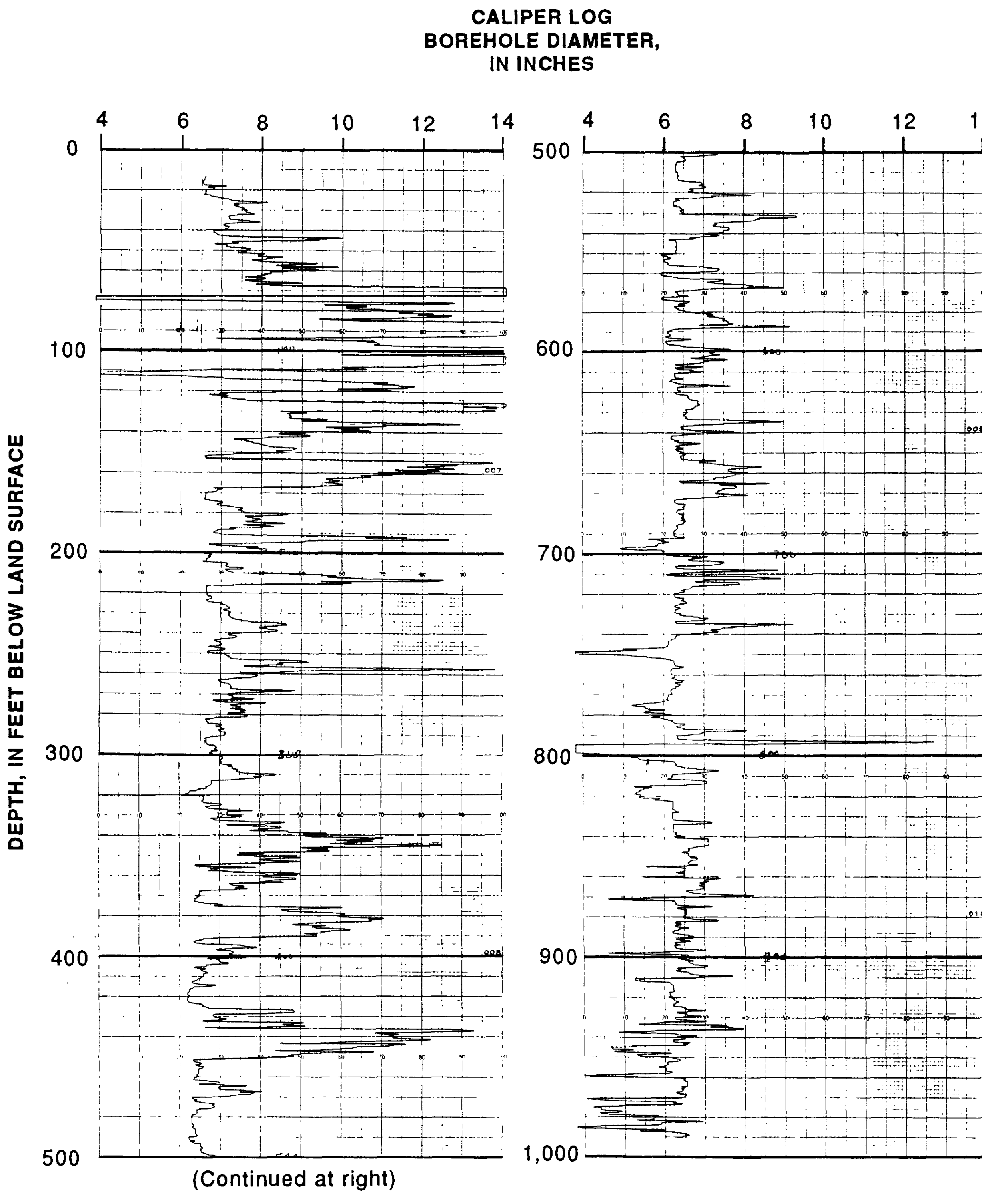


Figure 6.--Borehole-geophysical logs for test well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico--Concluded.

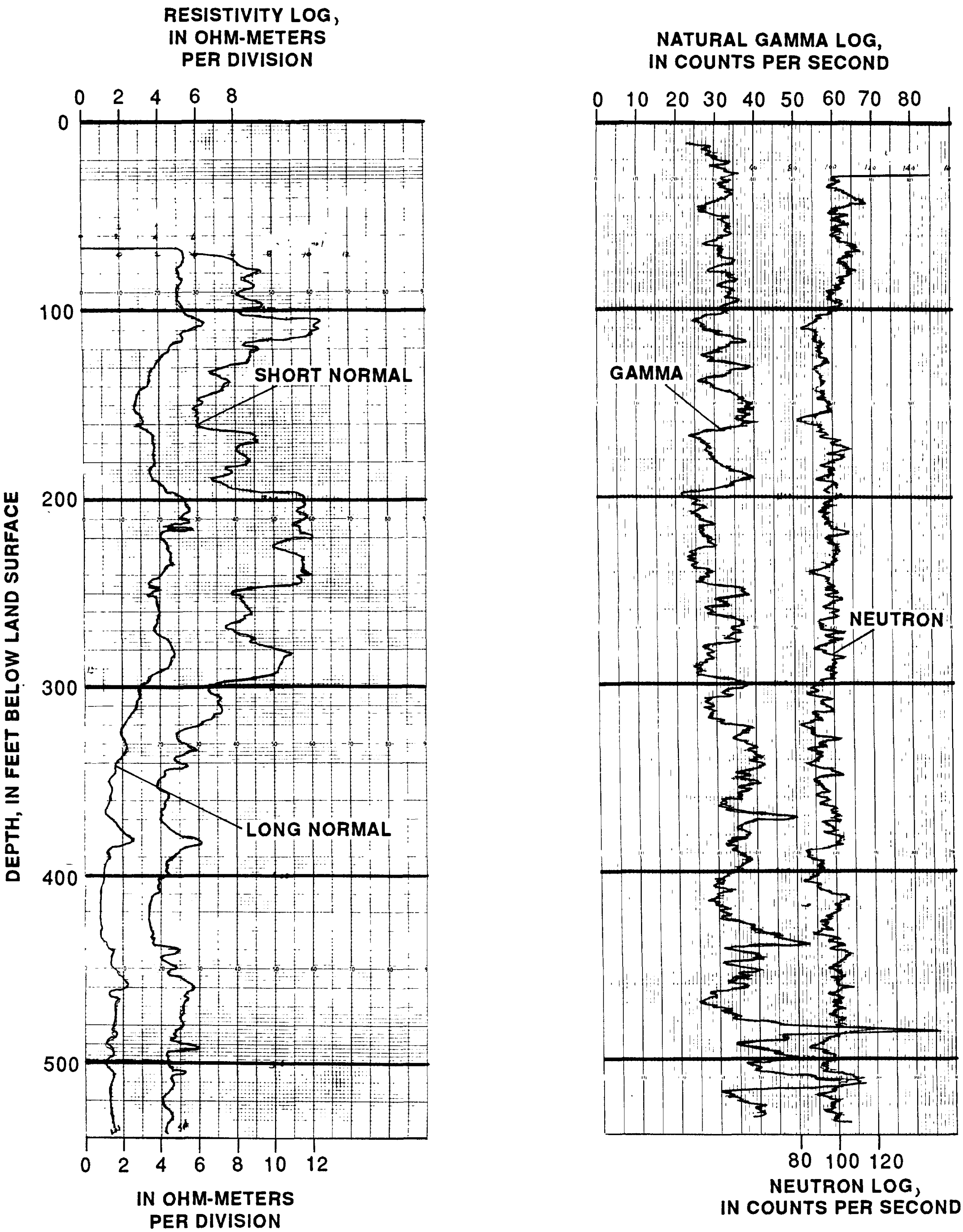


Figure 7.--Borehole-geophysical logs for test well HELSTF-3 (19S.06E.21.321A), White Sands Missile Range, New Mexico. See figure 4 for test well location.

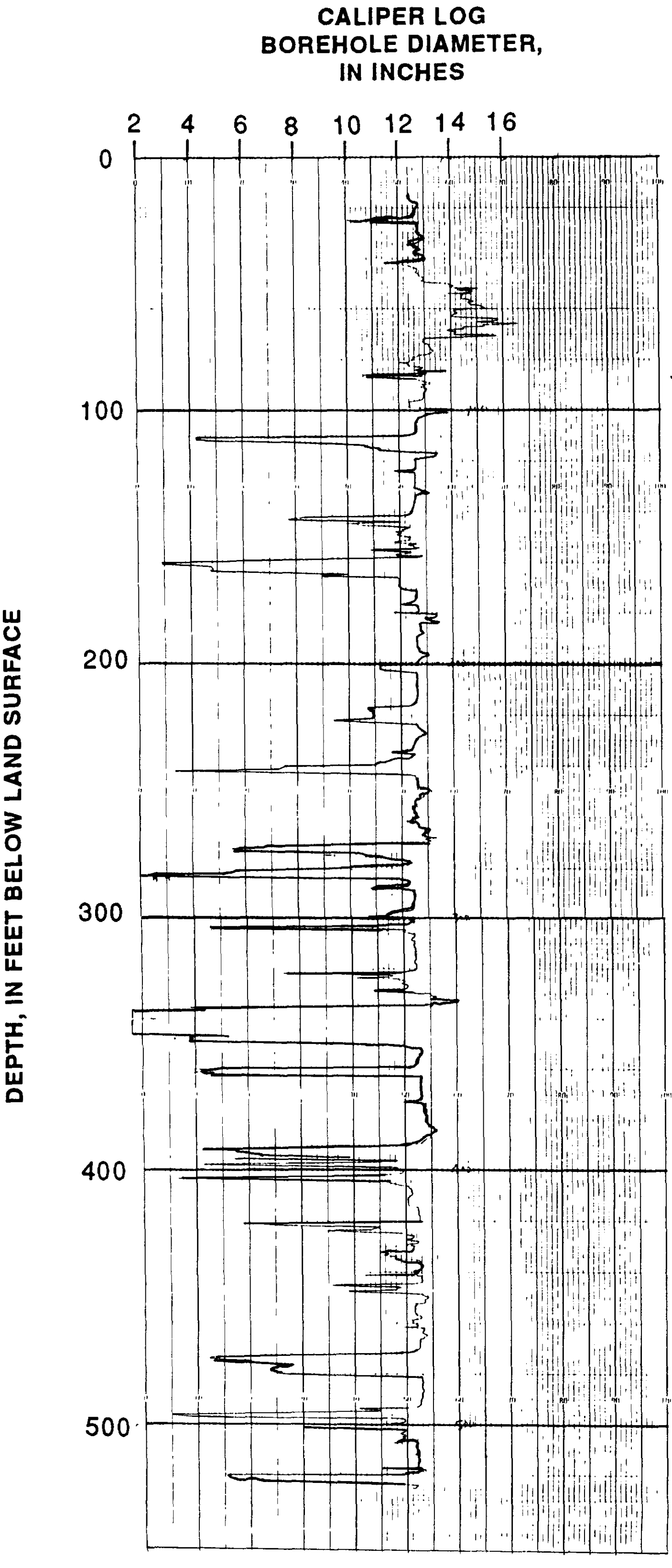
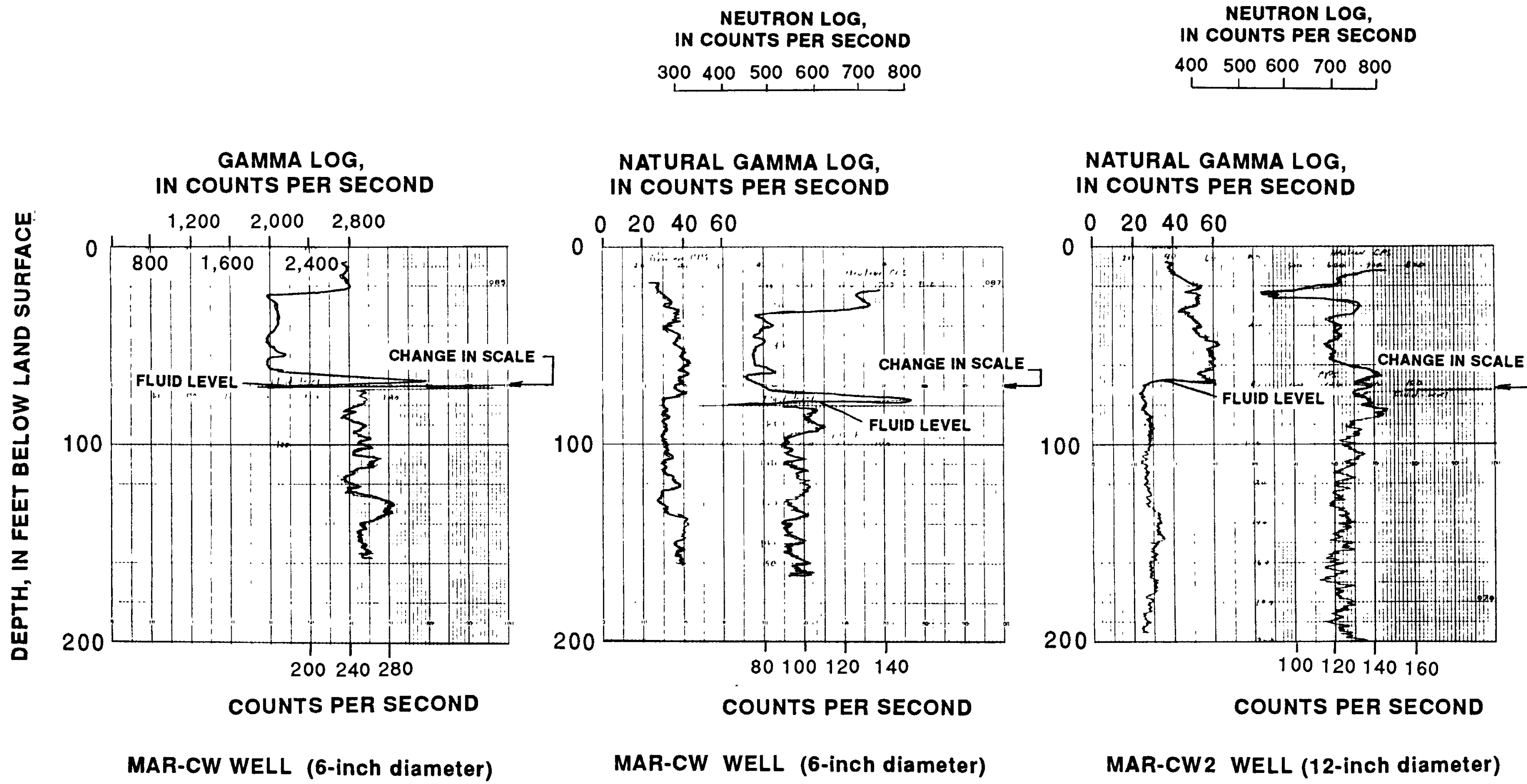


Figure 7.--Borehole-geophysical logs for test well HELSTF-3 (19S.06E.21.321A), White Sands Missile Range, New Mexico - Concluded.



*NOTE: ALL LOGS WERE MADE IN CASED DRILL HOLES FILLED WITH AQUIFER FLUID.

Figure 8.--Borehole-geophysical logs for the MAR-CW and MAR-CW2 test wells (19S.06E.28.221 and 19S.06E.28.221B), White Sands Missile Range, New Mexico. See figure 4 for test well locations.

Table 2.--Well-construction data for test wells at the High Energy Laser System Test Facility site, White Sands Missile Range, 1990

[Location of wells shown in figure 4; PVC, polyvinyl chloride; --, unknown]

Well name	Location	Date drilled	Hole depth (feet below land surface)	Well depth (feet below land surface)	Casing diameter (inches and type)	Slot or screened interval (depth below land surface, in feet)	Types of logs available
HELSTF-1	19S.06E.28.221A	5-90	132	100	4 PVC	70-90 screen	Gamma, neutron, long-short normal resistivity, lithologic
HELSTF-2	19S.06E.21.321	6-90	1,000	520	4 PVC	80-500 screen	Gamma, neutron, long-short normal resistivity, caliper, lithologic
HELSTF-3	19S.06E.21.321A	6-90	540	520	6 PVC	80-500 screen	Gamma, neutron, long-short normal resistivity, caliper, lithologic
MAR-CW	19S.06E.28.221	--	--	200	12 steel	73-200 slot	Gamma, neutron, gamma gamma, color video
MAR-CW2	19S.06E.28.221B	--	--	157	6 steel	Slot	Gamma, neutron, gamma gamma, color video

HELSTF-1

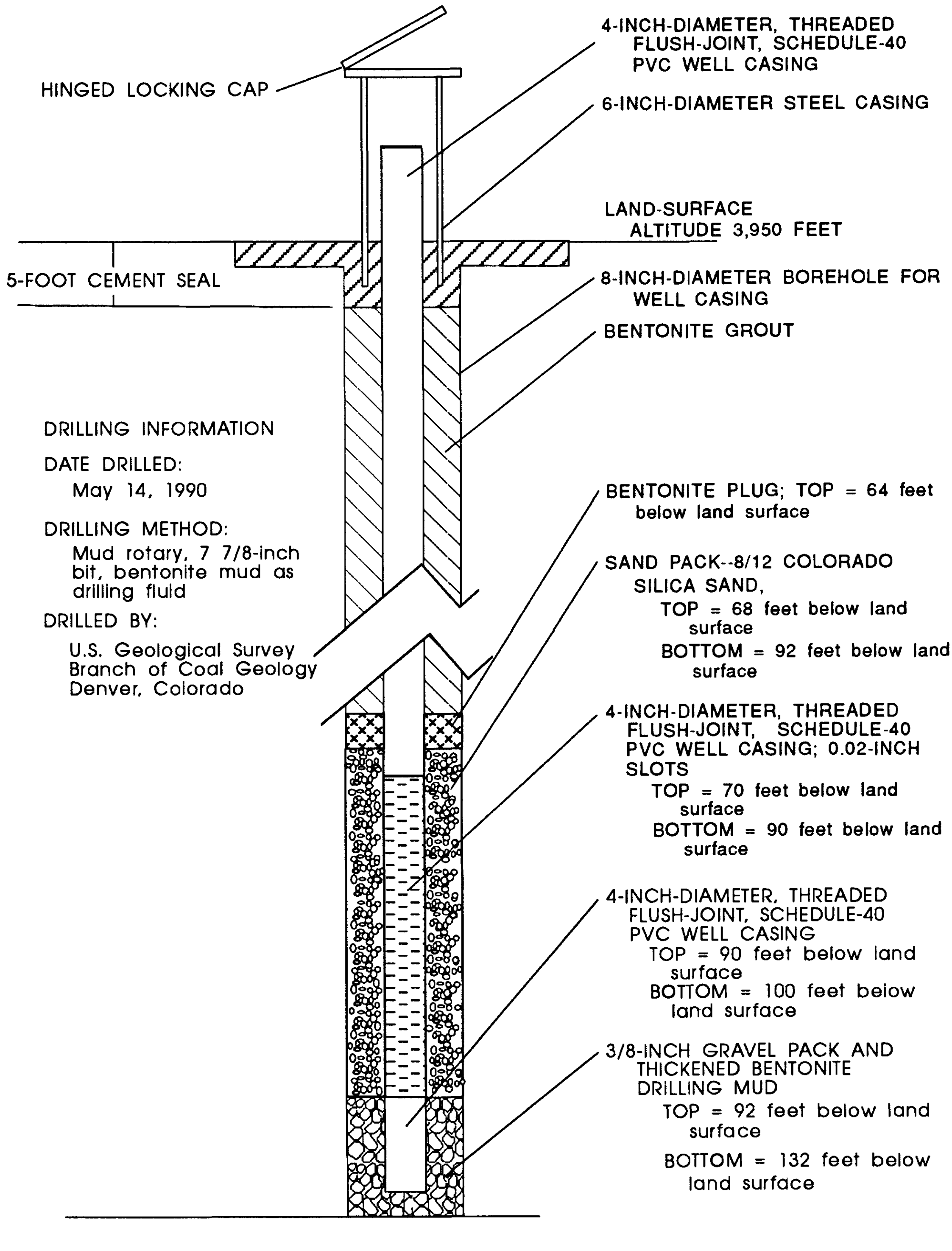


Figure 9.--Well construction for test well HELSTF-1 (19S.06E.28.221A), White Sands Missile Range, New Mexico.

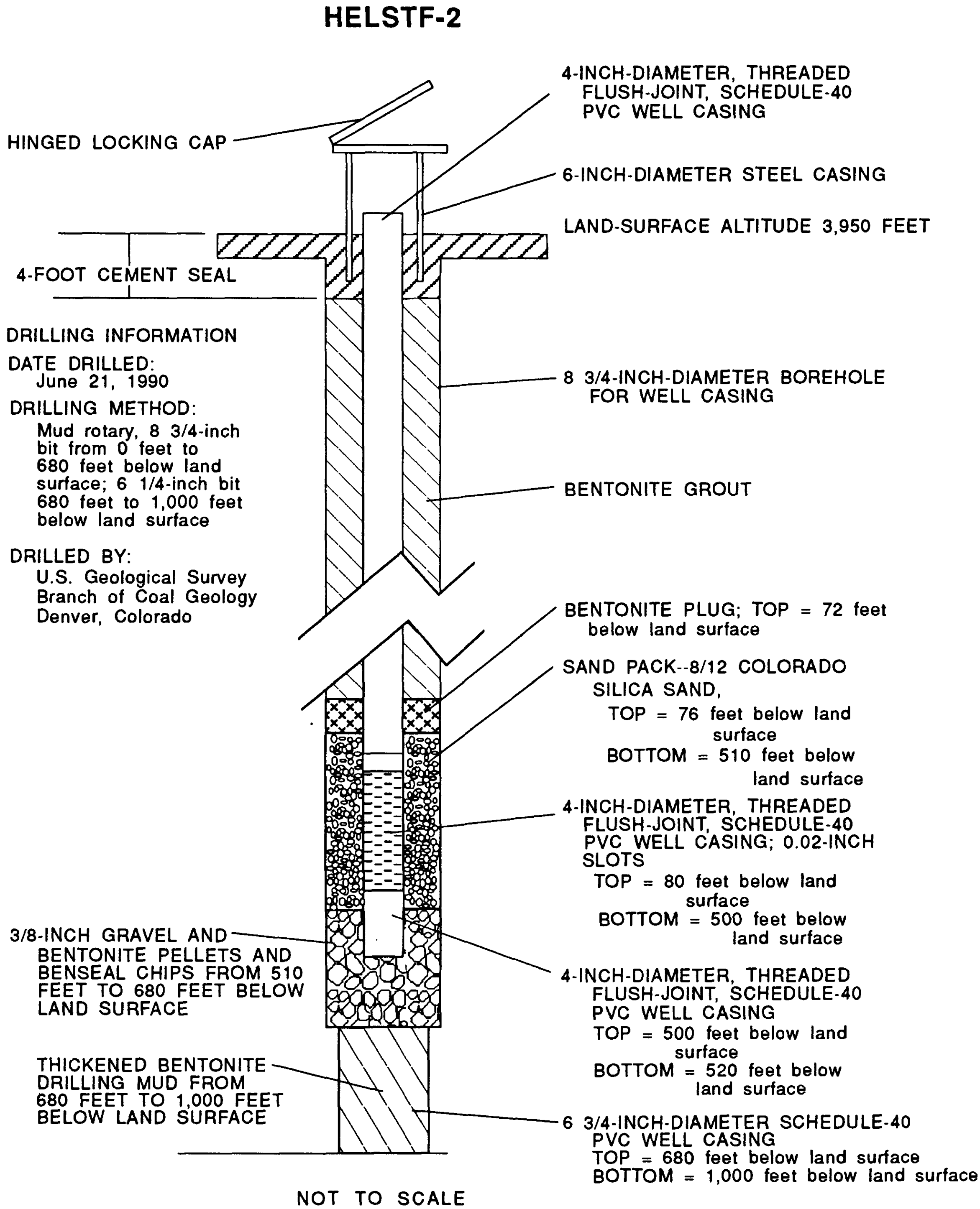


Figure 10.--Well construction for test well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico.

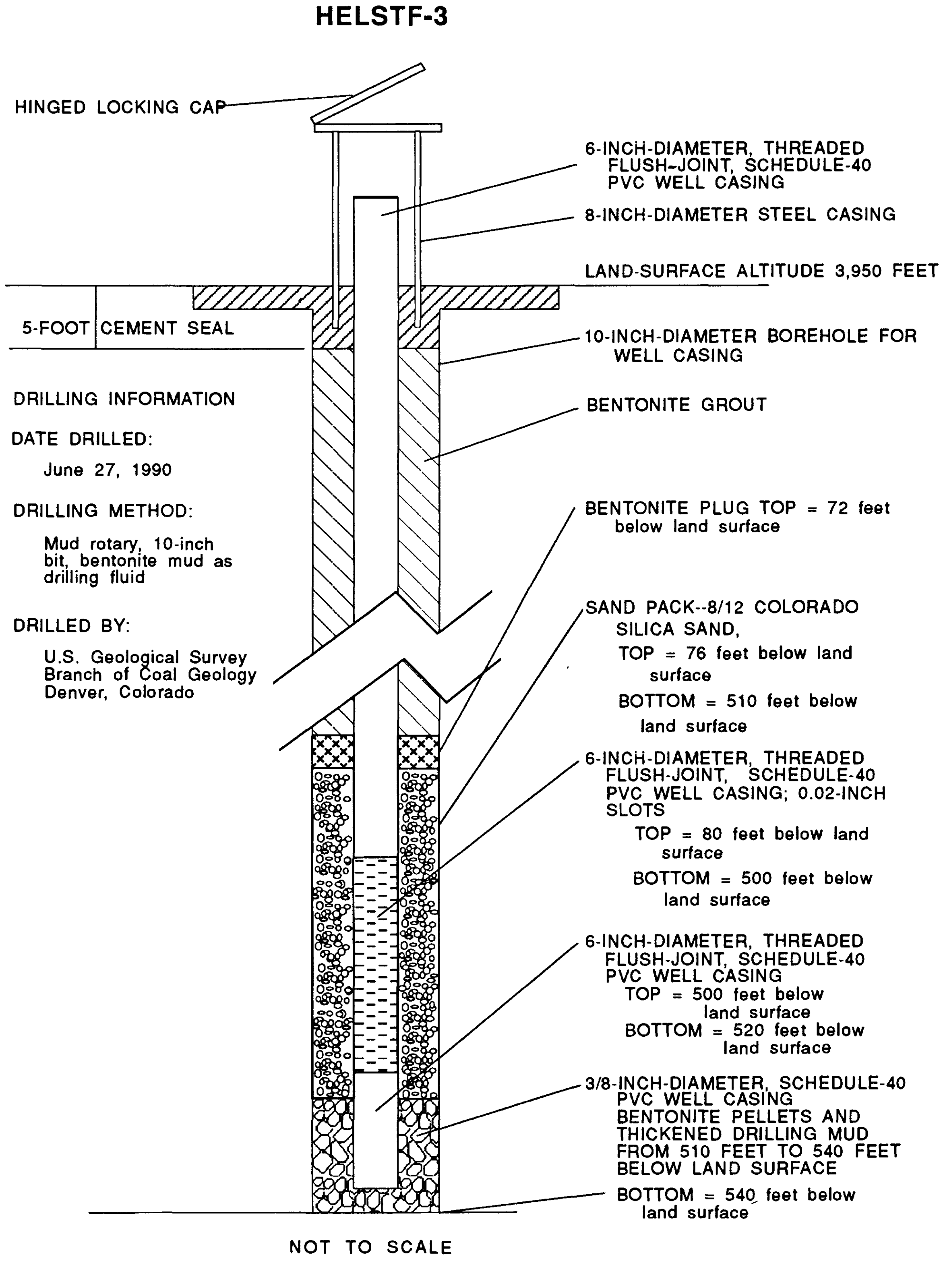


Figure 11.--Well construction for test well HELSTF-3 (19S.06E.21.321A), White Sands Missile Range, New Mexico.

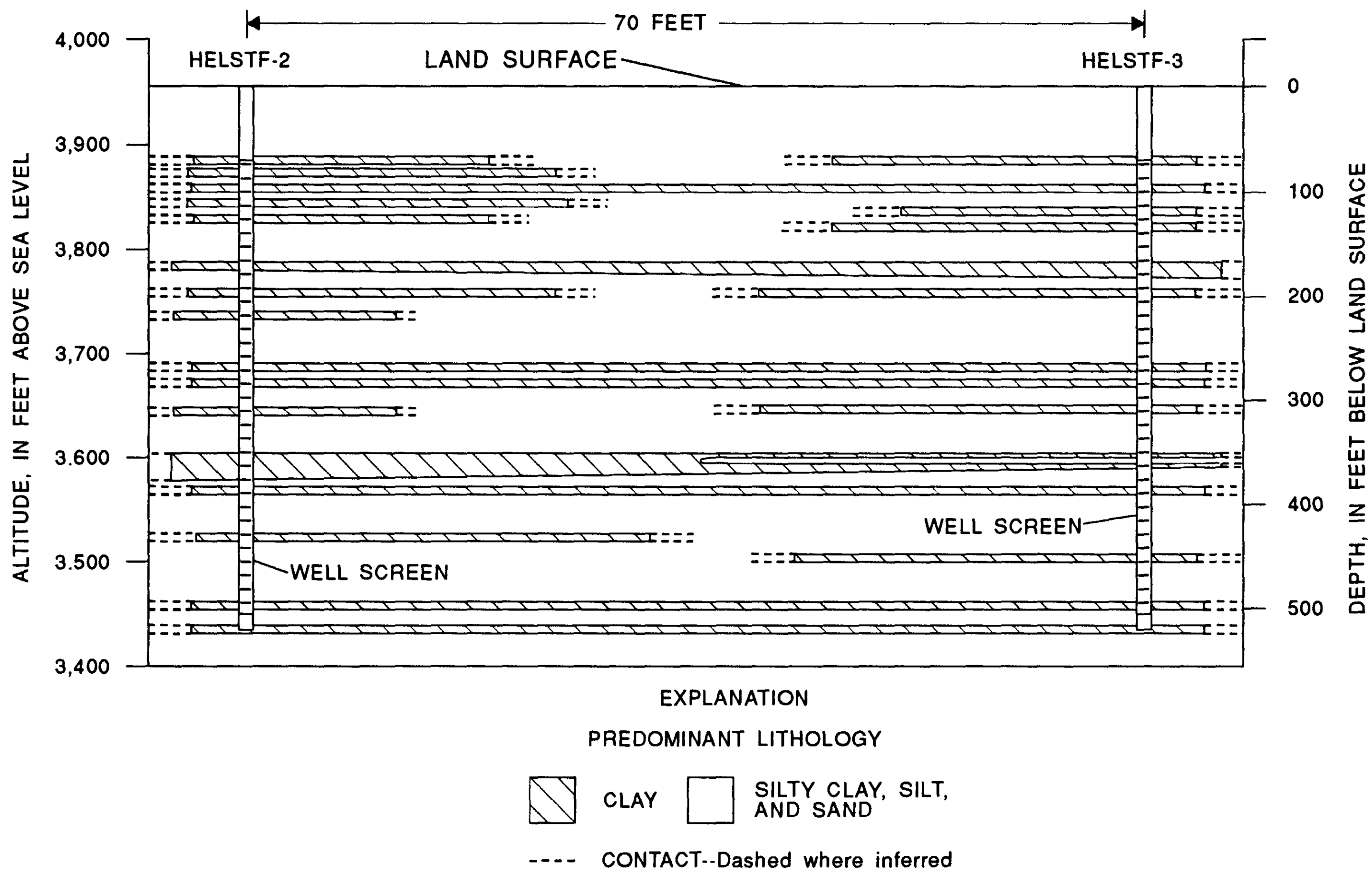


Figure 12.--Diagrammatic section of the subsurface lithology between test wells HELSTF-2 (19S.06E.21.321) and HELSTF-3 (19S.06E.21.321A), White Sands Missile Range, New Mexico. See figure 4 for test well locations.

Table 3.--X-ray mineral analysis of clay samples from test wells at selected depth intervals, White Sands Missile Range, New Mexico

[Samples analyzed by the New Mexico Bureau of Mines and Mineral Resources. Clay minerals reported as parts in ten. Accessory minerals: QTZ, quartz; PLAG, plagioclase; KSPAR, potassium feldspar; CAL, calcite; FELS, feldspar; DOL, dolomite; UNK, unknown, possibly huntite, a carbonate; GYP, gypsum; (?), mineral may be present. Color codes are from the Rock Color Chart (National Research Council, 1948). Location of wells shown in figure 4]

Well name	Depth interval (feet below land surface)	Clay minerals: Kaolinite	Illite	Chlorite	Smectite	Illite/smectite	Accessory minerals	Description of clay samples
HELSTF-1	85-95	4	2	0	1	3	QTZ, PLAG, KSPAR, CAL	Clay, grayish-pink (5 R 8/2) to light-brown (5 YR 6/4) with some selenite.
HELSTF-2	780-800	3	2	0	3	2	QTZ, FELS, DOL	Clay, grayish-orange-pink (5 YR 6/4).
HELSTF-2	950-960	2	2	0	2	4	QTZ, DOL, FELS	Clay, pale-brown (5 YR 5/2).
HELSTF-3	50-60	5	2	0	1	2	QTZ, DOL, FELS	Clay, pale-red (10 R 6/2) with some selenite.
HELSTF-3	110-120	5	3	0	1	1	QTZ, DOL, UNK, FELS	Clay, light-brown (5 YR 6/4).
HELSTF-3	110-120	4	3	0	0	3	QTZ, FELS (?)	Clay, pale-greenish-yellow (10 Y 8/2).
HELSTF-3	140-150	4	2	0	1	3	QTZ, GYP, CAL, (?)	Clay, pale-brown (5 YR 5/2).
HELSTF-3	190-200	4	1	0	2	3	QTZ, CAL, (?)	Clay, pale-brown (5 YR 5/2).
HELSTF-3	270-280	4	3	0	1	2	QTZ, FELS	Clay, pale-yellowish brown (5 YR 6/4) with some light-brown (5 YR 5/2) clay.
HELSTF-3	330-340	5	2	0	1	2	QTZ, GYP, FELS	Clay, pale-brown (5 YR 5/2) with some selenite.
HELSTF-3	370-380	4	3	0	1	2	QTZ, GYP, DOL, FELS	Clay, pale-yellowish-brown (10 YR 6/2) with some pale-greenish-yellow (10 Y 8/2) clay and some selenite.
HELSTF-3	480-500	4	2	0	1	3	QTZ, GYP, FELS, DOL, (?)	Clay, heterogeneous mix of colors with some organic material.

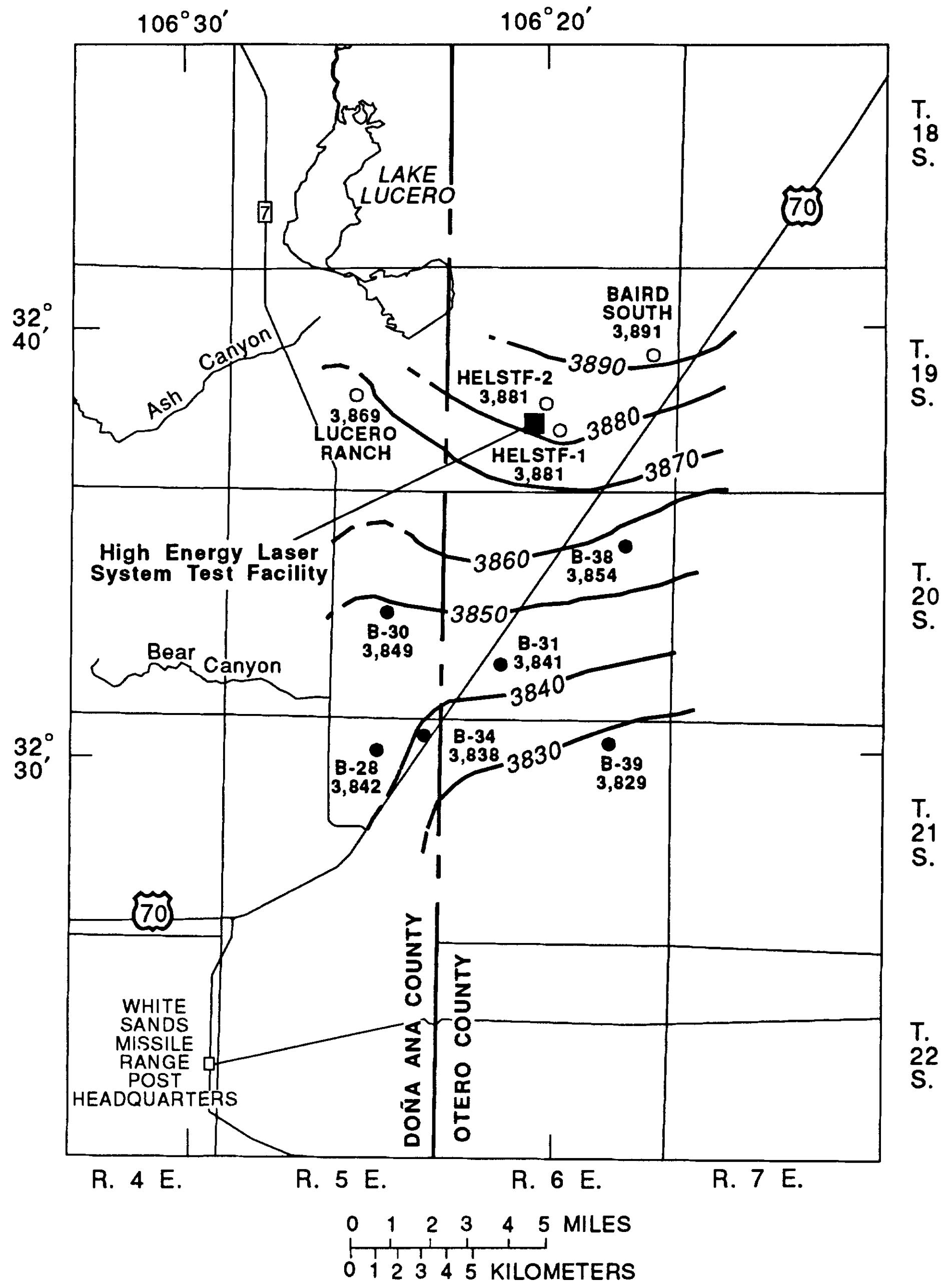
Potentiometric Surface

The altitude of the potentiometric surface and locations of observation wells, test wells, and boreholes in the vicinity of the HELSTF site are shown in figure 13. The potentiometric surface shown is assumed to be representative of the aquifer as a whole, but vertical variations in head are not considered. The potentiometric-surface contours are based on water levels measured in July 1990 (table 4) and indicate that ground water in the vicinity of the HELSTF site moves toward the south and southwest. The hydraulic gradient is estimated to be 5.3 feet per mile.

Measurements taken in 1990 of the static water level in the HELSTF-1 and HELSTF-2 test wells (table 4) indicate that the water level is about 69 feet below land surface. However, color video logs of the MAR-CW well showed water entering the well bore through a hole in the casing at about 34 feet below land surface. This water moves either horizontally along a clay layer or down the annular spacing from above until it reaches a less permeable zone where it begins to corrode the casing. This can be attributed to perched water above clay layers as indicated by geophysical logs. Discontinuous clay layers allow connection between permeable layers above the main aquifer and possible hydraulic connection with the main aquifer. Any discharge of water from the HELSTF facilities and percolation from precipitation could result in localized perched water.

Table 4.--Altitudes and water levels from selected test wells and boreholes, July 1990
[Location of wells and boreholes shown in figure 13]

Well or borehole name	Location	Altitude of land surface (feet above sea level)	Water level: Depth (feet below land surface)	Water level: Altitude (feet above sea level)
Lucero Ranch	19S.05E.22.334	4,040.0	171.07	3,868.9
Baird South	19S.06E.13.113	3,960.0	68.76	3,891.2
HELSTF-1	19S.06E.28.221A	3,950	69.40	3,880.6
HELSTF-2	19S.06E.21.321	3,950.0	68.57	3,881.4
B-28	21S.05E.02.341	3,982	140.52	3,841.5
B-30	20S.05E.23.213	3,938.6	89.74	3,848.9
B-31	20S.06E.29.123	3,964.0	123.26	3,840.7
B-34	21S.05E.01.224	3,964	126.55	3,837.5
B-38	20S.06E.11.234	3,984.0	129.72	3,854.3
B-39	21S.06E.02.142	3,985.0	156.2	3,828.8



EXPLANATION

3870 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, July 1990. Contour interval 10 feet. Datum is sea level. Dashed where inferred

o HELSTF-2 3,881 — WELL AND WELL NAME--Number is altitude of the potentiometric surface, in feet above sea level

● B-31 3,841 — BOREHOLE AND BOREHOLE NAME--Number is altitude of the potentiometric surface, in feet above sea level

Figure 13.--Approximate altitude of the potentiometric surface in the vicinity of the High Energy Laser System Test Facility site, July 1990.

Aquifer Characteristics

McLean (1970), Wilson and Myers (1981), and Orr and Myers (1986) inferred that the basin-fill sediments in the Tularosa Basin can be expected to respond as a leaky-confined aquifer in the deeper zones and as a water-table aquifer in the shallow zones. Evaluation of drill cuttings and borehole-geophysical logs from this study and descriptions of the lithology from previous studies in the area indicates that the lithology of the basin fill near the HELSTF site consists of thinly bedded sand, silt, and clay. Therefore, extrapolation of estimates for transmissivity, storage coefficient, and hydraulic conductivity from an aquifer test during this study to the aquifer as a whole might not be accurate because of the heterogeneity of the aquifer.

Continuous and discontinuous clay units are interbedded with the more permeable sand units (fig. 12). The continuous clay units effectively reduce the vertical movement of water, relative to the horizontal movement of water in the saturated sand during pumping. Therefore, the saturated sand adjacent to the screened interval in the production well probably will respond as a leaky-confined aquifer system. However, Orr and Myers (1986) suggested that the short-term effect of leakage on the water level in the pumped well is negligible.

Aquifer Test

Data collected during a 17-hour constant-discharge test on July 1-2, 1990, were used to estimate aquifer hydraulic properties. Water was pumped from well HELSTF-3 (fig. 4), and HELSTF-1 and HELSTF-2 were used as observation wells. Discharge from HELSTF-3 was held constant at 50,053 cubic feet per day (260 gallons per minute).

Water levels were observed in all three HELSTF wells. An electric tape was used to measure depth to water in wells HELSTF-1 and HELSTF-3. A water-level recorder was installed on well HELSTF-2 so that drawdown and recovery water levels could be manually and automatically monitored. The recorder was installed June 25, 1990, on HELSTF-2; the beginning water level was 69.05 feet below land surface. The recorder was removed July 7, 1990; the ending water level was 69.89 feet below land surface. Prior to the constant-discharge test, the water level in HELSTF-2 was 70.01 feet below land surface. Drawdown at the end of the test was 37.90 feet in HELSTF-3 and 22.55 feet in HELSTF-2. No drawdown was measured in HELSTF-1. Changes in barometric pressure can cause fluctuations in water levels. No significant changes in barometric pressure were observed during the 17-hour constant-discharge test.

Aquifer Hydraulic Properties

The aquifer hydraulic properties estimated from the data collected during the aquifer test include transmissivity, storage coefficient, and hydraulic conductivity. Transmissivity is defined as the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972).

The Theis-curve match method was used to estimate the transmissivity at the test site. The Theis-curve match method is based on the following assumptions: (1) the aquifer is homogeneous and isotropic, (2) the water body has infinite areal extent, (3) the discharging well penetrates the entire thickness of the aquifer, (4) the well has an infinitesimal diameter, and (5) the water removed from storage is discharged instantaneously with decline in head (Lohman, 1972, p. 15).

Some of the above assumptions were not met in this study and may have affected test results. The assumptions of the Theis-curve match method not met in this study include the following. (1) The aquifer is not homogeneous but heterogeneous, as evidenced by the discontinuous clay lenses and abundance of interbedded clay and silty sand (fig. 12). (2) The well does not penetrate the entire thickness of the aquifer. Partial penetration, however, is considered to be insignificant because of the laterally continuous layers of clay above and below the screened interval, which serve as confining layers relative to the stressed zone. (3) The well was still developing during the early part of the constant-discharge stress test, as evidenced by concentrations of silt in the discharge water; therefore, the efficiency and thus the water level in the pumped well change. The test data also were affected by turbulent flow cascading in the well bore.

Storage coefficient is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman, 1972, p. 8). This value is dimensionless. Storage-coefficient (specific-yield) values for an unconfined aquifer range from about 0.1 to about 0.3. Values for the storage coefficient in a confined aquifer range from about 10^{-5} to 10^{-3} (Lohman, 1972). Because the aquifer test was of short duration and applied to an aquifer that consists of thinly bedded sand, silt, and clay, data analyses would be expected to result in a storage coefficient that is characteristic of a confined aquifer.

Hydraulic conductivity is the capability of a unit area perpendicular to flow in an aquifer to transmit a unit volume of ground water in a unit time at a prevailing kinematic viscosity and unit hydraulic gradient (Lohman, 1972, p. 6). The hydraulic conductivity of sand was estimated by dividing the transmissivity by the saturated-sand thickness (about 130 feet) within the screened interval. The sand thickness was estimated from the borehole-geophysical logs and lithologic drill cuttings from test well HELSTF-3 (table 9; fig. 7). The hydraulic conductivity represents an estimate associated with saline water in the aquifer; the kinematic viscosity of brine is about 1.6 times that of pure water (Weist, 1983). Therefore, a freshwater aquifer having similar lithologic conditions could be expected to have larger hydraulic conductivity.

The Theis-curve match method (Lohman, 1972) was applied to drawdown data collected at observation well HELSTF-2. A log-log plot of the change in water level (drawdown) versus time of pumping was made and an acceptable curve fit was obtained for data collected in observation well HELSTF-2 using standard curve-matching procedures (Lohman, 1972, p. 18). From the type-curve match a transmissivity of 780 feet squared per day was estimated (fig. 14). The estimates for storage coefficient and hydraulic conductivity are 3.1×10^{-3} and 6.0 feet per day, respectively.

The Moench and Prickett (1972) method also was applied to the data because the aquifer may have been undergoing conversion from leaky-confined (artesian) to water-table conditions (John McLean, Hydrologist, U.S. Geological Survey, written commun., 1992). Unfortunately, the Moench and Prickett analysis could not be applied directly because the conversion from leaky-confined (artesian) to water-table conditions in the observation well occurred near the end of the test. Therefore, only the transmissivity estimated by the Theis-curve match method on data collected from the observation well is presented.

The estimated value of hydraulic conductivity is within the range of hydraulic-conductivity values for fine-grained sand as indicated by Bouwer (1978, p. 38) and for silty sand as indicated by Freeze and Cherry (1979, p. 29). This is consistent with the lithology observed in drill cuttings from the HELSTF wells.

To assist in analyzing the aquifer response to pumping, the Cooper-Jacob straight-line analysis procedures (Lohman, 1972, p. 21, eq. 56) also were used to estimate transmissivity, storage coefficient, and hydraulic conductivity for data collected in the production and observation wells. The estimates of transmissivity derived from the straight-line analyses are in general agreement with those derived from the Theis-curve match method (figs. 15-16; table 5).

By using the calculated values of transmissivity and storage coefficient from the semilogarithmic plots, the time (t) when the variable of integration (u) was equal to or less than 0.01 (Lohman, 1972, p. 22-23) was 893 minutes, which is the minimum pumping time required for proper data analysis. Comparison of the semilogarithmic plots with examples presented in Lohman (1972, p. 22) and in Driscoll (1986, p. 578) indicates that the drawdown data collected at HELSTF-2 will allow proper data analysis because the aquifer test continued longer (1,200 minutes) than the minimum (893 minutes) pumping time required.

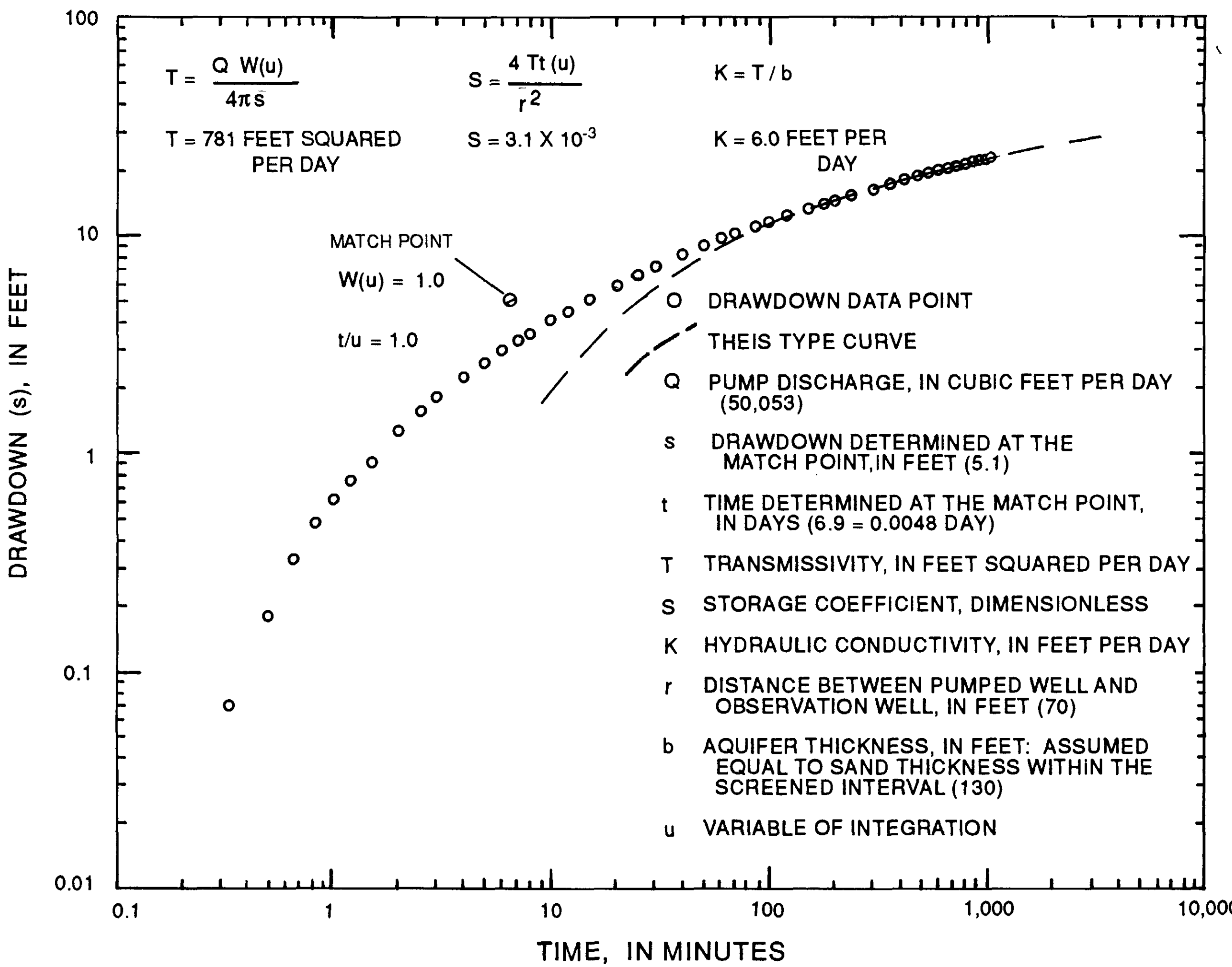


Figure 14.--Logarithmic plot of drawdown in well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico, during the 17-hour constant-discharge aquifer test, showing a match with Theis nonequilibrium type curve (Lohman, 1972).

Table 5.--Analysis methods and results of the aquifer test

[u, variable of integration; --, not applicable]

Figure	Analysis method	Well number	Pumping rate (cubic feet per day)	Transmissivity (feet squared per day)	Storage coefficient	Hydraulic conductivity (feet per day)	Remarks
14	Theis	HELSTF-2	50,053	780	3.1×10^{-3}	6.0	Theis nonequilibrium type-match
15	Cooper-Jacob	HELSTF-2	50,053	730	3.8×10^{-3}	5.6	Time (t) when u = 0.01 occurs is 893 minutes
16	Cooper-Jacob	HELSTF-3	50,053	750	--	5.8	Production well; no value for distance between production well and observation well

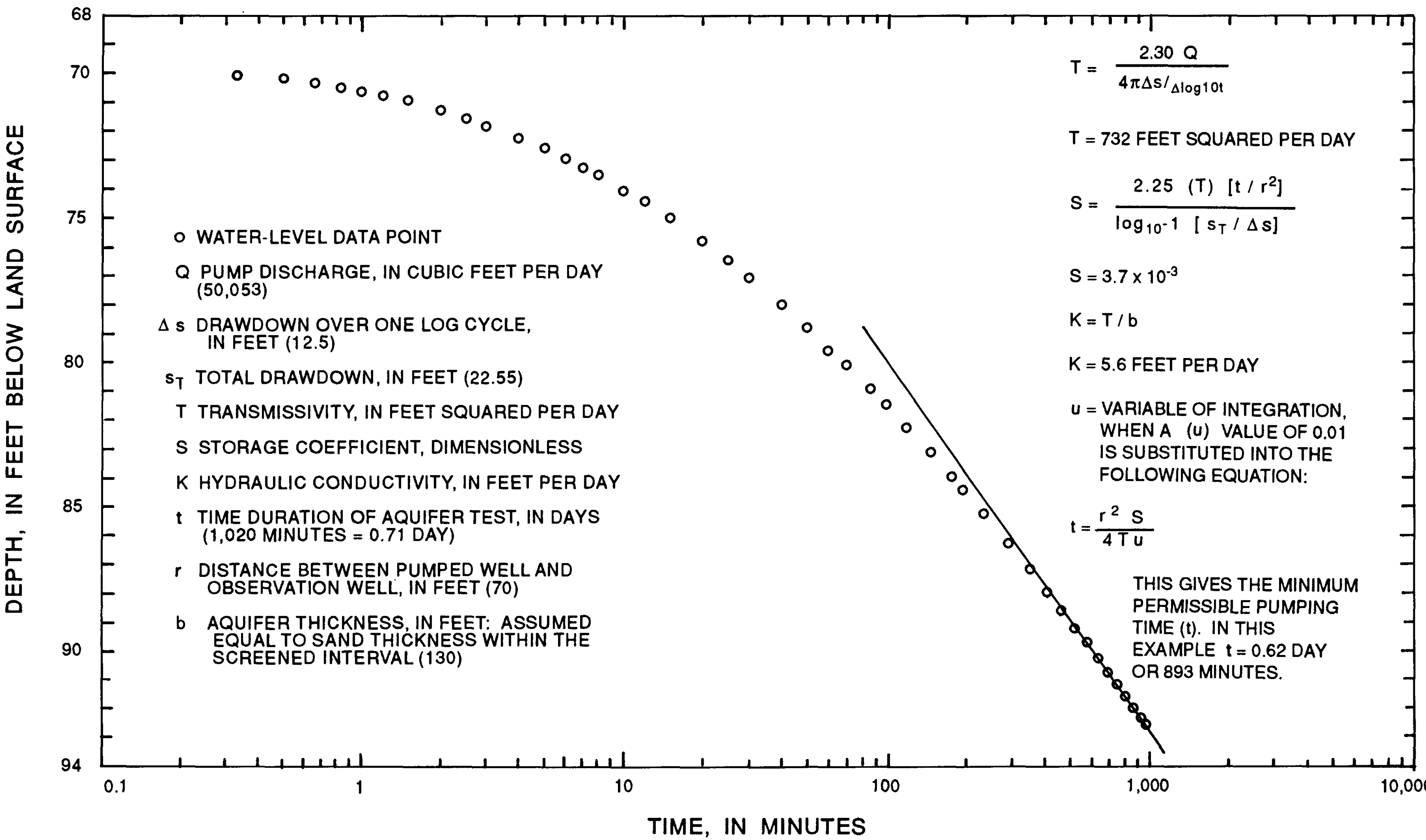


Figure 15.--Semilogarithmic plot of water levels in well HELSTF-2 (19S.06E.21.321), White Sands Missile Range, New Mexico, during the 17-hour constant-discharge aquifer test.

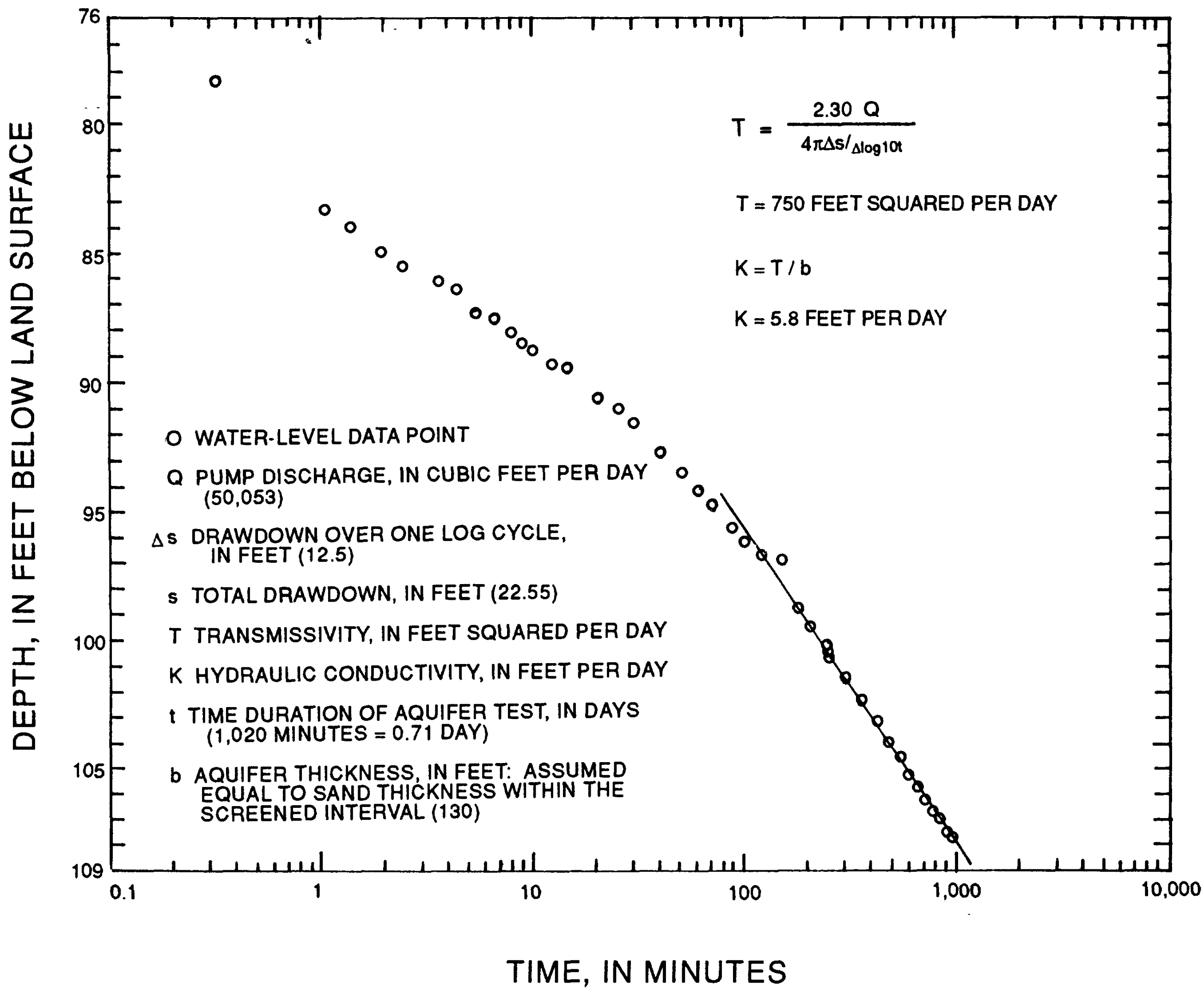


Figure 16.--Semilogarithmic plot of water levels in well HELSTF-3 (19S.06E.21.321A), White Sands Missile Range, New Mexico, during the 17-hour constant-discharge aquifer test.

Water Quality

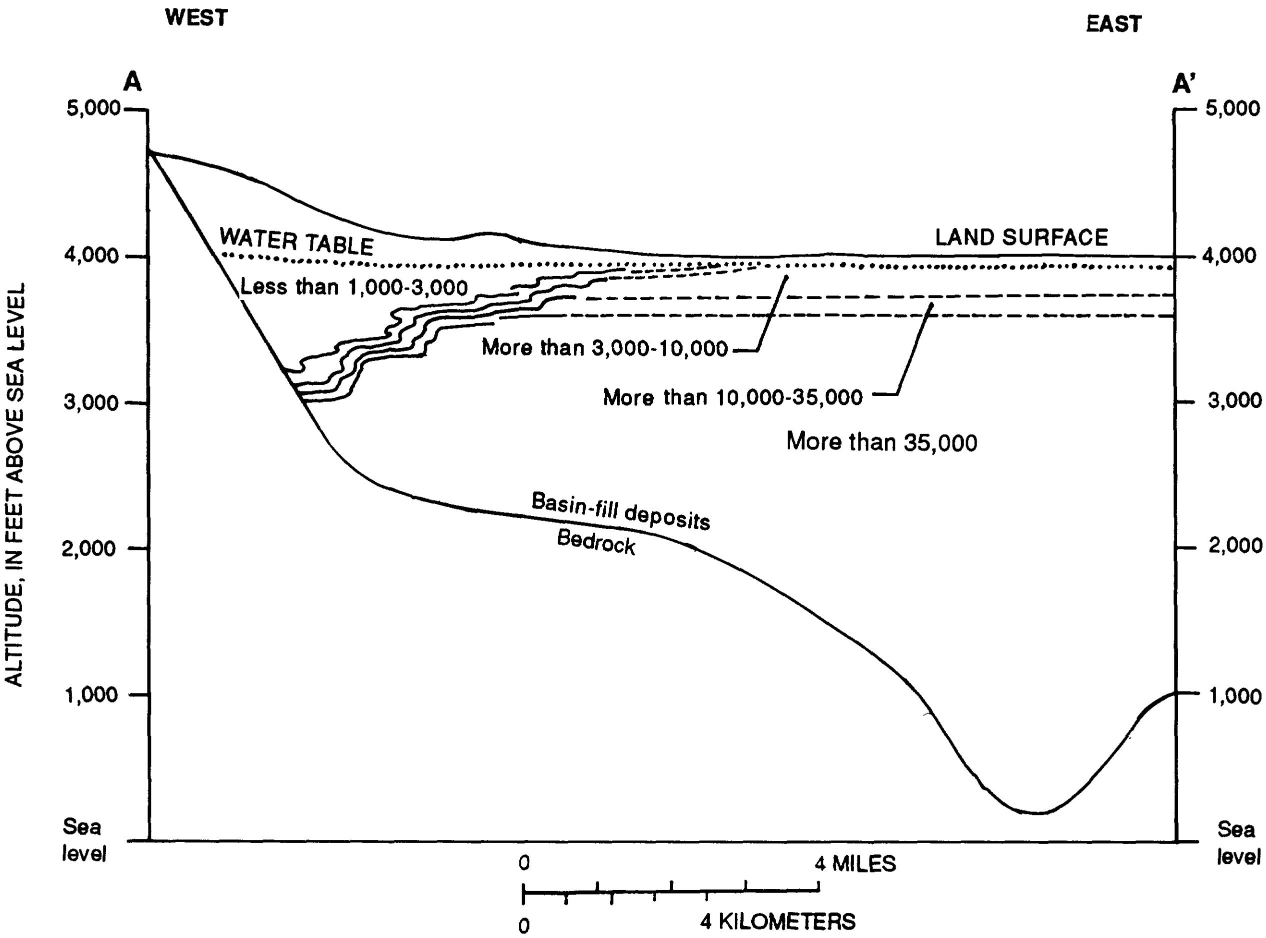
In this report, water is classified according to concentrations of dissolved solids (modified from Freeze and Cherry, 1979, p. 84) as follows:

Freshwater--Contains less than 1,000 milligrams per liter dissolved solids.
Brackish water--Contains 1,000 to 10,000 milligrams per liter dissolved solids.
Saline water--Contains greater than 10,000 to 100,000 milligrams per liter dissolved solids.
Brine--Contains greater than 100,000 milligrams per liter dissolved solids.

Fresh and slightly brackish ground water underlain by saline water is present in the vicinity of the alluvial-fan deposits along the western and eastern margins of the Tularosa Basin (Orr and Myers, 1986). Saline and brine ground water are present throughout the basin, but at shallower depths near the center of the basin (McLean, 1970). A west-to-east diagrammatic section of water-quality units from the San Andres Mountains to the center of the basin (McLean, 1970) near the HELSTF site is shown in figure 17. Water quality rapidly becomes more saline away from the mountain front.

Ground-water quality in the HELSTF area was determined by chemical analyses of water samples collected from test wells HELSTF-1, HELSTF-2, HELSTF-3, and the MAR-CW test well. Water samples were collected by bailing from test well HELSTF-1, by using the air-jet method in test well HELSTF-2, and by pumping with a submersible pump in test well HELSTF-3 and the MAR-CW well.

Prior to completion of test well HELSTF-2, water samples were collected at five progressively shallower depths using gravel envelopes and temporary casing. The depths below land surface of the sampling intervals, in ascending order, were: 833 to 815 feet, 693 to 675 feet, 493 to 475 feet, 413 to 395 feet, and 293 to 275 feet. An 18-foot section of perforated drill stem was attached to the end of the drill stem and placed at the selected sample depth in the test hole. Gravel was placed in the test hole up to a level above the section of perforated drill stem, and air was forced down an air-line in the drill stem. The temporary well was jetted at a rate of about 40 gallons per minute until the water became clear. Specific conductance of the production water was monitored during the jetting process until the conductance stabilized. A sample was then collected for chemical analysis. The bentonite drilling mud and wall cake above and below the jetted interval restricted vertical flow in the test hole. Water samples collected by this method are believed to be representative of the perforated interval. Air jetting may have affected some chemical characteristics of the sample, such as alkalinity, pH, and concentrations of some trace elements.



EXPLANATION

———— - - - -	LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER--Dashed where approximately located
3,000-10,000	RANGE OF DISSOLVED-SOLIDS CONCENTRATION IN WATER-QUALITY UNITS, IN MILLIGRAMS PER LITER--From McLean, 1970

Figure 17.--Diagrammatic section near the High Energy Laser System Test Facility site showing water-quality units on the western side of the Tularosa Basin (modified from McLean, 1970). Line of section is shown in figure 3.

Analyses indicate that the water chemistry in the study area varies primarily with depth. Dissolved-solids concentration in water in the upper part of the aquifer ranged from 5,940 to 11,800 milligrams per liter. The largest dissolved-solids concentration of 111,000 milligrams per liter was at the deepest interval sampled, 815 to 833 feet below land surface, in test well HELSTF-2 (table 6). These differences in dissolved-solids concentration among samples show that salinity increases with depth. The high specific conductance is probably related to the long residence time of the ground water in contact with highly soluble rocks and minerals and subsequent chemical degradation as described by Driscoll (1986, p. 96).

Trilinear plots of chemical analyses were constructed using water-chemistry data from the HELSTF test wells and the MAR-CW wells (fig. 18). The analyses indicate that the relative ion concentrations generally vary with depth. The predominant cation is sodium throughout the aquifer. The predominant anion is sulfate in the upper part of the aquifer. The predominant anion from sample intervals 675 to 693 feet and 815 to 833 feet below land surface is chloride. Concentrations of chloride and dissolved solids increase with depth whereas the concentration of sulfate decreases.

Water from the MAR-CW well was tested for volatile organic compounds and radionuclides. The analyses are presented in table 7. The analysis for volatile organic compounds determined that toluene may be present in the MAR-CW test well. However, the concentration is less than 1 microgram per liter.

Table 6.--Chemical analyses of water from selected wells: physical properties, major and minor constituents, and trace elements

[QTab, Quaternary and Tertiary bolson deposits; µS/cm, microsiemens per centimeter at 25 degrees Celsius; g/ml, grams per milliliter; deg C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; <, less than]

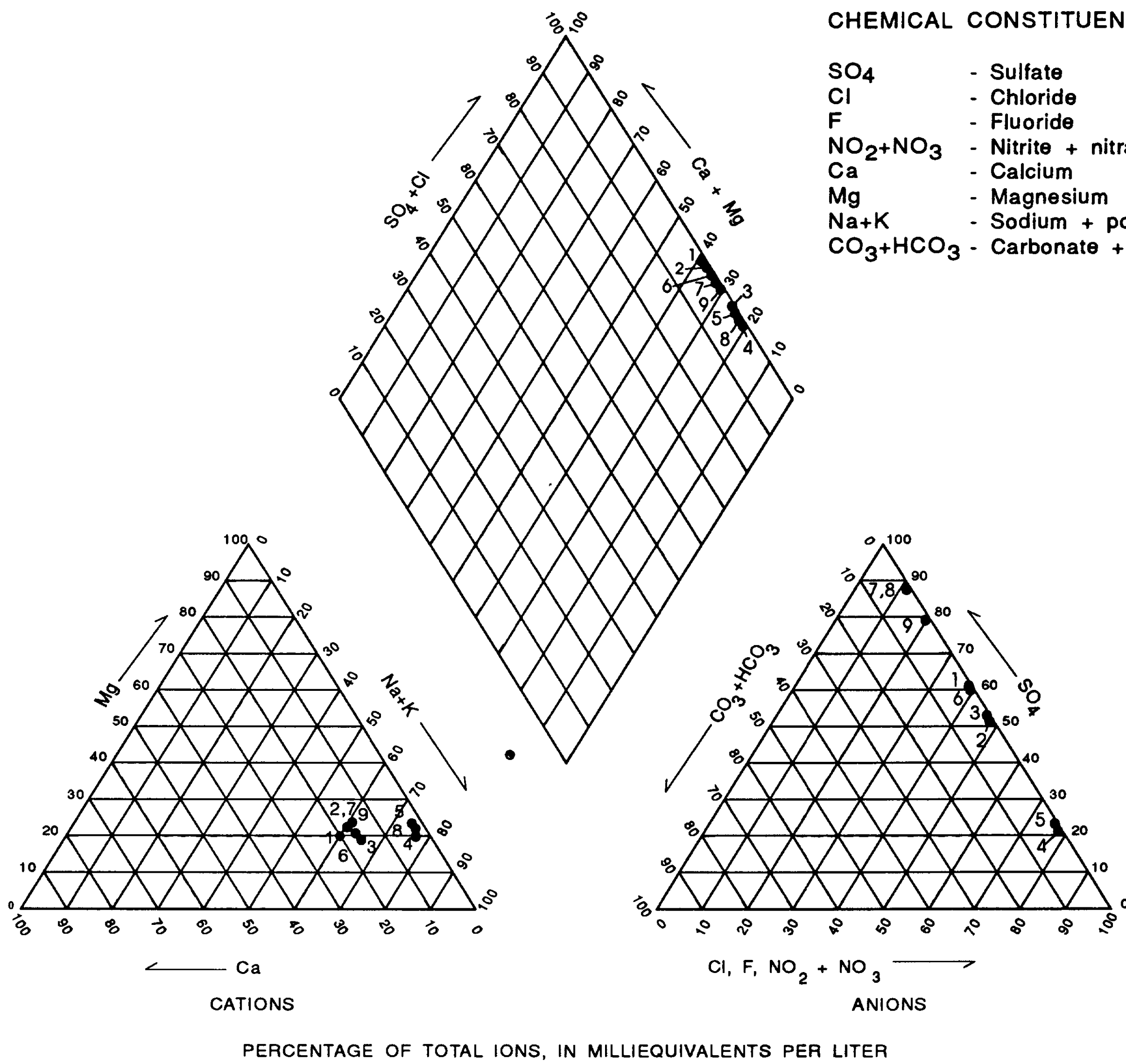
Well name	Well location	Date	Geologic unit	Depth to top of sample interval (feet)	Depth to bottom of sample interval (feet)	Specific conductance (µS/cm)	Density (g/ml at 20 deg C)	pH (standard units)	Water temperature (deg C)	Dissolved solids, residue at 180 deg C, dissolved (mg/L)	Alkalinity, lab (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
HELSTF-1	19S.06E.28.221A	05-14-90	QTab	70	90	11,600	--	7.3	--	10,900	200	440
HELSTF-2	19S.06E.21.321	06-09-90	QTab	815	833	106,000	--	7.3	--	111,000	146	760
		06-10-90	QTab	675	693	79,400	--	7.5	--	67,700	129	1,000
		06-11-90	QTab	475	493	21,900	--	7.9	--	18,700	147	590
		06-11-90	QTab	395	413	19,900	--	7.8	--	17,300	163	720
		06-11-90	QTab	275	293	7,790	--	7.9	--	5,940	142	370
HELSTF-3	19S.06E.21.321A	07-02-90	QTab	80	500	13,900	--	7.8	22	11,800	88	390
MAR-CW	19S.06E.28.221	11-21-84	QTab	--	--	10,500	--	--	21	9,930	120	69
		04-03-89	QTab	--	--	--	--	--	21	11,500	119	360
		08-31-89	QTab	--	--	16,200	--	7.9	--	--	--	--

Table 6.--Chemical analyses of water from selected wells: physical properties, major and minor constituents, and trace elements--Continued

Date	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)
05-14-90	410	2,100	29	6,700	750	<0.1	0.31	30.0	15.0	20	43.0	100.0	1,500
06-09-90	4,800	28,000	450	15,000	46,000	0.8	21.00	7.6	0.7	530	46.0	100.0	1,100
06-10-90	2,200	17,000	270	8,200	33,000	5.0	14.00	14.0	0.5	<100	39.0	100.0	14,000
06-11-90	550	4,400	98	7,400	4,500	1.8	1.70	19.0	0.9	20	52.0	100.0	980
06-11-90	680	3,800	98	6,600	4,600	2.0	2.00	16.0	1.7	30	15.0	100.0	720
06-11-90	210	1,200	34	2,800	1,200	0.4	0.54	20.0	2.5	10	3.0	100.0	490
07-02-90	420	2,500	53	5,100	2,400	1.6	0.98	25.0	1.3	<20	17.0	100.0	660
11-21-84	370	2,000	27	5,700	670	0.6	--	22.0	3.8	--	--	--	850
04-03-89	510	2,300	60	6,600	1,200	1.8	0.65	21.0	26.0	--	2.0	100.0	3,000
08-31-89	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 6.--Chemical analyses of water from selected wells: physical properties, major and minor constituents, and trace elements--Concluded

Date	Cadmium, dis- solved (µg/L as Cd)	Chro- mium, dis- solved (µg/L as Cr)	Chro- mium, hexa- valent, dis- solved (µg/L as Cr)	Copper, dis- solved (µg/L as Cu)	Iron, dis- solved (µg/L as Fe)	Lead, dis- solved (µg/L as Pb)	Lithium, dis- solved (µg/L as Li)	Manga- nese, dis- solved (µg/L as Mn)	Mercury, dis- solved (µg/L as Hg)	Sele- nium, dis- solved (µg/L as Se)	Silver, dis- solved (µg/L as Ag)	Stron- tium, dis- solved (µg/L as Sr)	Zinc, dis- solved (µg/L as Zn)
05-14-90	1.0	<2.0	<1.0	<1.0	30.0	<1.0	230.0	170.0	0.2	4.0	<1.0	60	1,200
06-09-90	<20.0	<12.0	<1.0	<10.0	1,100.0	<10.0	3,200.0	1,100.0	0.3	2.0	10.0	12,000	11,000
06-10-90	<10.0	<10.0	<1.0	<10.0	600.0	<10.0	1,700.0	490.0	0.3	<2.0	10.0	14,000	7,000
06-11-90	<2.0	4.0	1.0	<2.0	90.0	<2.0	620.0	150.0	0.5	2.0	<2.0	4,500	1,500
06-11-90	<2.0	3.0	1.0	<2.0	100.0	<2.0	500.0	150.0	0.8	7.0	<2.0	5,100	2,200
06-11-90	<1.0	3.0	1.0	3.0	80.0	<1.0	210.0	120.0	0.2	7.0	<1.0	6,300	390
07-02-90	<2.0	3.0	<1.0	<2.0	50.0	<2.0	370.0	130.0	0.4	12.0	<2.0	6,300	90
11-21-84	--	--	--	--	--	--	220.0	--	--	--	--	3,300	--
04-03-89	<1.0	110.0	--	2.0	40.0	<5.0	220.0	100.0	0.5	87.0	1.0	5,300	1,000
08-31-89	--	1,100.0	700.0	--	--	--	--	--	--	--	--	--	--



CHEMICAL CONSTITUENTS

SO_4	- Sulfate
Cl	- Chloride
F	- Fluoride
NO_2+NO_3	- Nitrite + nitrate
Ca	- Calcium
Mg	- Magnesium
Na+K	- Sodium + potassium
CO_3+HCO_3	- Carbonate + bicarbonate

EXPLANATION

WELL NAME	PLOT NUMBER	SAMPLE INTERVAL (feet below land surface)	SPECIFIC CONDUCTANCE (microsiemens per centimeter at 25 degrees Celsius)	DISSOLVED-SOLIDS CONCENTRATION (milligrams per liter, residue at 180 degrees Celsius)
HELSTF-2	1	275 - 293	7,790	5,940
HELSTF-2	2	395 - 413	19,900	17,300
HELSTF-2	3	475 - 493	21,900	18,700
HELSTF-2	4	675 - 693	79,400	67,700
HELSTF-2	5	815 - 833	106,000	111,000
HELSTF-3	6	80 - 500	13,900	11,800
HELSTF-1	7	70 - 90	11,600	10,900
MAR-CW	8	73 - 200	10,500	9,930
MAR-CW	9	73 - 200	--	11,500

MAR-CW WELL WAS SAMPLED TWICE--PLOT 8 ON 11/21/84 AND PLOT 9 ON 4/03/89

Figure 18.--Chemical analyses of ground water from test wells, White Sands Missile Range, New Mexico.

Table 7.--Chemical analyses of water from test well MAR-CW: radionuclides and volatile organic compounds

[µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than]

Well name	Well location	Date	Gross alpha, dis-solved (µg/L as U-NAT)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, dis-solved (pCi/L as Sr/Yt-90)	Radium 226, dis-solved, radon method (pCi/L)	Uranium, natural, dis-solved (µg/L as U)	Di-chloro-bromo-methane, total (µg/L)	Carbon-tetra-chlo-ride, total (µg/L)	1,2-Di-chloro-ethane, total (µg/L)
MAR-CW	19S.06E.28.221	04-03-89	58.000	130.00	85.000	0.390	36.000	<0.200	<0.200	<0.200

Date	Bromo-form, total (µg/L)	Chloro-di-bromo-methane, total (µg/L)	Chloro-form, total (µg/L)	Toluene, total (µg/L)	Benzene, total (µg/L)	Chloro-benzene, total (µg/L)	Chloro-ethane, total (µg/L)	Ethyl-benzene, total (µg/L)	Methyl-bromide, total (µg/L)	Methyl-chlo-ride, total (µg/L)	Methyl-ene chlo-ride, total (µg/L)
04-03-89	<0.200	<0.200	<0.200	0.700	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200

Table 7.--Chemical analyses of water from test well MAR-CW: radionuclides and volatile organic compounds--Concluded

Date	Tetra-chloro-ethyl-ene, total (µg/L)	Tri-chloro-fluoro-methane, total (µg/L)	1,1-Di-chloro-ethane, total (µg/L)	1,1-Di-chloro-ethyl-ene, total (µg/L)	1,1,1-Tri-chloro-ethane, total (µg/L)	1,1,2-Tri-chloro-ethane, total (µg/L)	1,1,2,2 Tetra-chloro-ethane, total (µg/L)	1,2-Di-chloro-benzene, total (µg/L)	1,2-Di-chloro-propane, total (µg/L)	1,2-Transdi-chloro-ethene, total (µg/L)	1,3-Di-chloro-propene, total (µg/L)
04-03-89	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200

Date	1,3-Di-chloro-benzene, total (µg/L)	1,4-Di-chloro-benzene, total (µg/L)	2-Chloro-ethyl-vinyl-ether, total (µg/L)	Di-chloro-di-fluoro-methane, total (µg/L)	Trans-1,3-di-chloro-propene, total (µg/L)	Cis 1,3-di-chloro-propene, total (µg/L)	Vinyl chlo-ride, total (µg/L)	Tri-chloro-ethyl-ene, total (µg/L)	Styrene, total (µg/L)	1,2-Dibromo ethane, water whole, total (µg/L)	Xylene, total, water whole, total recover-able (µg/L)
04-03-89	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.200	<0.200	<0.200	<0.200

SUMMARY AND CONCLUSIONS

The basin-fill deposits at the HELSTF site generally consist of clay, silt, and fine- to medium-grained sand. The upper 15 to 20 feet of the subsurface consists of varved gypsiferous clay and silt. These deposits are interpreted to be intertonguing fluvial and lacustrine (playa) deposits from the ancestral Lake Otero. The subsurface lithology at the site, as interpreted from borehole-geophysical logs and drill cuttings, consists of clay units interbedded with silty clay and sandy units. The interbedded clay layers create conditions for perched water tables. Analyses of selected clay samples indicate that the mineralogy of the samples is predominantly kaolinite and mixed-layer illite/smectite.

Three test wells were constructed in the vicinity of the HELSTF site. HELSTF-1 has a well depth 100 feet below land surface and a screened interval 70 to 90 feet below land surface. HELSTF-2 and HELSTF-3 have well depths 520 feet below land surface and screened intervals 80 to 500 feet below land surface. During an aquifer test, HELSTF-3 was pumped and HELSTF-1 and HELSTF-2 were used as observation wells.

The hydraulic characteristics of the saturated sand adjacent to the screened interval in test well HELSTF-2 were interpreted to be representative of a leaky-confined aquifer. The direction of ground-water flow is to the south and southwest and the hydraulic gradient was estimated to be 5.3 feet per mile. Hydraulic properties were estimated by applying the Theis-curve match method to the data collected in test well HELSTF-2. Transmissivity was estimated to be 780 feet squared per day. Storage coefficient was estimated to be 3.1×10^{-3}, and hydraulic conductivity was estimated to be 6.0 feet per day. Estimates of transmissivity, storage coefficient, and hydraulic conductivity derived from analyses of semilogarithmic plots agree with the estimates derived from the log-log plots. Factors that influenced the results of the aquifer test include: (1) interbedded lithology, (2) partial penetration of the production well into the aquifer, (3) incomplete development of the well during the early part of the aquifer test, and (4) turbulent water (cascading) in the well bore.

Water samples collected from the test wells indicate that ground water at the site is brackish to brine and that salinity increases with depth. The predominant cation is sodium throughout the aquifer. Dissolved-solids concentration of water near the top of the aquifer ranges from 5,940 to 11,800 milligrams per liter. The predominant anion is sulfate in the upper part of the aquifer. At 815 feet below land surface the dissolved-solids concentration is approximately 111,000 milligrams per liter. Chloride is the predominant anion with increasing depth and increasing dissolved-solids concentration.

Geohydrologic data compiled and collected during this study include the following: (1) soil type and characteristics, (2) interbedded geologic materials to be expected below the site, (3) potential for the development of perched water conditions because of the thinly bedded clay, silt, and sand, (4) mineralogy of clay samples in the regional aquifer, (5) depth to and estimated hydraulic gradient of the potentiometric surface, (6) water quality that can be expected at the surface and with depth in the regional aquifer, and (7) estimated hydraulic characteristics of the saturated sand interval in the regional aquifer. These data provide a better understanding of the geohydrology of the area and will assist the U.S. Army in planning and decision making related to use, management, and protection of the water resources at the HELSTF site.

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SUPPLEMENTAL DATA

Table 8.--Description of drill cuttings for test well HELSTF-1 (19S.06E.28.221A) [Location shown in figure 4. mm, millimeters; cm, centimeters; color codes are from the Rock Color Chart (National Research Council, 1948)]

Description of drill cuttings	Depth interval below land surface (feet)
Clay, white (N 9) with some silt; predominantly gypsiferous.	0-10
Clay, white (N 9) to light-greenish-gray (5 GY 8/1) with minor silt (gypsiferous); minor amounts of moderate-reddish-brown (10 R 4/6) clay.	10-15
Clay, yellowish-gray (5 Y 8/1) with some silt, minor amounts of moderate-reddish-brown (10 R 4/6) clay and pale-yellowish-green (10 GY 7/2) clay.	15-20
Clay, moderate-brown (5 YR 4/4); some small selenite crystals, approximately 2-3 mm in size.	20-25
Clay, moderate-reddish brown (10 R 4/6) with minor amounts of silt and very fine to fine-grained sand; minor amounts of small selenite crystals.	25-35
Selenite crystals, approximately 80 percent; some moderate-brown (5 YR 4/4) clay and 5 percent or less silt and very fine to fine-grained sand.	35-40
Selenite crystals, approximately 80 percent; some moderate-brown (5 YR 4/4) clay, with minor amounts of silt and fine-grained sand; less than 1 percent sticky, grayish-yellow-green (5 GY 7/2) clay.	40-45
Clay, moderate-brown (5 YR 4/4); with some selenite crystals 3 cm in size; minor amounts of grayish-yellow-green (5 GY 7/2) clay with fine-grained sand.	45-50
Clay, moderate-brown (5 YR 4/4); 10 percent or less sticky, grayish-green (5 G 5/2) clay; minor amounts of selenite crystals.	50-55
Clay, moderate-brown (5 YR 4/4).	55-60
Clay, moderate-brown (5 YR 4/4); with minor amounts of selenite crystals and silt.	60-65
Clay, moderate-brown (5 YR 4/4); with some selenite crystals; less than 2 percent grayish-yellow-green (5 GY 7/2) silty clay.	65-70
Clay, moderate-brown (5 YR 4/4); with some small indurated clasts of pale-yellowish-brown calcareous (10 YR 6/2) clay; some silt.	70-75
Clay, moderate-brown (5YR 4/4); with some very fine grained sand, silt, and some small selenite crystals.	75-80
Clay, moderate-brown (5 YR 4/4); with some small selenite crystals and silt; minor amounts of moderate-reddish-brown (10 R 4/6) clay.	80-85

Table 8.--Description of drill cuttings for test well HELSTF-1 (19S.06E.28.221A)--Concluded

Description of drill cuttings	Depth interval below land surface (feet)
Clay, moderate-brown (5 YR 4/4) and moderate-reddish-brown (10 R 4/6) with some selenite crystals 3 mm in size.	85-95
Clay, moderate-brown (5 YR 4/4) with silt and very fine grained sand; some small selenite crystals; minor amounts of indurated clumps of light-greenish-gray (5 Y 8/1) silt and very fine grained sand; sand is well sorted, subrounded, and composed of 85 percent quartz grains, 15 percent dark lithics.	95-100
Clay, moderate-brown (5 YR 4/4); with some very fine to fine-grained sand; minor amounts of moderate-reddish-brown (10 R 4/6) clay and small selenite crystals.	100-105
Clay, moderate-brown (5 YR 4/4) and moderate-reddish-brown (10 R 4/6); with some fine-grained sand; minor amounts of small selenite crystals and greenish-gray (5 GY 6/1) silt and fine-grained sand.	105-110
Clay, moderate-brown (5 YR 4/4); with silt and very fine to fine-grained sand; minor amounts of moderate-reddish-brown (10 R 4/6) clay with selenite crystals, to 2 cm.	110-115
Clay, moderate-brown (5 YR 4/4); with some silt and small selenite crystals.	115-120
Clay, moderate-brown (5 YR 4/4); with some fine-grained sand; minor amounts of small selenite crystals.	120-125
Clay, moderate-brown (5 YR 4/4); with silt and very fine to fine-grained sand; some small selenite crystals.	125-130

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)
[Location shown in figure 4. cm, centimeters]

Description of drill cuttings	Depth interval below land surface (feet)
Clay, white (N 9) to light-greenish-gray (5 GY 8/1), gypsiferous; minor amounts of light-brown (5 YR 5/6) clay.	0-10
Clay, moderate-brown (5 YR 4/4); with some silt and very fine grained sand; 10 percent selenite crystals (0.5 cm in size); a few indurated white (N 9) gypsum clasts.	10-20
Clay, light-brown (5 YR 5/6) with minor silt; 20-30 percent selenite crystals, some to 1 cm.	20-30
Clay, light-brown (5 YR 5/6); with minor amounts of silt and very fine grained sand; some selenite crystals, indurated gypsum clasts, and minor amounts of light-greenish-gray (5 GY 8/1) clay.	30-40
Clay, light-brown (5 YR 5/6); with minor amounts of silt; 5 percent selenite crystals.	40-50
Clay, light-brown (5 YR 5/6) with some silt and very fine grained sand; 30 percent selenite crystals.	50-60
Clay, light-brown (5 YR 5/6) and some moderate-brown (5 YR 4/4) clay with silt and very fine grained sand; 20 percent greenish-gray (5 GY 6/1) clay; minor amounts of selenite crystals.	60-70
No sample.	70-90
Clay, light-brown (5 YR 5/6) to moderate-brown (5 YR 4/4) with some silt; 5 percent or less greenish-gray (5 GY 6/1) clay; minor indurated white (N 9) gypsum clasts.	90-100
Clay, moderate-brown (5 YR 4/4); with some silt and very fine grained sand.	100-110
Clay, moderate-brown (5 YR 4/4) with some silt and very fine to fine-grained sand; sand is well rounded, well sorted, and composed of approximately 98 percent quartz grains; minor amounts of light-greenish-gray (5 GY 8/1) clay and large (1 cm) selenite crystals.	110-120
Clay, light-brown (5 YR 6/4) with some very fine to fine-grained sand; minor amounts of sticky, grayish-yellow-green (5 GY 7/2) clay with some silt, selenite crystals, and moderate-brown (5 YR 4/4) clay.	120-130
Clay, light-brown (5 YR 6/4) with some silt and very fine grained sand; some moderate-brown (5 YR 4/4) clay; minor amounts of sticky, medium-gray (N 5) clay, light-greenish-gray (5 GY 8/1) silty clay, and selenite crystals.	130-140

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)--Continued

Description of drill cuttings	Depth interval below land surface (feet)
Clay, light-brown (5 YR 6/4) with some silt and very fine to fine-grained sand; approximately 10 percent sticky, greenish-gray (5 G 6/1) clay and light-greenish-gray (5 GY 8/1) silty clay; minor amounts of selenite crystals.	140-150
Clay, light-brown (5 YR 5/6) and moderate-brown (5 YR 4/4) with some silt and very fine grained sand; minor amounts of medium-gray (N 5) clay.	150-160
Clay, light-brown (5 YR 5/6) with some silt and minor amounts of sticky medium-gray (N 5) clay and selenite crystals.	160-180
Clay, light-brown (5 YR 5/6) and moderate-brown (5 YR 4/4) with some silt and very fine grained sand; minor amounts of light-greenish-gray (5 G 8/1) clay and selenite crystals.	180-210
Same as above with some light-greenish-gray (5 GY 8/1) silty clay.	210-220
Clay, moderate-brown (5 YR 4/4) and light-brown and very fine to fine-grained sand; minor amounts of sticky, medium-gray (N 5) clay and greenish-gray (5 G 6/1) clay.	220-230
Clay, light-brown (5 YR 5/6) with silt and very fine to fine-grained sand; minor amounts of light-greenish-gray (5 GY 8/1) silty clay and selenite crystals.	230-240
Clay, moderate-brown (5 YR 4/4) with some silt; silt; minor amounts of sticky, greenish-gray (5 G 6/1) clay and small selenite crystals.	240-250
Clay, light-brown (5 YR 5/6) with some very fine grained sand; minor amounts of large selenite crystals.	250-260
Clay, moderate-brown (5 YR 4/4) and light-brown (5 YR 5/6) with some silt; minor amounts of greenish-gray (5 G 6/1) clay and light-greenish-gray (5 G 8/1) silty clay.	260-280
Clay, light-brown (5 YR 5/6) with some fine- to medium-grained sand; sand consists of approximately 95 percent well-rounded, well-sorted quartz grains; 2 percent dark lithic grains.	280-290
Clay, light-brown (5 YR 5/6) with some silt and very fine grained sand; minor amounts of greenish-gray (5 G 6/1) clay.	290-300
Clay, light-brown (5 YR 5/6) with silt; minor amounts of selenite crystals.	300-310
Clay, light-brown (5 YR 5/6) with some fine- to medium-grained sand; lesser amounts of light-greenish-gray (5 G 8/1) clay and greenish-gray (5 G 6/1) clay.	310-320

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)--Continued

Description of drill cuttings	Depth interval below land surface (feet)
Clay, light-brown (5 YR 5/6) with some silt and fine-grained sand; minor amounts of sticky, light-greenish-gray (5 G 8/1) clay and some small selenite crystals.	320-330
Clay, light-brown (5 YR 5/6) with silt and fine-grained sand; minor amounts of greenish-gray (5 GY 6/1) clay and selenite crystals.	330-340
Clay, light-brown (5 YR 5/6) with some silt; some light-greenish-gray (5 GY 8/1) clay and minor amounts of selenite crystals.	340-360
Clay, light-brown (5 YR 5/6) with fine- to medium-grained sand; sand consists of approximately 95 percent quartz grains; minor amounts of light-greenish-gray (5 GY 8/1) clay and selenite crystals.	360-380
Clay, light-brown (5 YR 5/6), approximately 60 percent; approximately 30 percent medium-gray (N 6) very fine grained sand, minor amounts of light-greenish-gray (5 G 8/1) clay, and selenite crystals.	380-390
Sand, light-gray (N 7), approximately 50 percent, fine- to medium-grained; well sorted and well rounded; composed of approximately 80 percent quartz and 20 percent lithic grains; 40 percent light-brown (5 YR 5/6) clay with minor amounts of light-greenish-gray (5 G 8/1) clay and selenite crystals.	390-400
Sand, light-gray (N 7), very fine to fine-grained, quartz-rich; some light-brown (5 YR 5/6) clay and minor amounts of light-greenish-gray (5 G 8/1) clay.	400-410
Same as above; sand comprises approximately 80-85 percent of the sample.	410-420
Clay, light-brown (5 YR 5/6); sand, very light gray (N 8) and predominantly fine grained.	420-430
Clay, moderate-brown (5 YR 3/4); minor amounts of light-gray (N 7) fine-grained sand, greenish-gray (5 G 6/1) clay, and selenite crystals.	430-440
Clay, moderate-brown (5 YR 3/4) with some greenish-gray (5 GY 6/1) clay; minor amounts of silty, light-brown (5 YR 5/6) clay and selenite crystals.	440-460
Same as above, except more greenish-gray (5 GY 6/1) clay.	460-470
Clay, moderate-brown (5 YR 3/4); some light-brown (5 YR 5/6) clay with lesser amounts of greenish-gray (5 G 6/1) clay.	470-480

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)--Continued

Description of drill cuttings	Depth interval below land surface (feet)
Clay, predominantly moderate-brown (5 YR 4/4), some light-brown (5 YR 6/4) with silt; minor amounts greenish-gray (5 G 6/1) clay and light-gray (N 7) fine- to medium-grained quartz-rich sand.	480-490
Clay, moderate-brown (5 YR 4/4), approximately 50 percent; approximately 30 percent light-greenish-gray (5 G 8/1) fine-grained sand; minor amounts of greenish-gray (5 GY 6/1) clay and a few blades of black (N 1) fissile mudstone (organic rich).	490-500
Clay, light-brown (5 YR 5/6); minor amounts of moderate-brown (5 YR 3/4) clay, light-gray (N 7), very fine to fine-grained sand, and greenish-gray (5 G 6/1) clay.	500-510
Sand, very light gray (N 8), predominantly fine grained; minor amounts of moderate-brown (5 YR 4/4) clay, greenish-gray (5 G 6/1) clay, and black (N 1) fissile mudstone.	510-520
Clay, light-brown (5 YR 5/6); minor amounts of greenish-gray (5 G 6/1) clay and very light gray (N 8) fine-grained quartz-rich sand.	520-530
Clay, moderate-brown (5 YR 3/4) to light-brown (5 YR 5/6); minor amounts of greenish-gray (5 G 6/1) clay and light-gray (N 7), fine-grained quartz-rich sand.	530-540
Clay, moderate-brown (5 YR 4/4); minor amounts of greenish-gray (5 G 6/1) clay and light-gray (N 7) fine-grained sand; very few cuttings coming to the surface (small sample).	540-550
Sand, very light gray (N 8), very fine to fine-grained quartz-rich sand; minor amounts of light-brown (5 YR 5/6) clay and greenish-gray (5 G 6/1) clay.	550-560
Sand, very light gray (N 8) with some silt; lesser amount of light-brown (5 YR 5/6) clay with silt.	560-570
Sand, very light gray (N 8), fine- to medium-grained; composed of approximately 98 percent quartz; some light-brown (5 YR 5/6) clay with silt.	570-580
Clay, very light gray (N 7); fine-grained quartz sand with some silt; minor amounts of light-brown (5 YR 5/6) clay and greenish-gray (5 G 6/1) clay.	580-590
Clay, moderate-brown (5 YR 3/4); fine-grained, very light gray (N 8) sand; minor amounts of greenish-gray (5 G 6/1) clay and selenite crystals (selenite possibly coming from the top of the drill hole).	590-600
Clay, moderate-brown (5 YR 3/4); some very light gray (N 8) sand; very few cuttings (small sample).	600-610

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)--Continued

Description of drill cuttings	Depth interval below land surface (feet)
Clay, moderate-brown (5 YR 3/4) with some greenish-gray (5 GY 6/1) clay; approximately 20 percent silt and very light gray (N 8), very fine to fine-grained quartz-rich sand.	610-620
Clay, moderate-brown (5 YR 4/4) with some light-greenish-gray (5 GY 8/1) clay; minor amounts of very light gray (N 8) sand, very fine to fine grained, moderately sorted, well rounded and composed predominantly of quartz.	620-630
Sand, light-gray (N 7), very fine to fine-grained; some moderate-brown (5 YR 4/4) clay; minor amounts of light-greenish-gray (5 G 8/1) clay and selenite crystals.	630-660
Same as above; very few cuttings coming up to the surface.	660-670
Sand, very light gray (N 8), very fine to fine-grained; some moderate-brown (5 YR 4/4) clay and minor selenite crystals; very few cuttings coming up to the surface (small sample).	670-690
Sand, very light gray (N 7), very fine grained with some silt; moderate-brown (5 YR 4/4) clay with minor amounts of light-greenish-gray (5 G 8/1) clay and selenite crystals.	690-710
Same as above; very few cuttings coming up the borehole.	710-720
Sand, very light gray (N 7), very fine to fine-grained with some silt; some moderate-brown (5 YR 4/4) clay and minor amounts of light-greenish-gray (5 G 8/1) clay.	720-740
Clay, moderate-brown (5 YR 4/4); minor amounts of very light gray (N 7), fine-grained sand and light-greenish-gray (5 G 8/1) clay.	740-750
Clay, light-brown (5 YR 5/6) with minor amounts of moderate-brown (5 YR 4/4) clay, light-greenish-gray (5 G 8/1) clay with silt and selenite crystals.	750-760
Sand, light-gray (N 7), very fine to fine-grained, well-rounded and well-sorted quartz sand; some light-brown (5 YR 5/6) silty clay and moderate-brown (5 YR 4/4) clay; minor amounts of light-greenish-gray (5 G 8/1) clay.	760-780
No sample; lost circulation.	780-790
Clay, moderate-brown (5 YR 4/4) to light-brown (5 YR 5/6); some light-greenish-gray (5 G 8/1) clay; minor amounts of very light gray (N 7), fine- to medium-grained sand.	790-800

Table 9.--Description of drill cuttings for test well HELSTF-2 (19S.06E.21.321)--Concluded

Description of drill cuttings	Depth interval below land surface (feet)
Clay, moderate-brown (5 YR 4/4) to light-brown (5 YR 5/6); some grayish-green (5 G 6/1) clay; minor amounts of very light gray (N 7), fine-to medium-grained sand.	800-810
Clay, light-brown (5 YR 5/6); some light-greenish-gray (5 G 8/1) clay with a few selenite crystals.	810-820
No sample; poor circulation.	820-900
Sand, very light gray (N 7), very fine to medium-grained; some moderate-brown (5 YR 4/4) and light-greenish-gray (5 G 8/1) clay with minor amounts of selenite crystals (poor sample).	900-910
Sand, very light gray (N 7), very fine to fine-grained; some moderate-brown (5 YR 3/4) clay.	910-920
Sand, very light gray (N 7), fine- to medium-grained; sand is well rounded and well sorted, and composed of approximately 95 percent quartz; minor amounts of medium-gray (N 5) clay and moderate-brown (5 YR 4/4) clay.	920-930
Clay, moderate-brown (5 YR 4/4) with some silt; some light-brown (5 YR 5/6) sandy clay; minor amounts of light-greenish-gray (5 G 8/1) clay, light-gray (N 7), very fine grained sand, and selenite crystals.	930-940
Clay, moderate-brown (5 YR 4/4) with some silt; some very light gray (N 8), silty to very fine grained sand; minor amounts of light-greenish-gray (5 G 8/1) clay and selenite crystals; very small (poor) sample.	940-950

Table 10.--Description of drill cuttings for test well HELSTF-3 (19S.06E.21.321A)
[Location shown in figure 4]

Description of drill cuttings	Depth interval below land surface (feet)
Clay, white (N 9), gypsiferous; some silt composed of gypsum.	0-10
Clay, white (N 9), gypsiferous; some light-brown (5 YR 5/6) clay with silt and very fine grained quartz-rich sand; minor amounts of light-greenish-gray (5 G 8/1) silty clay and selenite crystals.	10-20
Selenite crystals, approximately 80 percent; 20 percent moderate-reddish-brown (10 R 4/6) clay with silt and very fine grained quartz-rich sand.	20-30
Selenite crystals, approximately 80 percent; 20 percent light-brown (5 YR 5/6) clay with minor amounts of silt.	30-40
Selenite crystals, approximately 60 percent; 40 percent light-brown (5 YR 5/6) clay with silt and very fine grained quartz-rich sand.	40-50
Clay, light-brown (5 YR 5/6) with silt and very fine grained quartz-rich sand; approximately 30 percent selenite crystals; minor amounts of sticky, medium-gray (N 5) clay.	50-60
Clay, light-brown (5 YR 5/6) with silt; approximately 20 percent selenite crystals; minor amounts of greenish-gray (5 GY 6/1) clay and moderate-brown (5 YR 4/4) clay.	60-80
Clay, light-brown (5 YR 5/6) with silt and very fine grained quartz-rich sand; some selenite crystals; minor amounts of moderate-reddish-brown (10 R 4/6) clay and greenish-gray (5 GY 6/1) clay.	80-90
Same as above except for more selenite.	90-100
Clay, light-brown (5 YR 5/6) with some silt; some selenite; minor amounts of medium-light-gray (N 6) clay, moderate-brown (5 YR 4/4) clay, and moderate-reddish-brown (10 R 4/6) silty clay.	100-110
Clay, light-brown (5 YR 5/6) with silt and very fine to fine-grained quartz-rich sand; greenish-gray (5 GY 6/1) clay with silt and very fine to fine-grained sand; minor amounts of selenite crystals and moderate-brown (5 YR 4/4) clay.	110-120
Clay, light-brown (5 YR 5/6) with silt and very fine grained quartz-rich sand; greenish-gray (5 GY 6/1) clay with silt and fine-grained sand; minor amounts of selenite and moderate-brown (5 YR 4/4) clay.	120-130
Same as above except for slightly more moderate-brown (5 YR 4/4) clay.	130-140

Table 10.--Description of drill cuttings for test well HELSTF-3 (19S.06E.21.321A)--Continued

Description of drill cuttings	Depth interval below land surface (feet)
Clay, light-brown (5 YR 5/6) with some silt and fine-grained sand; approximately 20 percent moderate-brown (5 YR 4/4) clay; minor amounts of light-greenish-gray (5 G 8/1) clay and selenite.	140-160
Clay, light-brown (5 YR 5/6) with some fine- to medium-grained quartz-rich sand; some moderate-brown (5 YR 4/4) clay; minor amounts of selenite crystals.	160-170
Clay, light-brown (5 YR 5/6) with some silt and very fine to fine-grained quartz-rich sand; some moderate-brown (5 YR 4/4) clay; minor amounts of selenite, light-greenish-gray (5 G 8/1) clay with very fine grained quartz-rich sand, and sticky, medium-light-gray (N 6) clay.	170-190
Clay, moderate-brown (5 YR 4/4); some light-brown (5 YR 5/6) clay with silt and very fine grained sand; minor amounts of light-greenish-gray (5 G 8/1) clay and selenite.	190-210
Clay, light-brown (5 YR 5/6) with some silt and very fine to fine-grained sand; sand is well sorted, well rounded, and composed of 95 percent quartz; minor amounts of moderate-brown (5 YR 4/4) clay.	210-220
Clay, light-brown (5 YR 5/6) with some silt and very fine grained sand; moderate-brown (5 YR 4/4) clay.	220-250
Clay, light-brown (5 YR 5/6) with some silt; minor amounts of greenish-gray (5 G 6/1) clay.	250-270
Same as above, except for some moderate-brown (5 YR 4/4) clay.	270-280
Clay, light-brown (5 YR 5/6) with some silt and fine-grained quartz-rich sand; minor amounts of moderate-brown (5 YR 4/4) clay with some silt.	280-290
Clay, light-brown (5 YR 5/6) with some silt and very fine to fine-grained sand; minor amounts of moderate-brown (5 YR 4/4) clay and greenish-gray (5 G 6/1) clay.	290-300
Clay, light-brown (5 YR 5/6) with some silt and very fine to fine-grained quartz-rich sand; moderate-brown (5 YR 4/4) clay; minor amounts of greenish-gray (5 G 6/1) clay.	300-310
Clay, light-brown (5 YR 5/6) with some silt and very fine grained quartz-rich sand; minor amounts of greenish-gray (5 G 6/1) clay.	310-320
Clay, light-brown (5 YR 5/6) with silt and fine-grained quartz-rich sand; some moderate-brown (5 YR 4/4) clay; minor amounts of greenish-gray (5 G 6/1) clay and selenite.	320-330

Table 10.--Description of drill cuttings for test well HELSTF-3 (19S.06E.21.321A)--Concluded

Description of drill cuttings	Depth interval below land surface (feet)
Same as above except for more selenite.	330-340
Clay, light-brown (5 YR 5/6) with some silt; some moderate-brown (5 YR 4/4) clay; minor amounts of selenite crystals and greenish-gray (5 G 6/1) clay with some silt.	340-350
Clay, light-brown (5 YR 5/6) with some silt; some moderate-brown (5 YR 4/4) clay, greenish-gray (5 GY 6/1) clay, and minor amounts of selenite.	350-360
Clay, light-brown (5 YR 5/6) and moderate-brown (5 YR 4/4) clay; some light-greenish-gray (5 G 8/1) clay and selenite; minor amounts of light-gray (N 7), very fine to fine-grained quartz-rich sand.	360-370
Clay, moderate-brown (5 YR 4/4) and greenish-gray (5 G 6/1); some light-brown (5 YR 5/6) clay with silt; minor amounts of selenite crystals.	370-380
Clay, light-brown (5 YR 5/6) with some silt and fine-grained sand; sand is well sorted, well rounded, and quartz rich; some moderate-brown (5 YR 4/4) clay; minor amounts of greenish-gray (5 G 6/1) clay and selenite.	380-390
Same as above except with less of the greenish-gray (5 G 6/1) clay.	390-400
Sand, very light gray (N 8), very fine to fine-grained; sand is well rounded, well sorted, and composed of 95 percent quartz; some light-brown (5 YR 5/6) clay with silt; minor amounts of greenish-gray (5 G 6/1) clay, selenite, and moderate-brown (5 YR 4/4) clay.	400-410
Sand, light-gray (N 7), very fine to fine-grained; sand composition same as above; light-brown (5 YR 5/6) clay with some silt; minor amounts of greenish-gray (5 G 6/1) clay and selenite.	410-430
Sand, light-gray (N 7), very fine to fine-grained; some light-brown (5 YR 5/6) clay; minor amounts of greenish-gray (5 G 6/1) clay and selenite.	430-440
Sand, light-gray (N 7), very fine to fine-grained; some greenish-gray (5 G 6/1) clay with some silt; minor amounts of moderate- brown (5 YR 4/4) clay and selenite.	440-470
Sand, light-gray (N 7), very fine to fine-grained, moderately well sorted and well-rounded; some greenish-gray (5 G 6/1) clay with some silt, and minor amounts of moderate-brown (5 YR 4/4) clay and selenite.	470-480
Same as above except for approximately 5 percent fissile, black (N 1) organic material.	480-500

Table 10.--Description of drill cuttings for test well HELSTF-3 (19S.06E.21.321A)--Concluded

Description of drill cuttings	Depth interval below land surface (feet)
Clay, light-brown (5 YR 5/6); some greenish-gray (5 G 6/1) clay; minor amounts of light-gray (N 7), fine-grained sand, and fissile, black (N 1) organic material.	500-510
Sand, light-gray (N 7), very fine to fine-grained, well-sorted, well-rounded, and quartz-rich; some light-brown (5 YR 5/6) and greenish-gray (5 G 6/1) clay; minor amounts of fissile, black (N 1) organic material and selenite.	510-520
Sand, light-gray (N 7), very fine to fine-grained sand; sand is well sorted, well rounded, and composed of 90 percent quartz and 10 percent lithics; minor amounts of greenish-gray (5 G 6/1) clay with silt, moderate-brown (5 YR 4/4) clay, and selenite.	520-540

*U.S. GOVERNMENT PRINTING OFFICE:1994-576-878/05161