HYDROGEOLOGIC CHARACTERISTICS OF THE LEE ACRES LANDFILL AREA, SAN JUAN COUNTY, NEW MEXICO

By Kathy D. Peter, Robert A. Williams, and Kenneth W. King

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CONVERSION FACTORS

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
square foot	0.09294	square meter
foot per second	0.3048	meter per second
foot per day	0.3048	meter per day
cubic foot per day	0.02832	cubic meter per day
cubic foot per second	0.02832	cubic meter per second
gallon per minute	0.06309	liter per second
meter	3.281	foot
mile	1.609	kilometer
square mile	2.590	square kilometer
micromho per centimeter at 25 °Celsius	1.000	microsiemen per centimeter at 25 °Celsius
millimho per meter	1.000	millisiemen per meter
pound, avoirdupois	453.6	gram

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 "Mean Sea Level of 1929."

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ABSTRACT

Identification of the presence of volatile organic compounds in liquid-waste lagoons at the Lee Acres landfill, beneath a refinery south of the landfill, and in nearby residential wells has led to a hydrologic investigation of the area. The alluvium underlying an arroyo adjacent to the landfill mostly consists of fine to coarse quartz sand with some silt, gravel, and clay zones. Thickness of the alluvium measured in 12 drill holes ranged from 13.7 to 61.5 feet. A seismic survey indicates that buried channels are incised as much as 26 feet into the bedrock surface in some areas. The depth to water in seven piezometers ranged from 26.6 to 34.9 feet. The configuration of the water table in the alluvium indicates that ground-water flow is controlled by unidentified recharge north of the landfill, recharge from a pond southeast of the landfill, discharge to pumping wells, discharge to the alluvium of the San Juan River south of the study area, and hydraulic conductivity of the alluvial material. There also may be additional recharge to or discharge from the underlying Nacimiento Formation and recharge from runoff in the arroyo. Terrain-conductivity measurements indicate that the water in the alluvium southwest of the landfill may be more conductive than water in the underlying sandstone.

INTRODUCTION

Identification of the presence of volatile organic compounds in liquid-waste lagoons at the Lee Acres landfill, in ground water beneath the refinery south of the landfill, and in nearby residential wells (AEPCO, 1986; and McQuillan and Longmire, 1986) has led to a hydrologic investigation of the area to provide information needed to evaluate the hazards posed by the compounds and potential actions. The Lee Acres landfill, now closed, is approximately 6 miles east-southeast of Farmington, New Mexico (fig. 1), on Federal land administered by the U.S. Bureau of Land Management.

Purpose and Scope

The purpose of this investigation is to provide information needed to evaluate the hazards posed by the volatile organic compounds and potential actions. A better understanding of the hydrogeologic conditions of the alluvium underlying the landfill and adjacent areas is needed to design an efficient network of monitoring wells and to quantify ground-water flow in the alluvium. The purpose of this report is to present the results of the investigation and summarize interpretations. The scope of this report is limited to describing the investigation that took place January through March 1987 and presenting the results of water-quality analyses of ground-water samples collected in May 1987 and San Juan River samples collected in October 1987.

Study Area

The Lee Acres landfill is on the east side of an unnamed arroyo. The approximate confluence of the arroyo with the San Juan River is about 1 mile southwest of the landfill. The study area encompasses approximately 0.5 square mile and consists of the arroyo alluvium in the vicinity of the Lee Acres landfill (fig. 1). The northern boundary of the study area is approximately 2,500 feet north of the landfill, upgradient from potential influences of the landfill on ground water in the alluvium. The southern boundary is U.S. Highway 64. South of U.S. Highway 64, the arroyo crosses the flood plain of the San Juan River, and the hydrologic conditions are different than in the arroyo valley. Though it is recognized that further investigation of the San Juan River flood plain would be necessary to fully document the extent and nature of any contamination, the scope of this study was limited to the arroyo valley in order to provide needed information expeditiously.

Acknowledgments

Charles Pettee, U.S. Bureau of Land Management, Santa Fe, New Mexico, assisted in the field work. The adjacent refinery permitted access to their property for the surveys. The Farmington School District permitted installation of well 13 on school district property. James Mason, U.S. Geological Survey, Water Resources Division, was the site hydrologist for the drilling operations.

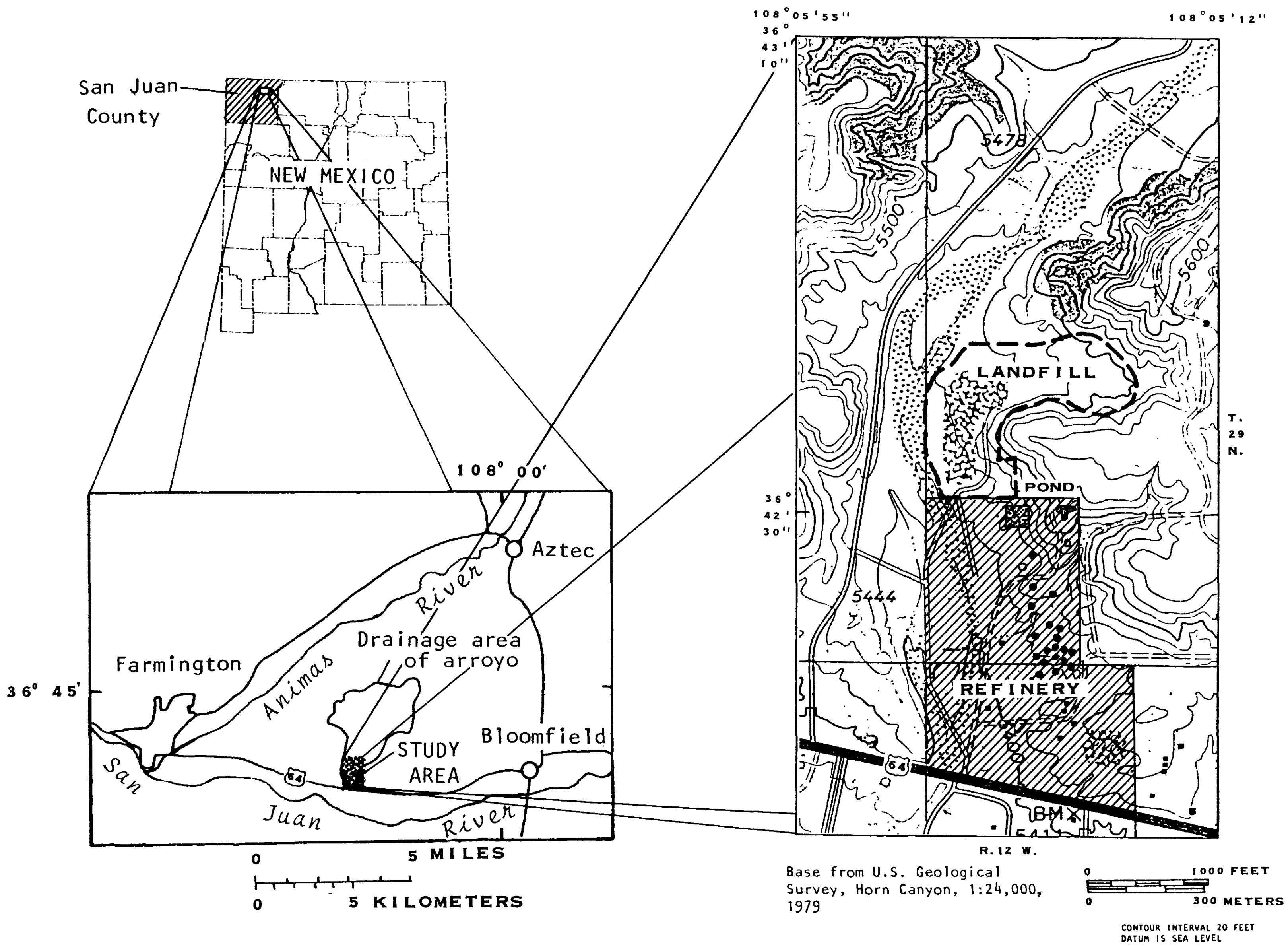


Figure 1.--Location of the study area.

Well-Numbering System

The well-numbering system in this report uses the common subdivision of land into townships, ranges, and sections. In this system, the location number is divided into four segments separated by periods (fig. 2). The first segment indicates the township north of the New Mexico Base Line, and the second denotes the range west of the New Mexico Principal Meridian. The third segment indicates the section within which the well is located. To determine the fourth segment of the location number, the section is divided into quarters numbered 1, 2, 3, and 4 for the NW$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, and SE$\frac{1}{4}$, respectively. The quarter section may be further subdivided in a similar manner. The number of digits in the fourth segment of the location number indicates the degree of accuracy in locating the well. Four digits indicate it can be located within a 2.5-acre tract. If two or more wells are within the same tract, consecutive letters, beginning with A, are added as suffixes to the second and succeeding wells in the same tract.

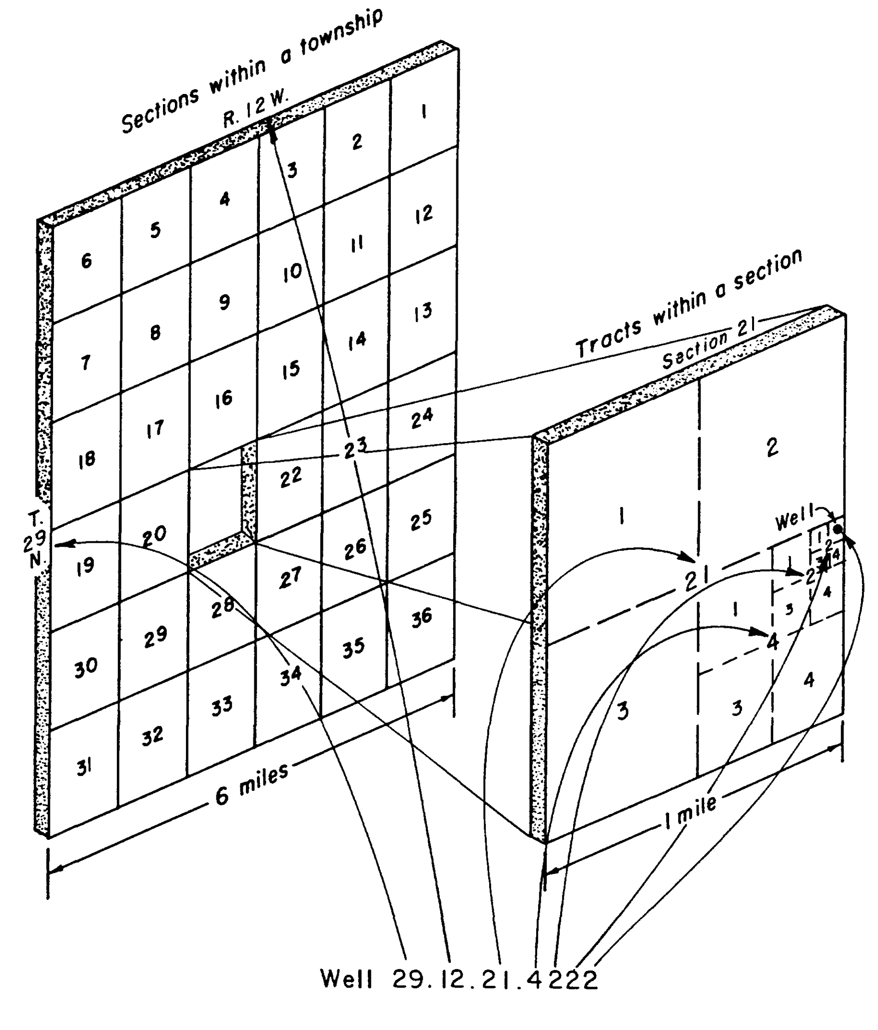


Figure 2.--Well-numbering system.

APPROACH AND METHODS

Three general methods were used to describe the hydrogeology of the alluvium. These were test drilling and installing piezometers, performing seismic-refraction surveys, and performing electromagnetic surveys.

Test Drilling and Piezometer Installation

Twelve holes were drilled in the area near the landfill to provide information on the thickness and lithology of the alluvium (fig. 3 and table 1). A hollowstem auger was used and samples were collected from the returned cuttings, a shelby tube, or a split-spoon sampler. Geologic logs of the holes are provided in table 6. Six samples collected with shelby tubes were analyzed for permeability using a method described by Olsen, Nichols, and Rice (1985); the results are listed in table 4.

Piezometers were installed in seven of the drill holes to monitor water levels (figs. 3 and 4 and table 1). Piezometers were developed by pumping with a submersible pump. A water-table map was prepared using water levels in these piezometers measured on February 13, 1987, and water levels in seven wells on the adjacent refinery property estimated from measurements made in 1986 (table 2).

Seismic-Refraction Survey

A seismic-refraction survey was used to construct depth sections that define the thickness of the alluvium, depth to the water table, shape and depth of the bedrock surface underlying the sediments, and seismic velocities of the layers within the alluvium. The seismic-refraction technique instead of the seismic-reflection technique was used at the site because of (1) the shallow and varying depth to the water table and underlying bedrock, and (2) the need to acquire the data quickly. A drawback of the seismic-refraction method is that it does not detect any sedimentary layer that has a slower seismic velocity than the layer directly above it. This drawback did not appear to create any known problems at the study area because in many locations the refraction interpretation could be correlated with known depths to the water table and bedrock surface determined by drilling.

Two digital seismograph systems were used in this study: a 24-channel system and a 12-channel system. Each system recorded the voltage produced by a single geophone connected to each seismograph channel: 4.5-hertz resonant-frequency geophones for the 24-channel system, 8-hertz geophones for the 12-channel system. The 24-channel system sampled incoming voltage data at 0.5-millisecond intervals and wrote these data to a 0.5-inch magnetic tape for storage. The 12-channel system also sampled at 0.5-millisecond intervals, but did not have any magnetic tape storage capability. Both systems generated real-time paper records of each seismic recording.

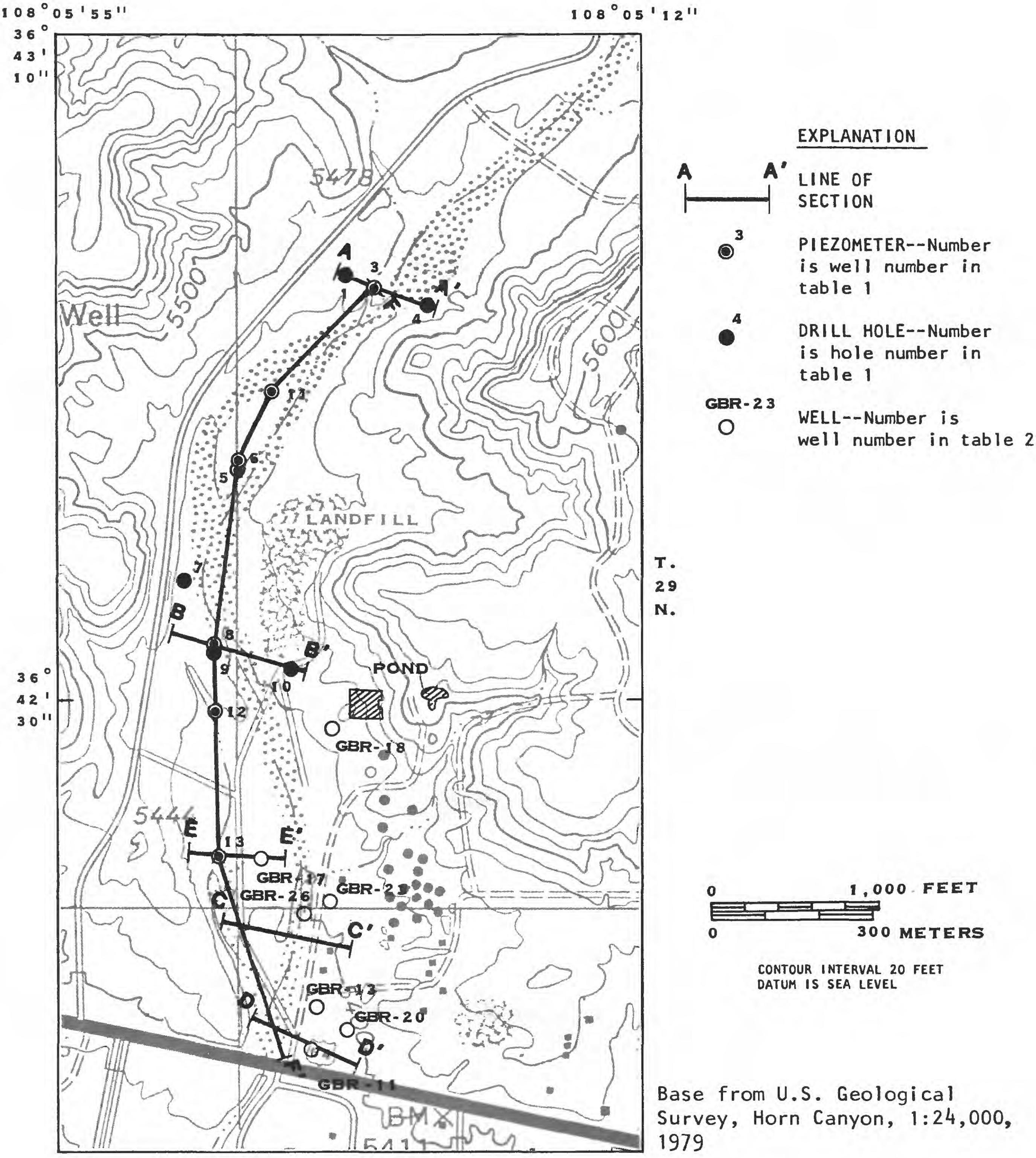


Figure 3.--Location of the drill holes and hydrogeologic sections.

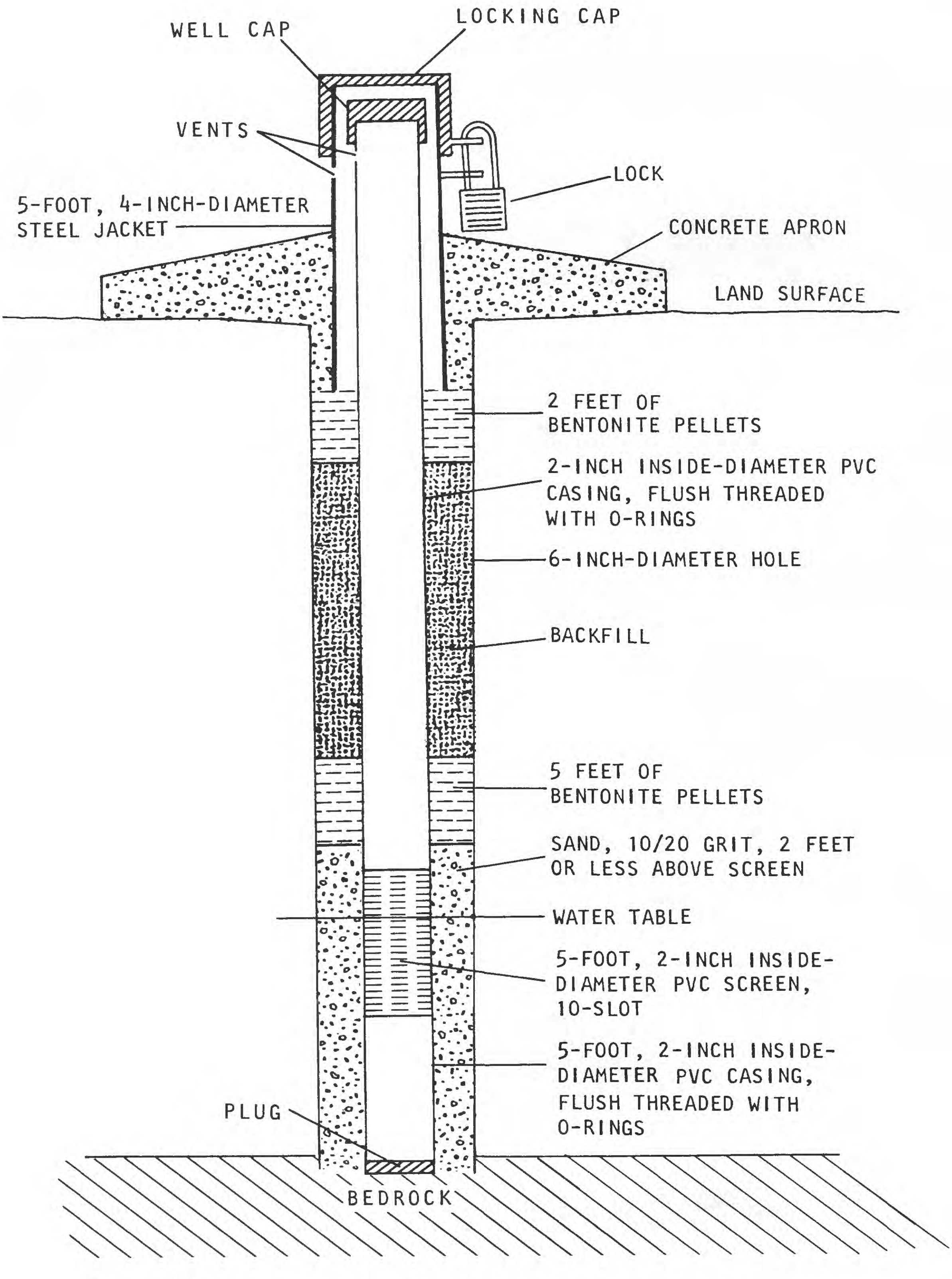


Figure 4.-General construction of piezometers.

Table 1. Description of holes and piezometers installed by the U.S. Geological Survey

[Altitude in feet above sea level; water levels measured February 13, 1987]

Number in fig. 3	Well number	Altitude of measuring point	Hole depth (feet below land surface)	Thickness of alluvium (feet)	Depth to water (feet below measuring point)	Remarks
1	29N.12W.22.1312	5,463.7	31.5	31.5	Dry	Bottomed at sandstone. Plugged and abandoned.
3	29N.12W.22.1321	5,461.8	61.5	61.5	38.3	Cased to 57.3 feet below land surface. Measuring point 3.5 feet above land surface.
4	29N.12W.22.1324	5,458.9	15.2	13.7	Dry	Bottomed in consolidated sandstone. Plugged and abandoned.
5	29N.12W.21.4222A	5,437.6	55.0	45.5	34.5	Bottomed in 9.5 feet of sandy clay. Cased to 54.0 feet below land surface. Measuring point 1.3 feet above land surface.
6	29N.12W.21.4222B	5,437.9	46.5	46.5	34.6	Cased to 43.7 feet below land surface. Measuring point 1.5 feet above land surface.
7	29N.12W.21.4242	5,425.3	20.5	18.0	Dry	Plugged and abandoned.
8	29N.12W.21.4244A	5,421.6	42.5	42.3	33.8	Bottomed in overconsolidated clay. Cased to 42.0 feet below land surface. Measuring point 1.8 feet above land surface.
9	29N.12W.21.4244B	5,419.8	50.5	40.5		Bottomed at sandstone. Plugged.
10	29N.12W.22.3133	5,418.7	19.6	15.5	Dry	Bottomed in silt streaked with red clay.
11	29N.12W.22.1331	5,447.1	52.5	52.0	36.4	Bottomed in overconsolidated clay. Cased to 48.8 feet below land surface. Measuring point 1.5 feet above land surface.
12	29N.12W.21.4422	5,411.0	43.5	40.0	28.0	Bottomed in overconsolidated clay. Cased to 43.0 feet below land surface. Measuring point 1.2 feet above land surface.
13	29N.12W.21.4444	5,402.2	57.0	54.5	29.6	Bottomed in liquid clay-sand mixture above overconsolidated clay. Cased to 32.1 feet, no blank below screen, no sand pack. Measuring point 3.0 feet above land surface.

Table 2. Description of selected wells at the adjacent refinery

[Altitude in feet above sea level. Modified from Geoscience Consultants, Ltd., 1986, p. 9 and 16-18]

Number in fig. 3	Well number	Altitude of land surface	Hole depth (feet below land surface)	Altitude of water level	Screened interval (feet below land surface)	Remarks
GBR-11	29N.12W.27.1132	5,388	55	5,350	40 - 50	Water level is the average of four measurements made in April 1986.
GBR-13	29N.12W.27.1114	5,390	48	5,353	32 - 42	Water level is the average of four measurements made in April 1986.
GBR-17	29N.12W.22.3333	5,401	68	5,368	31 - 51	Water level is the average of four measurements made in May, July, and August 1986.
GBR-18	29N.12W.22.3312	5,420	50	5,407	35 - 45	Water level is the average of two measurements made in April 1986.
GBR-20	29N.12W.27.1141	5,392	48	5,356	27 - 37	Water level is the average of four measurements made in April and May 1986.
GBR-23	29N.12W.22.3334	5,401	48.5	5,378	24 - 34	Water level is the average of five measurements made in April and May 1986.
GBR-26	29N.12W.27.1112	5,394	50	5,363	25 - 35	Water level is the average of five measurements made in April and May 1986.

Ground motion from either a 10-pound sledgehammer striking a heavy steel plate or an explosive charge detonated at the bottom of a 2-foot hole induced voltage generated by the geophones. Several hammerblow signals were electronically summed when noise from automobiles or wind interfered. This procedure enhanced the refracted waves that added constructively in comparison to the irregular noise signals.

The refraction survey consisted of four reverse sections: A-A', B-B', C-C', and D-D' (fig. 3). The survey was performed by dividing each section into several dozen subsections and using two configurations of sources and geophones. The primary data-acquisition mode, called "off-end" configuration, placed the seismic source in line on either end of the linear geophone spread (fig. 5). The secondary mode, called "fan-shot" configuration, placed the seismic source on a line perpendicular to the line of geophones (fig. 5). Four typical off-end field records from this study, one from each of the sections, are shown in figure 6.

Three-dimensional calculations of subsurface dip were made by using cross-spread configurations. In the cross spread, the geophones and seismic source were placed on a line perpendicular to the primary section being surveyed. Four or five cross-spread lines were made for each section. This technique also provided data used to check depth calculations made from the data collected at right angles to the cross spreads.

The geophones were evenly spaced in all sections, though different spacings were used on individual sections. The geophone spacing varied from 2 to 8 feet, depending on the specific target depth; shorter geophone spacing was used for shallow targets. The off-end seismic-source offset also varied, and several reversed seismic recordings were made with the source moved from 50 to 300 feet away from the geophones.

The slope-intercept method of analysis was used on the refraction data. The time of the onset of the first breaks for each channel was identified on a plot of a seismic record (fig. 7). A traveltime graph was produced by plotting the first-break time versus distance (fig. 8). The velocity structure and time intercepts were determined from the traveltime graph, allowing calculations of the thickness and dip for each velocity layer (Mooney, 1977). Calculated thicknesses were for the section beneath the seismic source.

Two common problems encountered in the data-processing stage were: (1) separation of arrivals of the 4- to 6-inch-thick frozen ground-surface layer from those of the underlying unfrozen ground in section C-C', and (2) difficulty in recognizing hidden layers. Arrivals from the frozen layer are not difficult to identify because they characteristically have anomalously short arrival times, which is fast velocity, compared to the unfrozen ground. The energy from the frozen layer, however, obscures some arrivals that immediately follow, thereby introducing error in calculating the velocity of the unfrozen layer. As the field work progressed, increasing temperatures melted the frozen layer and the problem was alleviated. The hidden layer problem was more pervasive. The drill-hole data show several thin layers that are seismically expressed as arrivals after the first breaks. Each record was examined for arrivals after the first breaks that might represent a hidden layer; when identified, these later arrivals were incorporated into the analysis to achieve a better depth model.

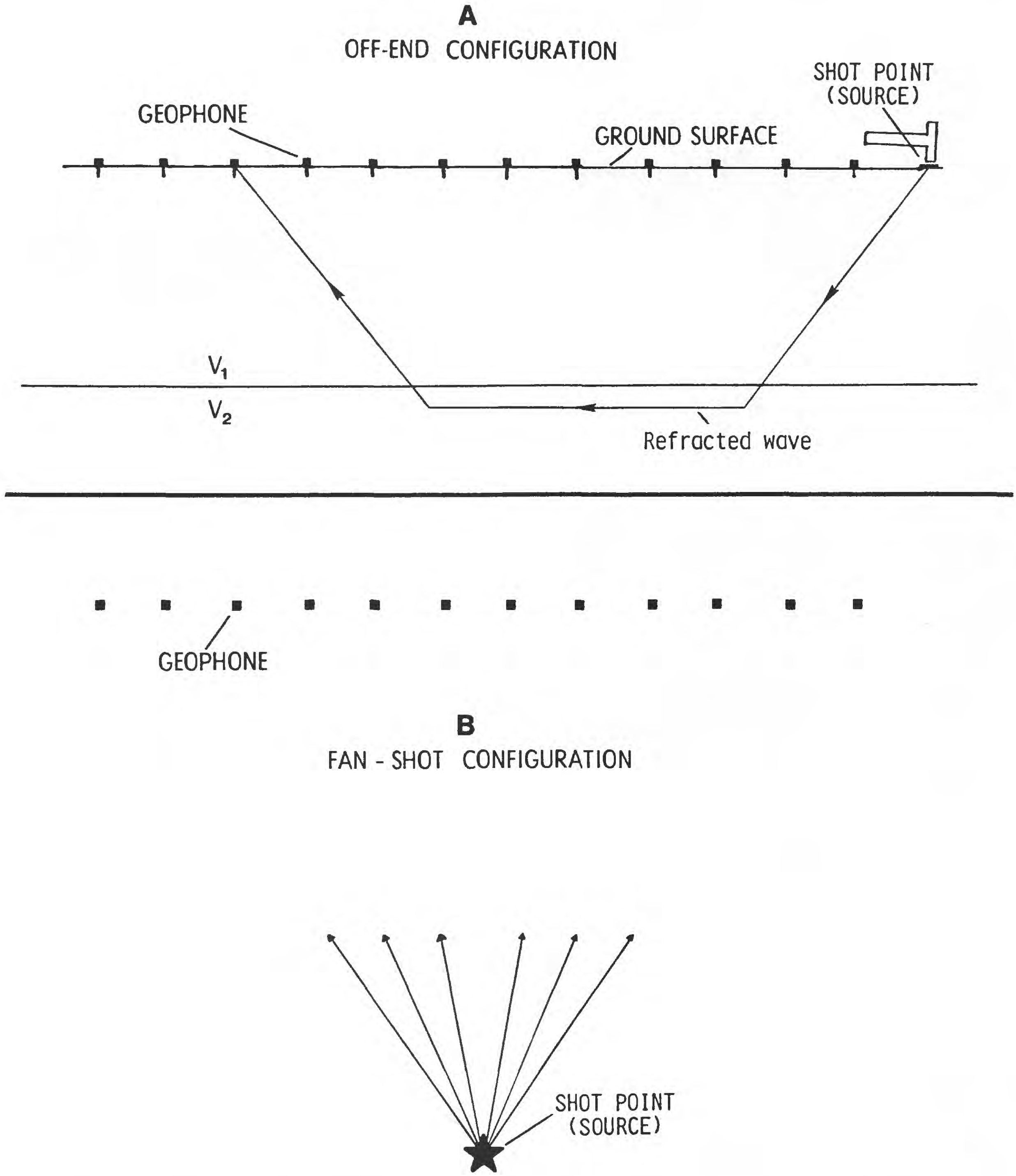


Figure 5.--Off-end and fan-shot source-geophone configurations used during acquisition of the refraction data.

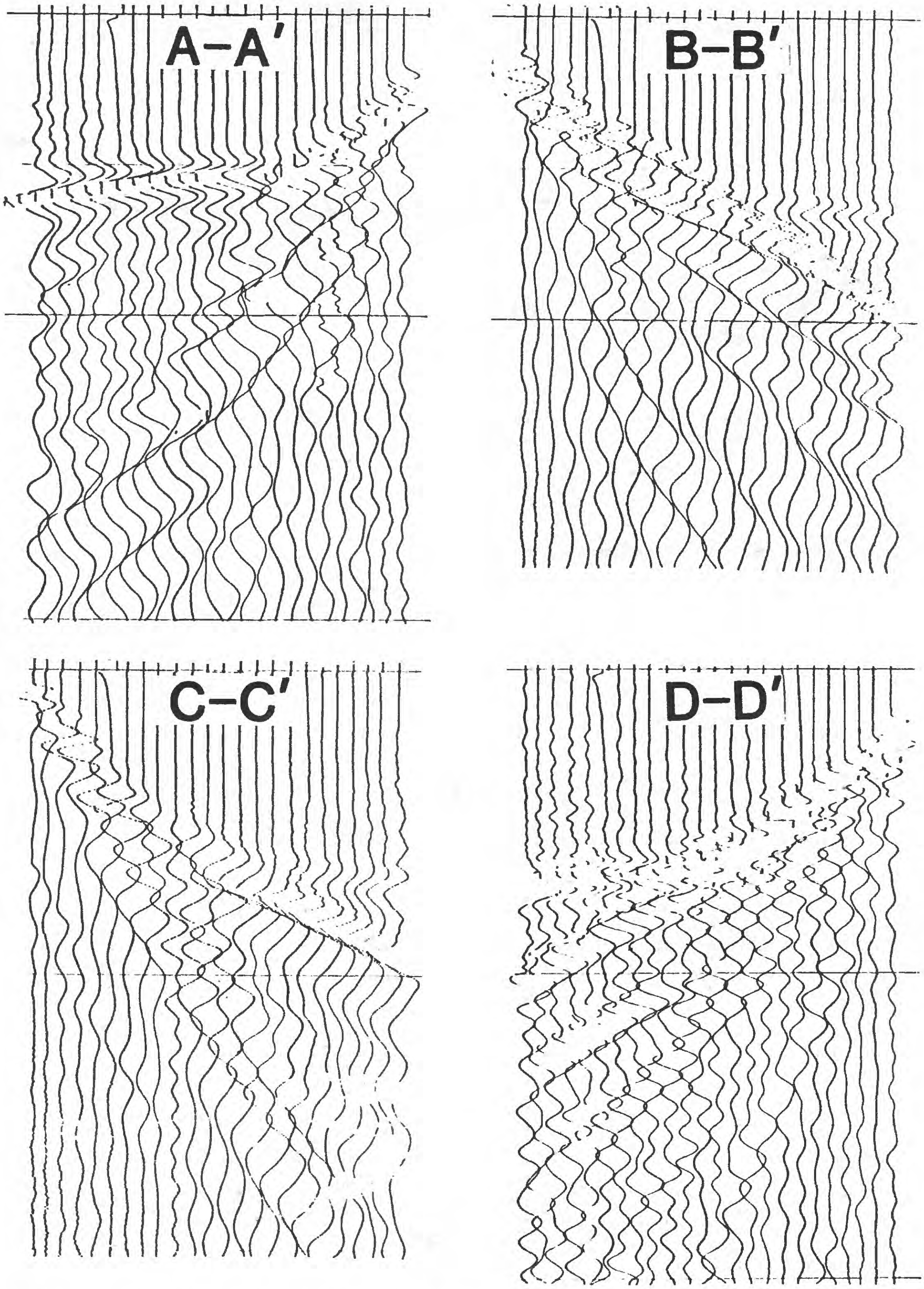


Figure 6.--Four typical unprocessed field records from sections A-A' through D-D'.

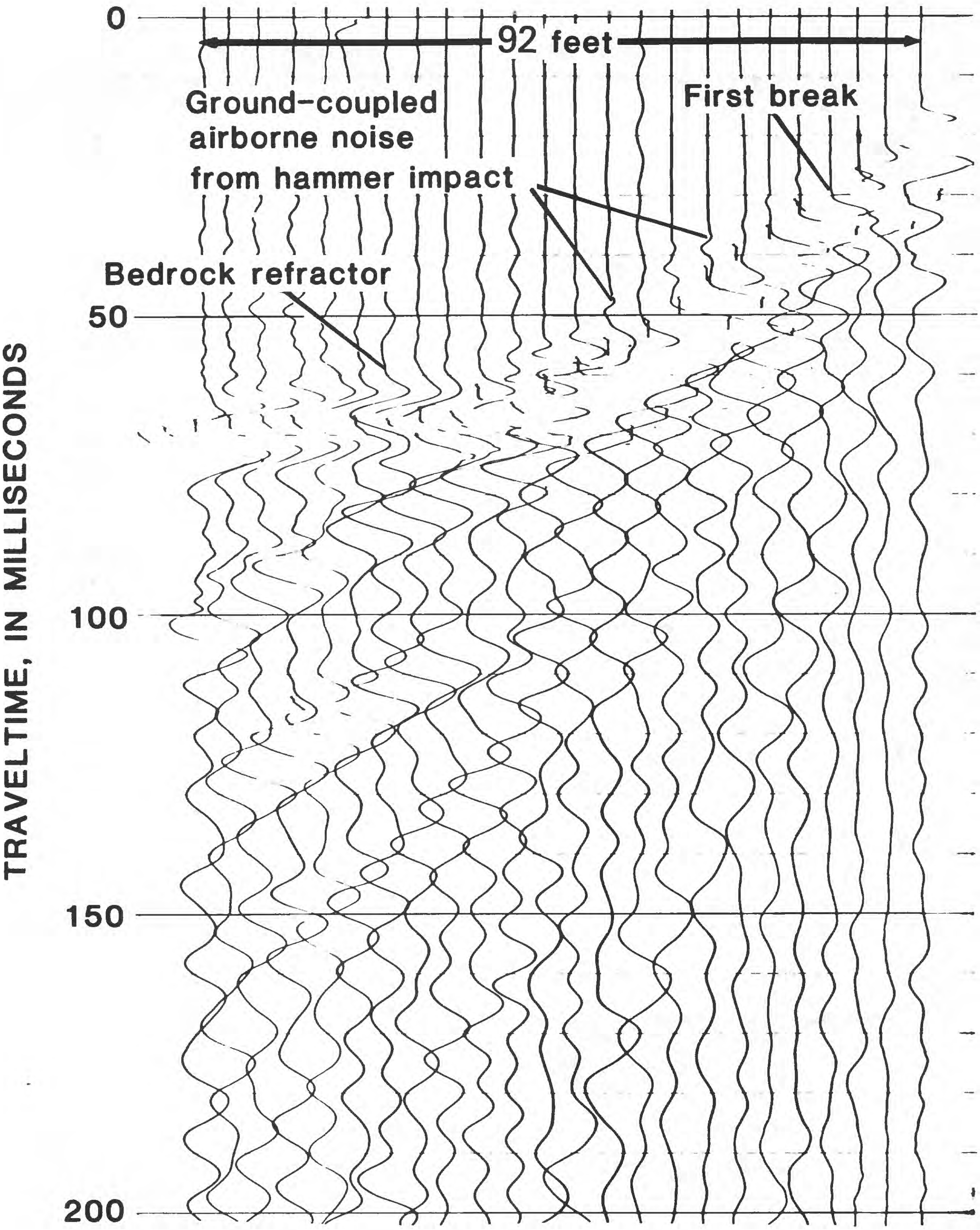


Figure 7.--Example of a field record that was used to pick the refraction arrivals.

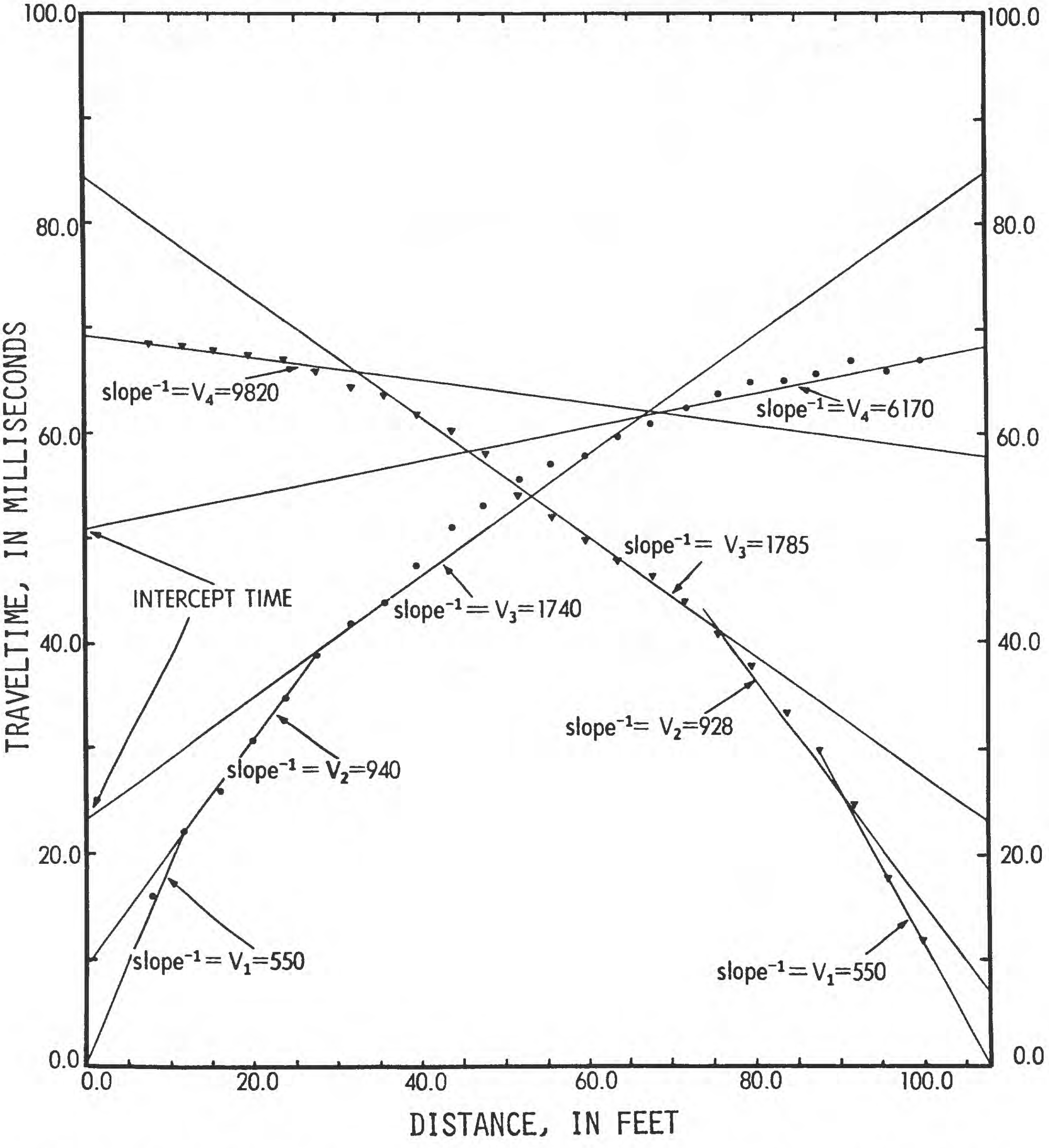


Figure 8.--A traveltime graph for a reversed survey from section A-A' showing a four-layer case. The layer velocity, in feet per second, is derived from the inverse of the slope of a line drawn through the points.

GEOLOGY

The Quaternary deposits in the study area are colluvium on and near the slopes and alluvium in the valley of the arroyo (fig. 9). Capping the ridges and mixed with the colluvium are rounded cobbles and boulders that appear to be remnants of terrace deposits, probably from the San Juan River. Underlying the colluvium and alluvium is the Nacimiento Formation of Tertiary age (Stone and others, 1983, fig. 17 on sheet 5).

The Nacimiento Formation crops out on the ridges bounding the study area (fig. 9). The lower part of the Nacimiento Formation consists of interbedded black, carbonaceous mudstones and white, coarse-grained sandstones; the upper part consists of somber beds of mudstone and sandstone. The sandstones are medium to very coarse grained, immature to submature arkose, and the mudstones display the popcorn weathering characteristic of swelling clays (Stone and others, 1983, p. 30). The Nacimiento Formation is underlain at an unknown depth by the Ojo Alamo Sandstone of Tertiary age, a sequence of sandstones, conglomeratic sandstones, and shales that crops out about 1 mile west of the study area (Stone and others, 1983, p. 31 and sheet 1). The Nacimiento and Ojo Alamo intertongue (Baltz and others, 1966, p. D15).

Alluvium Thickness and Bedrock Contact

The thickness of the alluvium measured in the 12 drill holes ranged from 13.7 to 61.5 feet (fig. 9 and tables 1 and 6) (table 6 is in "Supplemental Information"). The alluvium is thinnest at the foot of the slopes where it interfingers with colluvium. It is thickest near, but not always beneath, the active channel of the arroyo. Along section A-A' (fig. 10), the alluvium is thickest in the vicinity of well 3. The seismic survey shows a buried channel incised about 26 feet into the bedrock surface. This channel apparently opens out southward because it is not present at section B-B' (fig. 11). There is a shallow channel less than 8 feet deep incised in bedrock on the west side of section C-C' (fig. 12). Two buried channels are incised 8 to 10 feet into the bedrock on the west side of section D-D' (fig. 13).

The lithology and consolidation of the bedrock in contact with the alluvium vary areally because the Nacimiento is layered and because the erosional surface of the bedrock is irregular. Drill holes 1, 3, 4, and 7 bottomed at a sandstone (tables 1 and 6). Drill holes 5, 8, 10, 11, 12, and 13 bottomed in clay or sandy clay. Drill hole 9 bottomed at a consolidated sandstone beneath the tight, overconsolidated clay at the bottom of drill hole 8, located 10 feet north of 9. Drill hole 13 bottomed at a tight clay beneath a fluid sandy clay.

Electromagnetic Survey

An electromagnetic survey was used to identify anomalously large values of terrain conductivity that might represent zones of contaminated ground water (McNeill, 1980 and 1985). The specific conductivity of water in lagoons in the landfill, which probably had a large concentration of chloride, was reported to be 13,500 microsiemens per centimeter at 25 °Celsius (AEPCO, 1986, p. 4-5). If this saline water from the lagoons is present in the alluvium, it might be detected by changes in the terrain conductivity. Four sections, A-A', B-B', E-E', and F-F', having a total length of approximately 5,000 feet, were surveyed (fig. 3). Two sections (A-A' and B-B') also were surveyed using seismic refraction. All the sections intercepted drill holes for control.

As many as six combinations of dipole orientation and intercoil spacing were used on individual sections in order to identify layers of differing terrain conductivity. The relative response (or proportion of measured conductivity) using a vertical dipole is zero for near-surface materials, increases to a maximum at a depth of about four-tenths of the intercoil spacing, and then decreases with depth (McNeill, 1980, p. 7). The response using a horizontal dipole is greatest for near-surface materials and decreases with depth. Both dipoles were used on sections B-B' and E-E'. A horizontal dipole was used on sections A-A' and F-F'. Spacings of 10, 20, and 40 meters were used on sections A-A', B-B', and E-E'. Spacings of 20 and 40 meters were used on section F-F'.

A technique described by McNeill (1985) was used to reduce the sensitivity to near-surface material of the measurements made using a horizontal dipole. For every measurement station, two adjusted values were calculated:

$$\text{sigma10} = (2 \times \text{sigmaH20}) - \text{sigmaH10, and} \qquad (1)$$
$$\text{sigma20} = (2 \times \text{sigmaH40}) - \text{sigmaH20}$$

where

sigmaH10, sigmaH20, and sigmaH40 are the terrain conductivity measured with a horizontal dipole at spacings of 10, 20, and 40 meters, respectively, in millisiemens per meter.

The adjusted values, sigma10 and sigma20, have a maximum relative response at one-quarter of the larger of the intercoil spacings, or 5 meters for sigma10 and 10 meters for sigma20.

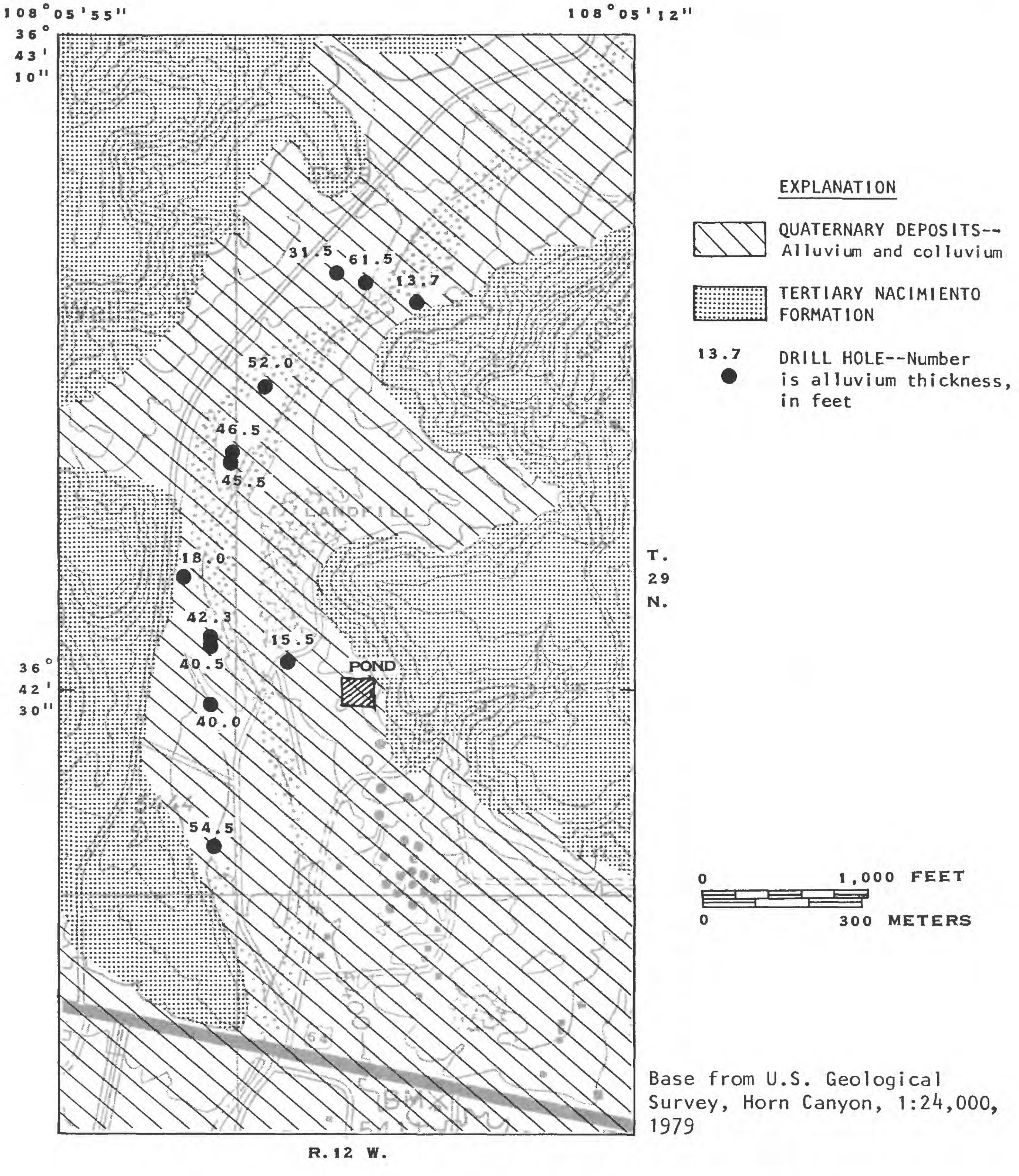


Figure 9.--Extent and thickness of Quaternary deposits.

Seismic velocity in the bedrock generally is slower on the eastern side of the alluvium than elsewhere, which may indicate that the bedrock is more weathered on the east. In drill hole 4, on the east side of section A-A' (fig. 10), the top of the bedrock consists of weathered sandstone that is increasingly consolidated with depth. The contact with the alluvium was not identifiable from the cuttings. Along section B-B', the seismic velocity in the bedrock beneath drill hole 9 is 10,000 feet per second, whereas beneath drill hole 10, the velocity is 7,700 feet per second (fig. 11). The slower velocity indicates that a weathered sandstone similar to that found in drill hole 4 may be beneath the tight clay at the bottom of drill hole 10.

A buried weathered zone in the bedrock on the east side of the arroyo may be related to the erosional plateaus on that side. The west side of the buried bedrock valley is steeper and may not be as deeply weathered. The nature of the bedrock surface on the east side is significant to further investigations because the permeability of weathered sandstone is larger than that of consolidated sandstone. The hydrologic continuity of the weathered sandstone with the consolidated sandstone and the alluvium, which may be locally separated from it by a clay layer, and the potential of the weathered sandstone to transport contaminated water are unknown.

Description of Alluvium

The alluvium mostly consists of fine to coarse quartz sand with some silt. There also are gravel and clay zones that generally are less than 1 foot thick (table 6). The seismic-refraction survey of sections A-A', B-B', C-C', and D-D' (figs. 10-13) showed that generally there are three layers of alluvium. These layers, defined by seismic velocity, appear to represent the degree of consolidation and saturation. The shallowest layer, which probably consists of loose, dry sand, is less than 10 feet thick and has a slow seismic velocity of 600 to 1,000 feet per second. Beneath this layer is a 10- to 20-foot-thick layer that has a seismic velocity of 1,500 to 2,500 feet per second. This layer may represent more consolidated sand, possibly with interstitial water near its base. Typically, this layer is underlain by a saturated zone that has a velocity of 5,500 to 6,000 feet per second. The top of this zone would approximate the water table.

The terrain-conductivity measurements also show, although less clearly, layering in the alluvium. The terrain conductivity generally was smallest in the shallowest material (figs. 10, 11, and 14), as measured with the 10-meter intercoil spacing and horizontal dipole. The terrain conductivity of the shallow material on the east end of section B-B' may be greater because of shallow bedrock and metal in the landfill. The terrain conductivity of the deepest material generally was largest in areas not suspected of containing contamination, as measured by the 40-meter intercoil spacing and horizontal dipole (figs. 10 and 15).

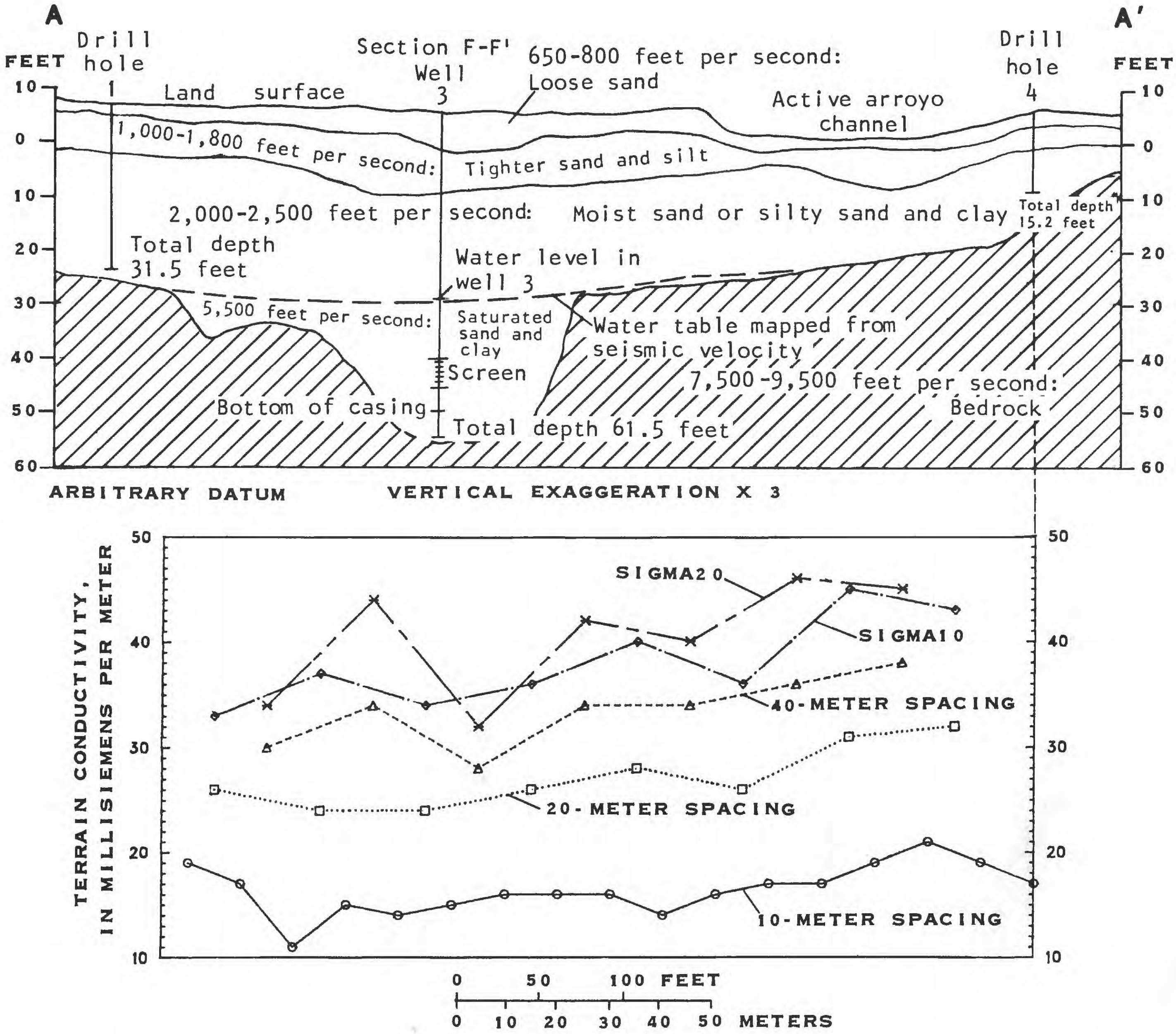
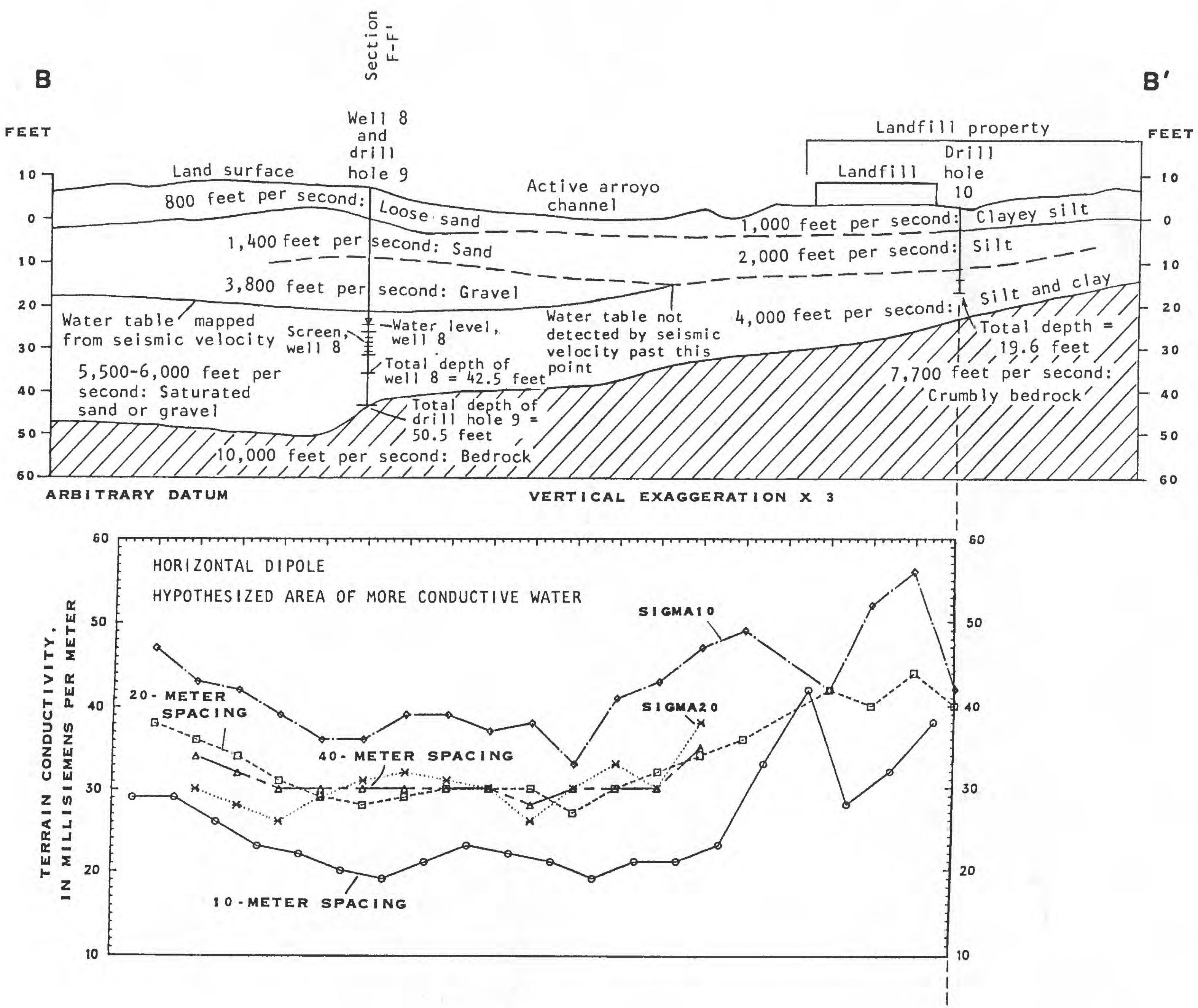


Figure 10.--Generalized hydrogeologic section A-A' and terrain conductivity along line of section.



B
B'
Section F-F'
FEET
Well 8 and drill hole 9
Landfill property
Landfill
Drill hole 10
Land surface
Active arroyo channel
800 feet per second: Loose sand
1,000 feet per second: Clayey silt
1,400 feet per second: Sand
2,000 feet per second: Silt
3,800 feet per second: Gravel
4,000 feet per second: Silt and clay
Water table mapped from seismic velocity
Screen, well 8
Water level, well 8
Total depth of well 8 = 42.5 feet
Water table not detected by seismic velocity past this point
Total depth = 19.6 feet
5,500-6,000 feet per second: Saturated sand or gravel
Total depth of drill hole 9 = 50.5 feet
7,700 feet per second: Crumbly bedrock
10,000 feet per second: Bedrock
ARBITRARY DATUM
VERTICAL EXAGGERATION X 3
HORIZONTAL DIPOLE
HYPOTHESIZED AREA OF MORE CONDUCTIVE WATER
SIGMA10
SIGMA20
20-METER SPACING
40-METER SPACING
10-METER SPACING
TERRAIN CONDUCTIVITY, IN MILLISIEMENS PER METER

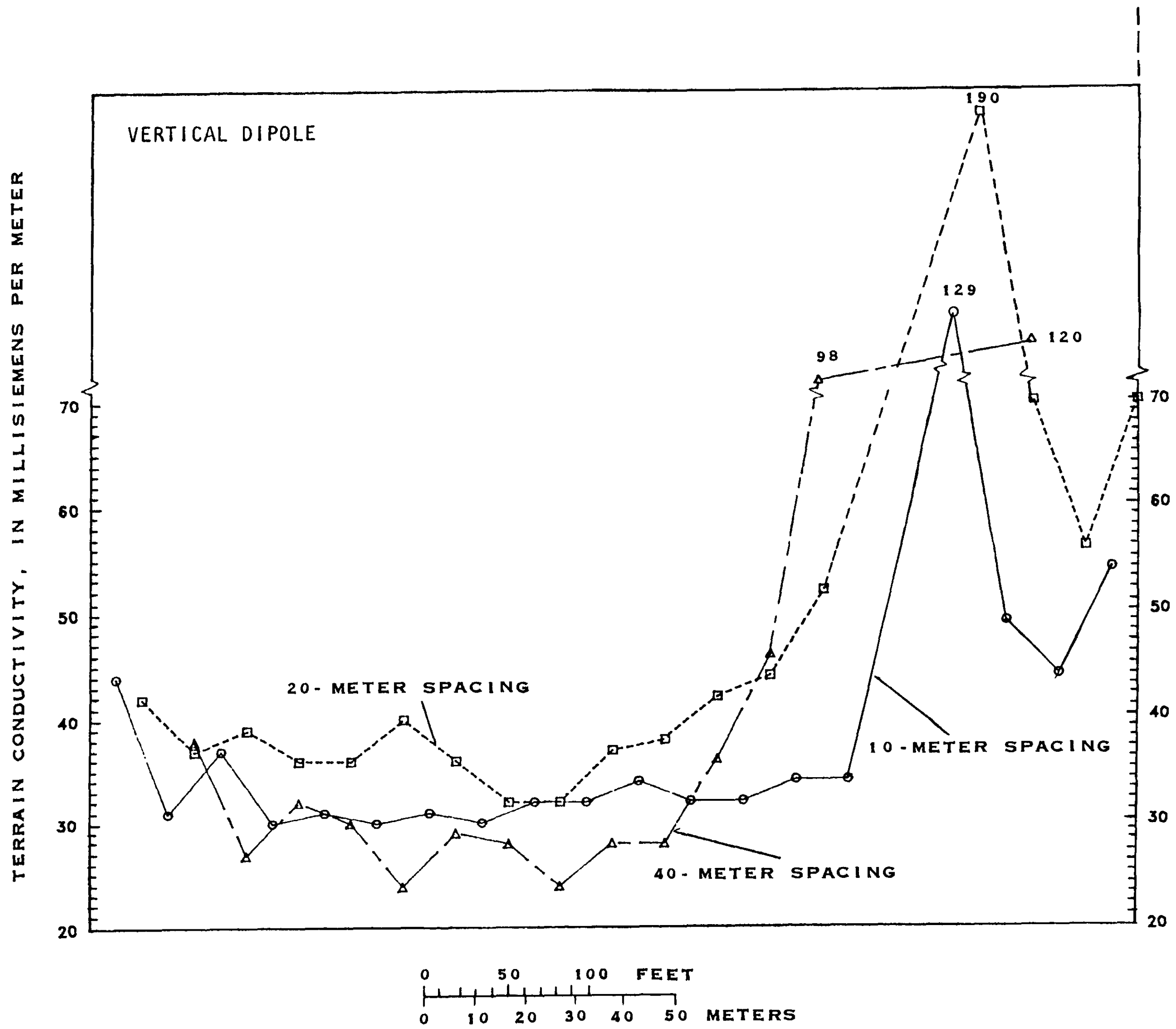


Figure 11.--Generalized hydrogeologic section B-B' and terrain conductivity along line of section.

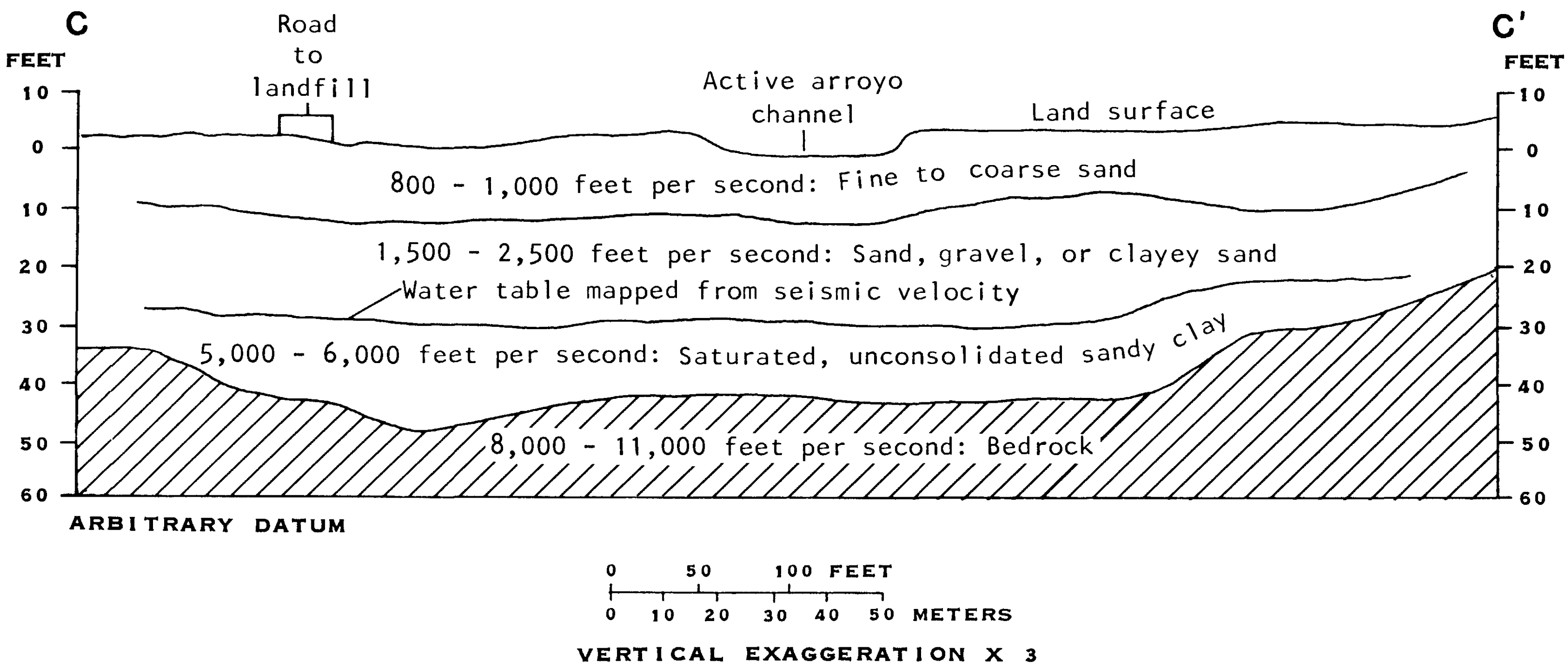


Figure 12.--Generalized hydrogeologic section C-C'.

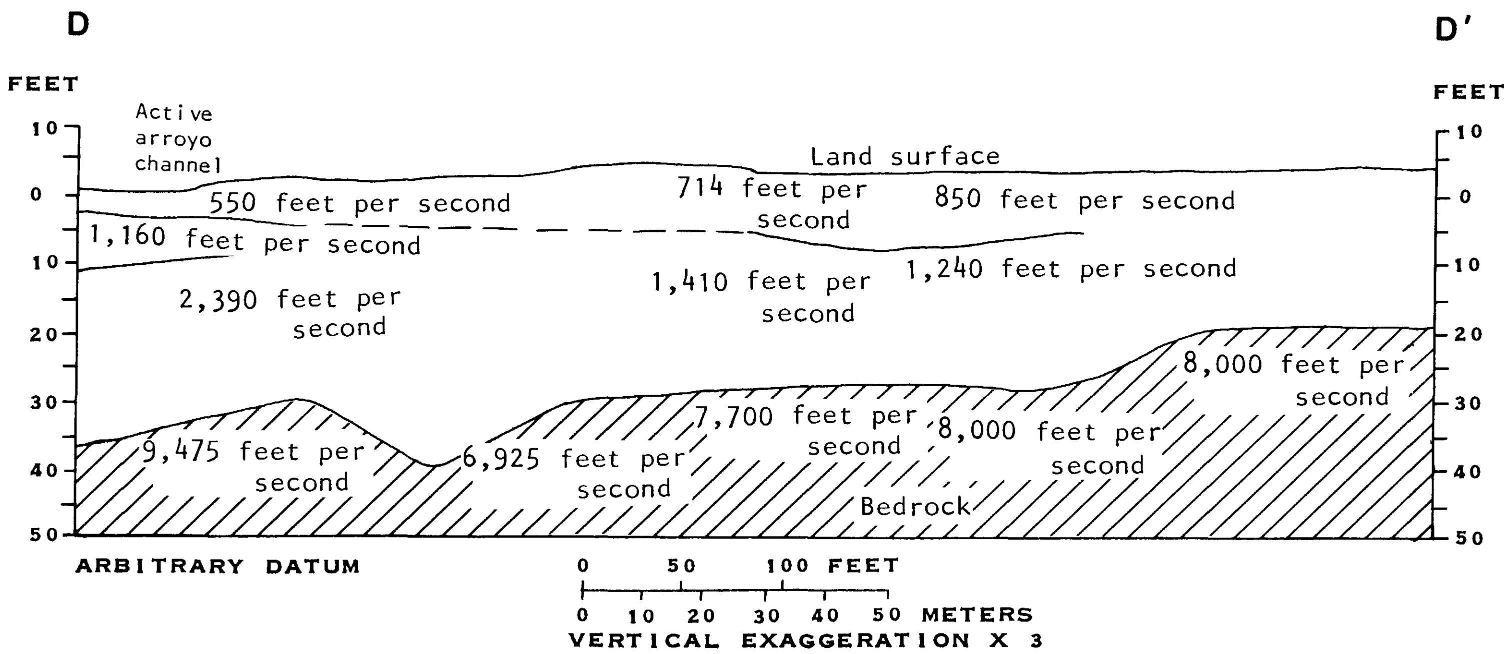


Figure 13.--Generalized hydrogeologic section D-D'.

HYDROLOGY

The water table in the arroyo is shallow; depth to water in the seven piezometers ranged from 26.6 to 34.9 feet below land surface on February 13, 1987 (table 1). The configuration of the water table in the alluvium (fig. 16) indicates ground-water flow is controlled by: (1) unidentified recharge north of the landfill, (2) recharge from a pond southeast of the landfill, (3) discharge to pumping wells on the adjacent refinery property, (4) discharge to the alluvium deposited by and hydraulically connected to the San Juan River south of U.S. Highway 64, and (5) hydraulic conductivity of the alluvial material. In addition, there may be recharge to or discharge from the Nacimiento Formation and recharge from runoff in the arroyo. Information on the fluctuations of the water table is insufficient to evaluate seasonal effects.

Water-Table Configuration in the Alluvium

The results of the test drilling program and the seismic surveys showed that the alluvium north of well 8 is saturated with water near the center of the arroyo valley, where the alluvium is the thickest (fig. 16). South of well 8, the saturated area is wider, in part because of the greater width of the valley and in part because of recharge from the pond southeast of the landfill.

North of well 8, ground-water flow generally is southward (fig. 16), and the hydraulic gradient is about 0.01 foot per foot. At section A-A' (fig. 10), the saturated alluvium is almost entirely within the incised channel. At section B-B' (fig. 11), no deeply incised channel occurs in the bedrock, and the saturated part of the alluvium is wider than at section A-A'. The eastern boundary of the saturated alluvium at section B-B' appears to be controlled by a relatively impermeable zone that extends from about halfway between holes 9 and 10 to the eastern end of the section. Information is insufficient to describe more accurately the change in the extent of the saturated alluvium between sections A-A' and B-B'.

As evidenced by water-level measurements in wells, particularly in GBR-18, and the increased vegetation and salt deposits downslope from the pond, the pond southeast of the landfill leaks water to the alluvium. Recharge from this pond has created a water-table mound beneath it (fig. 16). Though this mound may extend to the vicinity of well 8, explaining the wider saturated zone at section B-B', its area of influence appears to be mainly south and southwest, in part because of the relatively impermeable zone penetrated by hole 10. It is not known if this mound is reflected in the potentiometric surface in the Nacimiento as a result of downward leakage.

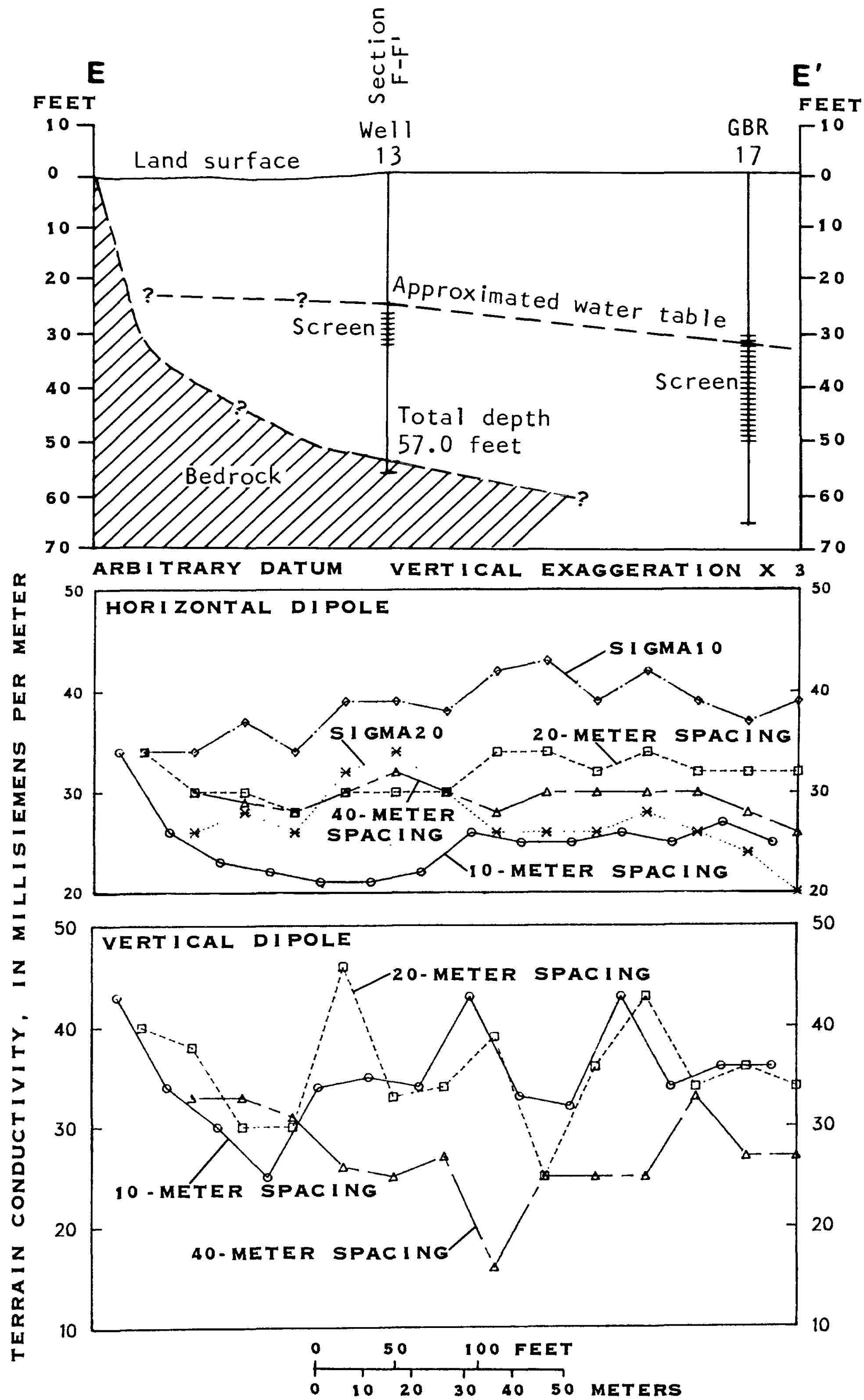


Figure 14.--Generalized hydrogeologic section E-E' and terrain conductivity along line of section.

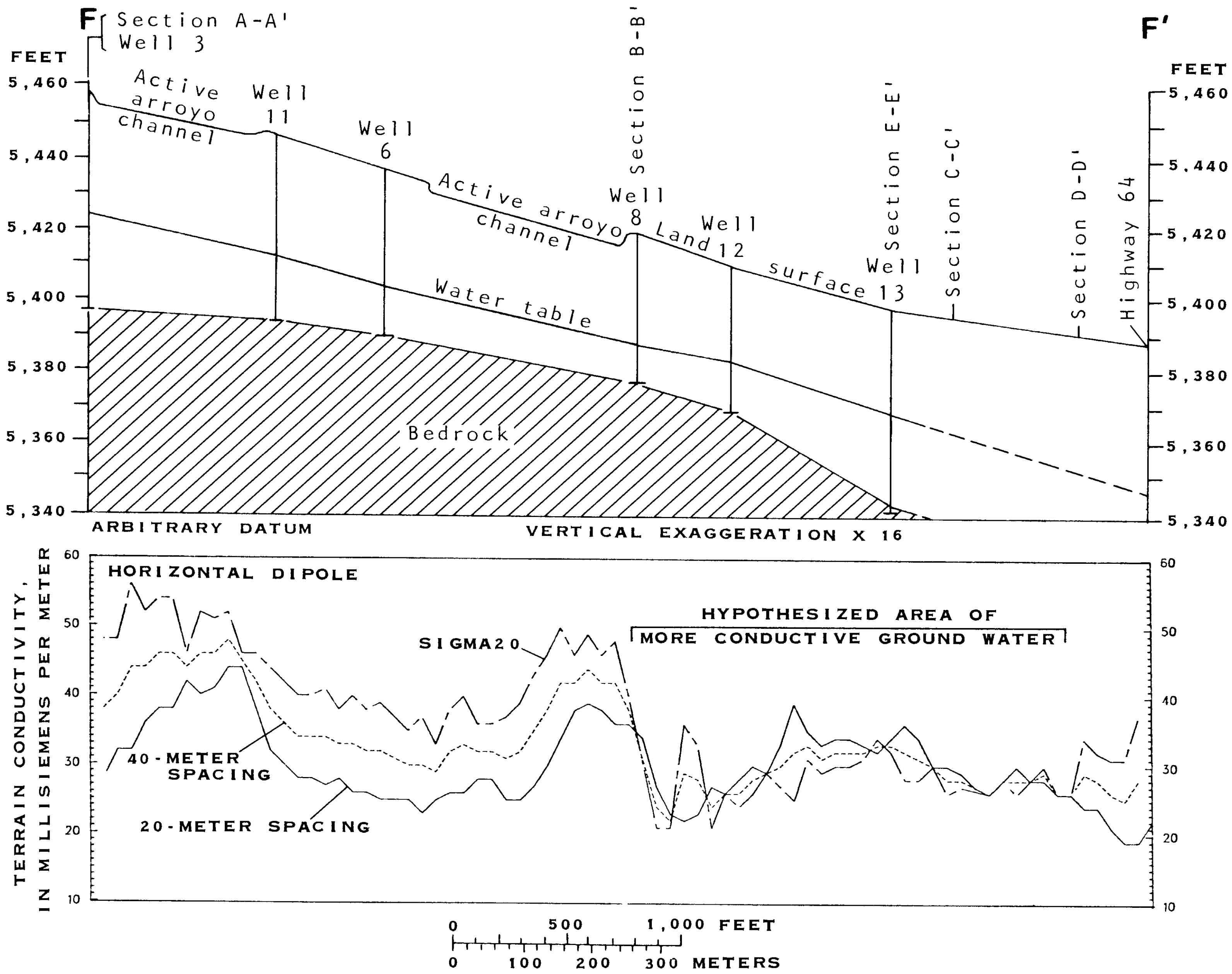
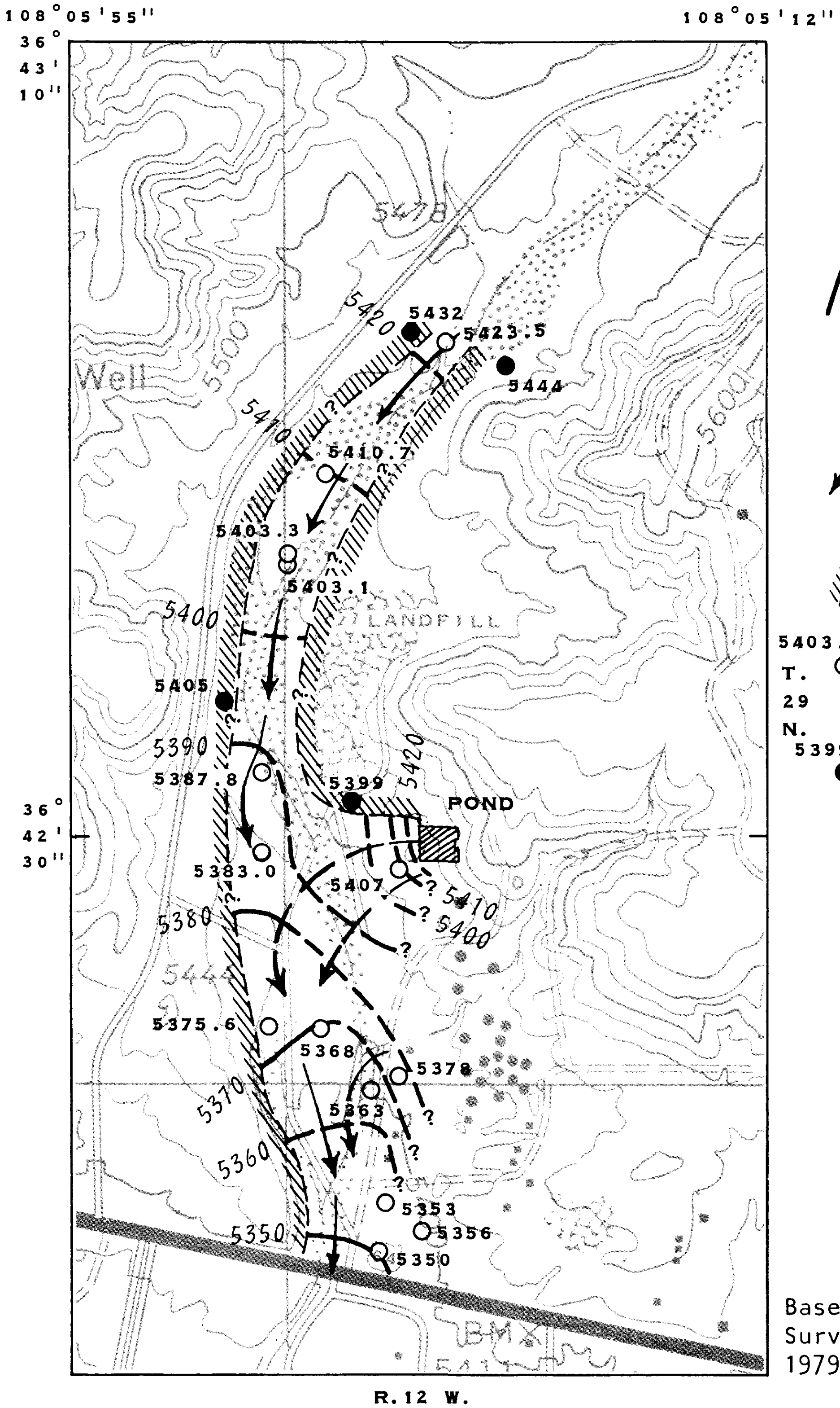


Figure 15.--Generalized hydrogeologic section F-F' and terrain conductivity along line of section.



EXPLANATION

WATER-TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet. Dashed where approximately located

DIRECTION OF GROUND-WATER FLOW--Dashed where approximately located

BOUNDARY OF SATURATED ALLUVIUM--Queried where approximately located

5403.1 ○ PIEZOMETER OR WELL--Number is altitude of water level, in feet above sea level

5399 ● DRY DRILL HOLE--Number is altitude of the bottom of hole, in feet above sea level

0 — 1,000 FEET

0 — 300 METERS

CONTOUR INTERVAL 20 FEET
DATUM IS SEA LEVEL

Base from U.S. Geological Survey, Horn Canyon, 1:24,000, 1979

Figure 16.--Water table and extent of the saturated alluvium, February 13, 1987.

Water from the mound generally flows west and southwest (fig. 16) toward the buried channels identified in sections C-C' and D-D' (figs. 12 and 13), where the saturated thickness of the alluvium is greater and therefore more transmissive. On the western side of the valley, flow generally is southward (fig. 16) toward the confluence with the alluvium of the San Juan River. The gradient is steepest, exceeding 0.06 foot per foot, near the pond. Accurate measurement of the water-table gradient is not possible using the estimated water levels south of well 8, but the gradient is estimated to be approximately 0.02 to 0.05 foot per foot.

The adjacent refinery is pumping ground water and floating hydrocarbon product from beneath its property as part of a containment and recovery program (R.L. McClenahan, Jr., Giant Industries, oral commun., 1987). The effect of pumping on the water table has not been measured, but the water table shown in figure 16 probably will change in response to this discharge.

Recharge and Discharge

Recharge to the alluvium comes from several sources, some of which are suspected but not confirmed. These sources are: direct infiltration of precipitation, infiltration of runoff in the arroyo, leakage from manmade ponds, and leakage from the Nacimiento Formation.

Normal annual precipitation in northwestern New Mexico is about 8 inches (Soil Conservation Service, 1972). However, the amount of precipitation that percolates through contaminated soil at the landfill and its effect on the quality of water in the alluvium are unknown. Infiltration of ephemeral flow in the arroyo recharges the alluvium for brief periods. No streamflow measurements exist, but estimates of runoff made using the drainage area of the arroyo upstream from its intersection with U.S. Highway 64 and regression equations developed by Waltemeyer (1986) indicate that given the large error of the estimate, runoff exceeding 200 cubic feet per second has a 50-percent chance of occurring in any year (table 3). The duration of the runoff probably is brief. The infiltration capacity of the sand probably is large, but the actual amount of recharge from runoff has not been determined.

The presence of water flowing southward through the alluvium at section A-A' indicates a source of recharge north of the study area; however, that source has not been determined. It may be from drainage of water that infiltrates the arroyo in the upper part of the drainage basin during runoff or it may be, at least in part, from manmade sources. Ponds and septic-tank leaching fields north of the study area also may be recharging the alluvium. An undetermined amount of recharge to the alluvium comes from the manmade pond southeast of the landfill. The lagoons in the landfill, when they existed, also may have recharged the alluvium. Water in the alluvium discharges to the San Juan River alluvium south of U.S. Highway 64 (figs. 1 and 16) and to wells at the adjacent refinery. The hydraulic connection between the alluvium and the Nacimiento Formation is unknown. The Nacimiento may either be a source of recharge or a sink for discharge, depending on the difference in hydraulic heads between the Nacimiento and the alluvium.

Aquifer Coefficients and Flow Rates

Measured values of the hydraulic conductivity of six samples of the alluvium collected during the test drilling ranged from 0.006 to 220 feet per day (table 4). These values, for materials ranging in grain size from a clayey sand to a coarse sand, are reasonable when compared with typical values (fig. 17). Estimates of ranges of flow rate through the alluvium upgradient of the landfill can be made using the gradient measured from figure 16, the area of saturated alluvium in section A-A' (fig. 10), and estimates of hydraulic conductivity and porosity (table 4 and fig. 17). The volumetric rate of flow through a cross section of aquifer oriented perpendicular to the direction of flow is determined by the following equation, which is modified from Lohman and others (1972, p. 4):

$$Q = -K\,(dh/dl)A \qquad (2)$$

where

Q is the volumetric flow rate, in cubic feet per day;

K is the hydraulic conductivity, in feet per day;

dh/dl is the hydraulic gradient, in foot per foot; and

A is the cross-sectional area, in square feet.

On the basis of descriptions of cuttings collected during drilling, hydraulic conductivity of the alluvium appears to be similar to that of mixtures of sand, silt, and clay or medium sand and would range from about 0.1 foot per day to 10 feet per day (fig. 17). The hydraulic gradient in the vicinity of section A-A' is estimated to be about 0.01 foot per foot. The saturated cross-sectional area is about 11,900 square feet (fig. 10). The resultant volumetric flow rate would range from 12 to 1,200 cubic feet per day, or less than 0.1 to more than 6 gallons per minute. The rate could be as much as 130 gallons per minute if the alluvium is mostly coarse sand; hydraulic conductivity was 220 feet per day in one sample of sand from piezometer 3 (table 4). The largest source of error is the estimate of an average hydraulic conductivity, ranging over at least three orders of magnitude.

The rate of movement of a particle of water through pore spaces in alluvium is the interstitial velocity. The velocity and direction of travel vary over a wide range because of irregularities in the geometry of the pore spaces.

The average interstitial velocity (Lohman and others, 1972, p. 14) is determined by the equation:

$$v_i = -\frac{K(dh/dl)}{n_e} \qquad (3)$$

where

v_i is the average interstitial velocity, in feet per day;

K is the hydraulic conductivity, in feet per day;

dh/dl is the hydraulic gradient, in foot per foot; and

n_e is the effective porosity, dimensionless.

Using measured values of hydraulic conductivity and porosity and assuming hydraulic gradient ranges from 0.01 to 0.06 foot per foot, average interstitial velocity for the six samples was calculated (table 4). Calculated values ranged from 0.0002 to 37 feet per day. The fastest velocity was for a coarse sand with a porosity of 0.43. These values compare reasonably well with ranges shown in a graph of v_i versus K for typical hydrologic conditions in alluvium (fig. 17).

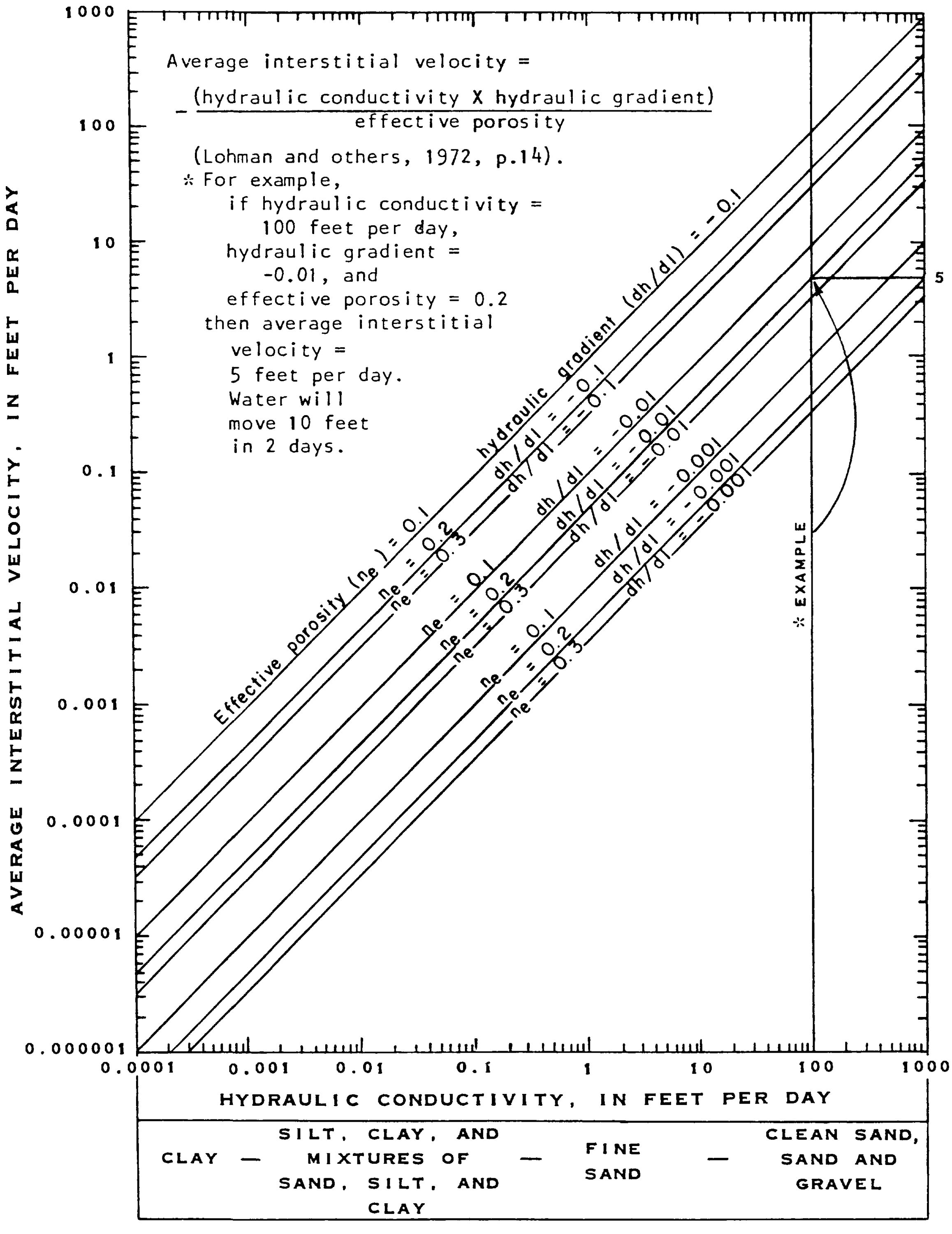


Figure 17.--Relation of average interstitial velocity and hydraulic conductivity for typical values of effective porosity and hydraulic gradient. (Peter, 1987, p. 23. Values for hydraulic conductivity modified from U.S. Water and Power Resources Service, 1981, p. 29).

Table 3. Flood-frequency equations, error, and peak discharges for the unnamed arroyo adjacent to the Lee Acres landfill

[A, drainage area of the arroyo = 7.05 square miles upstream from U.S. Highway 64; Q, discharge, in cubic feet per second. Equations and estimates of error from Waltemeyer, 1986, p. 46]

Equations	Recurrence interval (years)	Estimated discharge (cubic feet per second)	Standard error of estimate			
			Log units	Percentage		
				Maximum	Minimum	Average
$Q_{0.50} = 8.03 \times 10\ A^{0.5}$	2	222	0.377	+138	-58	98
$Q_{0.20} = 2.05 \times 10^2\ A^{0.47}$	5	510	.326	+112	-53	82
$Q_{0.10} = 3.36 \times 10^2\ A^{0.44}$	10	790	.309	+104	-51	78
$Q_{0.04} = 5.70 \times 10^2\ A^{0.41}$	25	1,270	.298	+99	-50	74
$Q_{0.02} = 8.03 \times 10^2\ A^{0.39}$	50	1,720	.297	+98	-50	74
$Q_{0.01} = 1.09 \times 10^3\ A^{0.37}$	100	2,245	.300	+99	-50	74

Table 4. Aquifer-coefficient measurements

[Consolidation stress calculated for the unit weight of mixed-grained sand = 108 pounds per cubic foot. Hydraulic gradient assumed to range from 0.01 to 0.06 foot per foot. Measurements made by method described in Olsen and others, 1985]

Hole or piezometer number in fig. 3	Description	Sample depth (feet below land surface)	Depth to water (feet below land surface)	Consolidation stress (pounds per square inch)	Porosity		Hydraulic conductivity (feet per day)	Range of average interstitial velocity (feet per day)	
					Initial	Final			
3	Coarse sand	37.5	34.8	29.3	0.43	0.36	220	5.1	-37
6	Clayey sand	40.0	33.1	33.0	.38	.28	.008	.0002	-.0017
9	Silty sand	48.0	32.0	42.9	.42	.26	.130	.003	-.03
11	Clayey sand	41.0	34.9	33.4	.38	.32	.006	.0002	-.001
11	Fine sand	51.0	34.9	45.2	.38	.29	5.8	.15	-1.20
12	Find sand	35.4	26.8	30.3	.44	.37	27	.61	-4.4

Terrain Conductivity and Ground-Water Contamination

Comparison of terrain conductivity upgradient from and adjacent to or downgradient from the landfill indicates that some areas may contain water of larger conductivity. Background values of terrain conductivity can be deduced from section A-A' (fig. 10), assuming it is in an area that does not contain water that has been contaminated by more saline water. In general, terrain conductivity in section A-A' increases with depth, as would be expected for alluvium overlying bedrock because bedrock is more conductive than alluvium. The smaller value of terrain conductivity at well 3, measured with the 40-meter intercoil spacing, may represent the thicker alluvium in that area.

A survey along the length of the arroyo from well 3 to U.S. Highway 64, using 20- and 40-meter spacing and a horizontal dipole, showed a change in the terrain conductivity south of well 8 (fig. 15). North of well 8, the changes in terrain conductivity measured by the two intercoil spacings are similar, indicating the changes possibly are controlled by thickness or grain-size changes in the near-surface alluvium. South of well 8, the relation changes between the 20-meter-spacing (shallow) and 40-meter-spacing (deep) readings (fig. 15). McNeill (1985, p. 2) generalized that the 20-meter readings represent material at depths of less than about 24 feet, and the sigma20 readings represent material deeper than 24 feet. Therefore, the terrain conductivity is larger near land surface, in the alluvium, in the part of section F-F' where the value calculated for sigma20 is less than the value measured with the 20-meter spacing. This may indicate that ground water in this area is more conductive, given that there are no changes in the bedrock or the depth to water (fig. 15).

Sections B-B' and E-E' show a similar relation (figs. 11 and 14). The east end of section B-B' also shows the largest measured values of terrain conductivity. These values probably are partly the result of buried metal at the landfill (fig. 11) and also may be partly the result of the shallow bedrock and tight clay. The measurements of the terrain conductivity made with the vertical dipole converge at the west end of sections B-B' and E-E', probably because the bedrock is shallow.

Water samples from the piezometers installed in the alluvium were analyzed for major ions and volatile organic compounds. The concentration of chloride was larger, more than 100 milligrams per liter, in water from piezometers 8, 12, and 13, all of which are downgradient from the landfill, than in the upgradient piezometers (table 5). The chloride concentration did not exceed the drinking-water standard of 250 milligrams per liter in any of the samples (U.S. Environmental Protection Agency, 1979). Water from piezometers 12 and 13 was slightly acidic, having a pH of less than 7.0. Water from the other piezometers was slightly alkaline, having a pH of more than 7.0. The concentration of sulfate was more than 1,000 milligrams per liter in all the samples, probably because of dissolution of the gypsum in the alluvium. This large concentration of sulfate would make the water undesirable for drinking; the secondary drinking-water standard is 250 milligrams per liter for sulfate (U.S. Environmental Protection Agency, 1979).

Volatile organic compounds were detected in water from piezometers 3, 5, 8, 11, and 12 (table 5). Toluene and benzene are found in grease, oil, and gasoline, and it is not known if their presence at concentrations greater than the detection limits in water from piezometers 3, 5, and 11, all upgradient from the landfill, was a result of the drilling operation because no precautions, such as steam cleaning equipment and use of stainless steel casing, were taken to prevent introduction of these compounds. A by-product of the degradation of 1,1,1-trichloroethane, 1,1-dichloroethane, and 1,1,1-trichloroethane was found in concentrations greater than the detection limits in water from piezometers 8 and 12 downgradient from the landfill. The San Juan River was also sampled upstream and downstream from the study area and analyzed for volatile organic compounds listed in table 5. None were found at concentrations greater than the detection limits.

Table 5. Chemical analyses

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; <, less than. All other constituents in milligrams per liter]

Number in fig. 3	Well number	Date	Water temperature (°C)	Air temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved cations: Calcium	Magnesium	Sodium	Potassium
3	29N.12W.22.1321	04-29-87	16.0	25.0	3,000	7.11	290	32	370	1.8
5	29N.12W.21.4222A	04-30-87	16.5	29.0	2,800	7.22	290	32	340	2.6
6	29N.12W.21.4222B	04-29-87	16.0	27.5	2,700	7.10	320	34	280	1.1
8	29N.12W.21.4244A	04-30-87	16.0	24.5	3,040	7.15	320	32	330	1.0
11	29N.12W.22.1331	04-30-87	17.0	22.5	2,750	7.12	280	31	320	3.2
12	29N.12W.21.4422	05-01-87	15.0	15.0	2,980	6.90	330	32	330	.90
13	29N.12W.21.4444	05-01-87	15.5	19.5	2,850	6.65	320	32	300	.90

Number in fig. 3	Date	Dissolved anions: Bicarbonate	Sulfate	Chloride	Fluoride, dissolved	Silica, dissolved	Boron, dissolved (µg/L)	Iron, dissolved (µg/L)	Strontium, dissolved (µg/L)
3	04-29-87	334	1,600	55	0.90	13	290	20	7,500
5	04-30-87	336	1,500	51	.80	13	280	20	7,600
6	04-29-87	336	1,400	56	.80	13	260	20	7,700
8	04-30-87	311	1,500	110	.70	13	230	20	7,500
11	04-30-87	317	1,500	52	.80	14	300	<10	7,300
12	05-01-87	275	1,500	140	.80	13	230	20	7,800
13	05-01-87	237	1,400	130	.70	12	200	20	6,000

Number in fig. 3	Date	Toluene total (µg/L)	Benzene total (µg/L)	1,1,-Dichloroethane total (µg/L)	1,1,1-Trichloroethane total (µg/L)
3	05-12-87	<0.20	0.40	<0.20	<0.20
5	05-12-87	.60	< .20	< .20	< .20
8	05-12-87	< .20	< .20	1.3	.20
11	05-12-87	3.0	< .20	< .20	< .20
12	05-12-87	< .20	< .20	1.4	.20
13	05-12-87	< .20	< .20	< .20	< .20

Other volatile organic compounds not detected (detection level 0.2 µg/L):

Dichloro-bromomethane
Carbon-tetrachloride
1,2-Dichloroethane
Bromoform
Chlorodibromomethane
Chloroform
Chlorobenzene
Chloroethane
Ethylbenzene
Methylbromide
Methylchloride
Methylene-chloride
Tetrachloroethylene
Trichlorofluoromethane
1,1-Dichloroethylene
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
1,2-Dichlorobenzene
1,2-Dichloropropane
1,2-Transdichloroethylene
1,3-Dichloropropane
1,3-Dichlorobenzene
1,4-Dichlorobenzene
2-Chloroethylvinylether
Dichlorodifluoromethane
Trans-1,3-dichloropropene
Cis 1,3-Dichloropropene
1,2-Dibromoethylene
Vinyl chloride
Trichloroethylene
Styrene
Xylene

SUMMARY AND CONCLUSIONS

The Quaternary deposits in the study area are colluvium on and near the slopes and alluvium in the valley of the arroyo. Capping the ridges and mixed with the colluvium are rounded cobbles and boulders that appear to be remnants of terrace deposits, probably from the San Juan River. Underlying the colluvium and alluvium is the Nacimiento Formation of Tertiary age. The Nacimiento crops out on the ridges bounding the study area.

The alluvium mostly consists of fine- to coarse-grained quartz sand with some silt. There are also gravel and clay zones that generally are less than 1 foot thick. The seismic-refraction survey of four sections showed that generally there are three layers of alluvium. These layers, defined by seismic velocity, appear to represent the degree of consolidation and saturation. The thickness of the alluvium measured in the 12 drill holes ranged from 13.7 to 61.5 feet. The alluvium is thinnest at the foot of the slopes where it interfingers with colluvium. It is thickest near, but not always directly beneath, the active channel of the arroyo. The seismic survey showed a buried channel incised about 26 feet into the bedrock surface north of the landfill. This channel apparently opens southward. A shallow, less than 8-foot-deep channel is present in the west side of the valley south of the landfill. There are two buried channels incised 8 to 10 feet into the bedrock on the west side of the valley about 200 feet north of U.S. Highway 64.

The lithology and consolidation of the bedrock in contact with the alluvium vary areally because the Nacimiento Formation is layered and because the erosional surface of the bedrock is irregular. The seismic survey indicated that bedrock velocities generally were slower on the east side than in the center and western parts of the sections. This may indicate that the bedrock on the east side is more weathered. A buried weathered zone in the bedrock on the east side of the arroyo may be related to the erosional plateaus on the bedrock surface on that side. The west side of the buried bedrock valley is steeper and may not be as deeply weathered.

The configuration of the water table in the alluvium indicates that ground-water flow is controlled by unidentified recharge north of the landfill, recharge from a pond southeast of the landfill, discharge to pumping wells on the adjacent refinery property, discharge to the alluvium deposited by and hydraulically connected to the San Juan River south of U.S. Highway 64, and hydraulic conductivity of the alluvial material. There also may be recharge to or discharge from the Nacimiento Formation and recharge from ephemeral runoff in the arroyo.

At the north boundary of the study area, the saturated alluvium is almost entirely within an incised channel. In the northern one-half of the study area, the alluvium is saturated with water near the center of the arroyo valley where the alluvium is the thickest. Flow generally is southward, and the hydraulic gradient is about 0.01 foot per foot.

In the middle of the study area, no deeply incised channel is present in the bedrock, and the saturated part of the alluvium is wider. In this area, the east boundary of the saturated alluvium appears to be controlled by a relatively impermeable zone.

In the southern one-half of the study area, the saturated part of the alluvium is wider, in part because of the greater width of the valley and in part because of recharge from a manmade pond on the slope southeast of the landfill. Recharge from this pond to the alluvium has created a water-table mound beneath the pond. Water from the mound generally flows west and southwest toward the buried channels in the bedrock, where the saturated thickness of the alluvium is greater and therefore more transmissive. On the west side of the valley, flow generally is southward toward the confluence with the alluvium of the San Juan River. The gradient is steepest, exceeding 0.06 foot per foot, near the pond. Accurate measurement of the water-table gradient is not possible using estimated water levels south of well 8, but the gradient is estimated to be approximately 0.02 to 0.05 foot per foot.

The volumetric flow rate through the alluvium north of the landfill is estimated to range from 12 to 1,200 cubic feet per day, or less than 0.1 to more than 6 gallons per minute, using values for hydraulic conductivity ranging from about 0.1 foot per day to 10 feet per day, a hydraulic gradient estimated to be about 0.01 foot per foot, and a saturated cross-sectional area of 11,900 square feet. Using measured values of hydraulic conductivity and porosity and assuming hydraulic gradient ranges from 0.01 to 0.06 foot per foot, average interstitial velocity for the six samples was calculated. Calculated values ranged from 0.0002 to 37 feet per day. The fastest velocity was for a coarse sand with a porosity of 0.43.

In general, terrain conductivity in the northern one-half of the study area increases with depth, as would be expected for alluvium overlying bedrock. In the northern part, terrain conductivity as measured by two intercoil spacings is similar, indicating the changes are controlled by material relatively near the land surface, possibly thickness or grain-size changes in the alluvium. In the southern one-half of the study area, the relation between the shallow and deep material changes, and the terrain conductivity is larger near land surface in the alluvium. This may indicate that ground water in the alluvium in this area is more conductive, given that there are no changes in the bedrock or the depth to water.

The east side of the valley in the middle of the study area had the largest measured values of terrain conductivity. These values probably are partly the result of buried metal at the landfill and also may be partly the result of the shallow bedrock and tight clay. The alluvium is unsaturated in this area.

Water samples from the piezometers installed in the alluvium were analyzed for major ions and volatile organic compounds. The concentration of chloride was larger, more than 100 milligrams per liter, in water downgradient from the landfill than in the upgradient water. The chloride concentration did not exceed the drinking-water standard of 250 milligrams per liter in any of the samples. The concentration of sulfate was more than 1,000 milligrams per liter in all the samples, probably because of dissolution of gypsum in the alluvium. This large concentration of sulfate would make the water undesirable for drinking; the secondary drinking-water standard is 250 milligrams per liter for sulfate. Toluene and benzene are found in grease, oil, and gasoline, and it is not known if their presence at concentrations greater than the detection limits in water upgradient from the landfill was a result of the drilling operation because no precautions, such as steam cleaning equipment and use of stainless steel casing, were taken to prevent introduction of these compounds during piezometer installation. A by-product of the degradation of 1,1,1-trichloroethane, 1,1-dichloroethane, and 1,1,1-trichloroethane was found in concentrations greater than the detection limits in water from two piezometers downgradient from the landfill. The San Juan River was also sampled upstream and downstream from the study area and analyzed for volatile organic compounds. None were found at concentrations greater than the detection limits.

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SUPPLEMENTAL INFORMATION

Table 6. Geologic logs of holes

Hole number:	1	Date started:	January 31, 1987
Hydrologist:	Mason	Date finished:	January 31, 1987
Drillers:	Eddy, Shanahan, Rider		
Location:	29N.12W.22.1312		
Land-surface elevation:	5,463.7 feet		

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Nothing coming up at first. After adding second flight, returned samples. Sand, 10 YR 4/2, fine to medium with large amount of silt and clay. Moist.
5.5-10.5	C	Sand, 10 YR 6/6, silty, fine to medium. Slow going. Dry, still not much return.
10.5-12.5	S (55%)	0.4 foot - sand, 10 YR 5/4, silty and some medium to coarse grains. Dry. 0.6 foot - silt or clay, 10 YR 7/4, some fine to medium grains. 0.1 foot - clay, 10 YR 7/4, hard and dry.
13.0-14.5:	S (100%)	
13.0-13.1		Clay, 10 YR 7/4, hard and dry.
13.1-14.5		Silt, 10 YR 7/4, sandy, consolidated or hard, fine to coarse sand grains.
14.5-19.5	C	Changed to different auger-tooth configuration; drilled faster.
19.5-21.5	S (0%)	No recovery. Dry and cohesionless?
21.5-26.5	C	Silt, sandy, 10 YR 5/4, fine to medium sand grains. Relatively fast with little recovery.
26.5-31.5	C	Silt, sandy, 10 YR 5/4, fine to medium sand grains. Rock or cobble at about 29 feet.
31.5	C	Sand, silty, 10 YR 8/2, fine-grained, semiconsolidated to consolidated. Looks the same as material in bottom of hole 3, except dry. Lost bit in bottom of hole, sheared off. Refused at 31.5 feet. Plugged and abandoned.

Table 6. Geologic logs of holes - Continued

Hole number: 3 | Date started: January 30, 1987
Hydrologist: Mason | Date finished: January 31, 1987
Drillers: Shanahan, Rider
Location: 29N.12W.22.1321
Land-surface elevation: 5,458.3 feet

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Sand, 10 YR 5/4, fine to coarse.
5.5-10.5	C	Sand, 10 YR 7/4, fine to coarse, 1/4- to 1-inch gravel, rounded, very dry.
10.5-12.5	S (75%)	Sand, 10 YR 7/4, fine to coarse, angular, incohesive, bottom 0.2 foot more cohesive.
12.5-15.5	C	Sand, same as above. Very dry and incohesive.
15.5-20.5	C	Sand, 10 YR 7/4, fine to coarse with fine material increasing with depth, silt. Very dry. Small percentage of 1/4-inch gravel.
20.5-22.1:	S (95%)	Hit rock, bending shelby tube.
20.5-20.7		Sand, 10 YR 7/4, fine to coarse, mostly coarse. Incohesive and dry.
20.7-21.8		Sand, medium to coarse, mostly coarse. Moist.
21.8-22.1		Sand, 10 YR 7/4, fine to coarse, silty, dry.
22.1-25.5	C	Hitting rocks. Sand, 10 YR 7/4, fine to coarse, silty. Increasing fines. Gravel to as much as 1 1/2 inches.
25.5-30.5	C	Sand, 10 YR 5/4, fine to coarse, angular, some gravel less than 1/8 inch. Larger percentage of coarse material. Moist.
30.5-32.5:	S (70%)	May be compacted.
30.5-30.8		Clay, 10 YR 4/2, with some medium sand.
30.8-31.5		Sand, 10 YR 6/6, fine-grained and silty.
31.5-32.5		Clay, 10 YR 7/4, sandy. Tighter.
32.5-35.5	C	No return. Alternates from soft to tight.

Table 6. Geologic logs of holes - Continued

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
35.5-37.5:	S (90%)	
35.5-35.7		Sand, 10 YR 7/4, fine to medium, silty, tight.
35.7-36.7		Sand, 10 YR 5/4, coarse with small amount of fine sand or silt. Wet.
36.7-37.5		Sand, 10 YR 5/4, fine to medium, silty. Wet.
37.5-39.5	S (unknown)	Kept for testing.
39.5-41.5:	S (87%)	May include heaved material in top.
39.5-41.0		Sand, 10 YR 5/4, coarse, with some fine to medium.
41.0-41.5		Sand, 10 YR 5/4, fine-grained and silty.
41.5-43.0:	S (75%)	May include heaved material in top.
41.5-42.4		Clay, 10 YR 5/4, and fine sand.
42.4-43.0		Sand, 10 YR 5/4, medium-grained and silty.
43.0-45.0:	S (100%)	May include heaved material in top.
43.0-44.5		Sand, 10 YR 5/4, coarse with smaller, some fine to medium.
44.5-45.0		Sand, 10 YR 5/4, fine and silty.
45.0-47.0	S (100%)	Sand, 10 YR 5/4, medium to coarse. Bottom 0.1 foot is clay with minor amount of very fine sand, 10 YR 5/4.
47.0-50.0:	S (63%)	Hit rock at 50 feet. Chewed up bottom of tube. Entire sample 10YR 5/4.
47.0-47.7		Sand, medium to coarse.
47.7-48.1		Sand, very fine and silty.
48.1-48.5		Sand, medium to coarse.
48.5-48.9		Sand, fine to medium and silty.
50.0-55.0	C	Easy augering. No rocks, no return.
55.0-60.0	C	Mostly same as above. Slows for a few inches periodically.
60.0-61.5	C	Slow, hard, lifts back end of rig. Tight at 61.5 feet. Tried to sample. No return.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 60-foot casing.
Sand tagged at 41 feet. Bentonite, 25 pounds, 1/4-inch pellets.

Table 6. Geologic logs of holes - Continued

Hole number: 4 | Date started: January 29, 1987
Hydrologist: Mason | Date finished: January 29, 1987
Drillers: Nichols, Shanahan, Rider
Location: 29N.12W.22.1324
Land-surface elevation: 5,458.9 feet

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Sand, 10 YR 5/4, medium to coarse. Gravel, to as much as 1/4 inch, well-rounded at 2 feet.
5.5-10.5	C	Same. At 8 feet, cobbles to as much as 2 inches, well-rounded, mixed with sand. Hit some larger rocks.
10.5-12.5	S (75%)	Sand, 10 YR 7/4, fine to medium, 1/4-inch gravel interbedded. May have compacted during sampling.
13.2-15.2:	S (85%)	Tighter drilling.
13.2-13.7		Sand, 10 YR 6/6, fine to medium, and silt. Incohesive.
13.7-14.2		Sand, silty, 10 YR 5/4, fine to medium, more cohesive.
14.2-14.5		Clay, 10 YR 4/2, small layers of interbedded sand.
14.5-15.2		Sand, silty, 10 YR 5/4, fine to medium, tighter, partly cemented. Refused at 15.2 feet. Plugged and abandoned.

Table 6. Geologic logs of holes - Continued

Hole number:	5 (south of 6)	Date started:	January 31, 1987
Hydrologist:	Mason	Date finished:	January 31, 1987
Drillers:	Eddy, Shanahan, Rider		
Location:	29N.12W.21.4222A		
Land-surface elevation:	5,436.3 feet		

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Sand, 10 YR 5/4, fine to coarse, mostly medium. Moist. Occasionally hit rocks.
5.5-10.5	C	Sand, 10 YR 5/4, fine to coarse, mostly medium. Hitting cobbles more frequently. Returning 1-inch size.
10.5-15.5	C	Sand, 10 YR 5/4, fine to coarse, mostly medium.
15.5-20.5	C	Sand, 10 YR 5/4, fine to coarse, mostly medium. No cobbles. Fast augering.
20.5-22.5	S (75%)	Sand, 10 YR 5/4, medium to coarse, some fine. Moist.
22.5-25.5	C	Sand, 10 YR 5/4, medium to coarse, some fine. Fast augering.
25.5-30.5	C	Rock at 26 and 29 feet. Fast augering.
30.5-35.5	C	Sand, 10 YR 5/4, medium to coarse, some fine. Fast augering.
35.5-40.5	C	Sand, 10 YR 5/4, medium to coarse, some fine. Smaller amount of clay, 10 YR 5/4, very soft and plastic. Auger did not slow.
40.5-45.5	C	Sand, 10 YR 5/4, medium to coarse, some fine. Clay. Auger slower. No water coming up.
45.5-47.5	S (75%)	0.4 foot of clay, 10 YR 6/6, plastic, with sand grains. 1.1 feet of clay, 10 YR 5/4, very sandy and plastic.
47.5-50.5	C	Clay, sandy. Auger is slowing. Tighter.
50.5-55.0	C	Very slow at 50.5 feet for 1/2 foot, then faster. Tight at 55.0 feet, stopped.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 45-foot casing.
Sand not tagged. Bentonite, 25 pounds, 1/4-inch pellets.

Table 6. Geologic logs of holes - Continued

Hole number: 6
Hydrologist: Mason
Drillers: Eddy, Shanahan, Rider
Location: 29N.12W.21.4222B
Land-surface elevation: 5,436.4 feet

Date started: February 1, 1987
Date finished: February 1, 1987

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Sand, 10 YR 5/4, coarse, minor amounts of fine to medium. Occasional cobbles.
5.5-10.5	C	Sand, 10 YR 5/4, coarse, minor amounts of fine to medium. Layer of cobbles at 10 feet.
10.5-15.5	C	Sand, 10 YR 5/4, coarse, minor amounts of fine to medium. Rocks through 11 feet, some are 2 to 3 inches, rounded.
15.5-30.5	C	Sand, 10 YR 5/4, coarse, minor amounts of fine to medium.
30.5-33.5	C	Sand, 10 YR 5/4, coarse, minor amounts of fine to medium. Tight layer. Clay, 10 YR 5/4, sandy and plastic on teeth of plug.
33.5-35.5	S (80%)	Sand, 10 YR 5/4, fine to medium, with large amount of silt and clay. Cobble at center of sample and at bottom.
35.5-38.5		Hit rocks.
38.5-40.5	S (100%)	Unknown. Kept for testing.
40.5-46.5		Tight at 46.5 feet.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 35-foot casing.
Sand not tagged.
Bentonite, 25 pounds, 1/4-inch pellets.

Table 6. Geologic logs of holes - Continued

Hole number: 7 | Date started: February 1, 1987
Hydrologist: Mason | Date finished: February 1, 1987
Drillers: Eddy, Shanahan, Rider
Location: 29N.12W.21.4242
Land-surface elevation: 5,425.3 feet

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0-10.5	C	Sand, 10 YR 5/4, medium to very coarse, mostly coarse. Hit occasional rock.
10.5-15.5	C	Tighter at 12 feet, then faster. Gravel return.
15.5-17.5	S (65%)	0.2 foot - sand, 10 YR 5/4, medium with clay. Dry. 1.1 feet - sand, 10 YR 5/4, fine to medium with clay, tight and cohesive.
17.5-20.5	C	Very slow. Hard layer, no chatter at 20 feet. Nothing on plug.
Moved south about 5 feet:		
0 - 5.5	C	Sand and cobbles as before.
5.5-10.5	C	Same as before; gravel at 10 feet.
10.5-15.5	C	Refused.
Moved north of first attempt:		
5.5-10.5	C	Same as before; less gravel.
10.5-15.5	C	Cobble layer at 11 feet. Tighter below 13 feet.
15.5-20.5	C	Very slow at 18 feet, refused at 20. Probably very hard and consolidated. Plugged and abandoned.

Table 6. Geologic logs of holes - Continued

Hole number: 8
Hydrologist: Peter
Drillers: Nichols, Shanahan, Rider
Location: 29N.12W.21.4244A
Land-surface elevation: 5,419.8 feet

Date started: January 27, 1987
Date finished: January 28, 1987

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.0	C	Sand, brown, fine to medium. Moist and frozen at surface. At 4 feet, 1/2-inch gravel. Less than 5 percent gray clay.
5.0- 7.0:	SS (100%)	
5.0- 5.8		Sand and clay, 10 YR 5/4, moist and plastic.
5.8- 6.3		Sand, 10 YR 7/4, very fine to medium, dry. Sandstone fragment at 6 feet, broken, 1 inch.
6.3- 7.0		Sand, 10 YR 7/4, medium to coarse, dry. No staining, quartz grains, no cement, no structure.
7.0-12.0	C	Sand, fine to coarse, gypsum grains. Grinding on rock at 7.5 feet.
12.0-14.5	C	Gravel, 3-inch.
14.5-18.0	C	Gravel, hard drilling.
18.3-20.3	SS (70%)	Sand, 10 YR 7/4, fine to medium, quartz, 2-inch piece of gravel. No staining, no odor, dry.
20.3-25.0		No return.
25.0-26.5	C	Gravel, 1- to 1 1/2-inch, rounded.
26.5-29.5	C	Sand, easy drilling.
29.5-31.5	SS (50%)	Sand, 10 YR 7/4, fine to medium to coarse. Broken quartzite pebble at 30.5 feet. Quartz, no stain, no odor.

Table 6. Geologic logs of holes - Continued

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
31.5-40.0	C	Sand, medium to coarse, no gravel, water table. Drilling slowed.
40.5-42.5:	SS (90%)	
40.5-41.8		Sand, silt to very coarse. More than 50% medium. Wet and flowing. 10 YR 5/4.
41.8-42.3		Gravel, 1/2- to 1 1/2-inch, rounded, in matrix of coarse sand.
42.3-42.5		Clay, 5 Y 5/2, tough with embedded shale particles. Iron staining at top. No odor. Sand is quartz.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 35-foot casing.
Sand, 75 pounds, tagged at 35 feet.
Bentonite, 25 pounds, 1/4-inch pellets, tagged at 30 feet.

Table 6. Geologic logs of holes - Continued

Hole number: 9
Hydrologist: Peter
Drillers: Nichols, Shanahan, Rider
Location: 29N.12W.21.4244A (10 feet south of 8)
Land-surface elevation: 5,419.8 feet

Date started: January 28, 1987
Date finished: January 28, 1987

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0-10.5	C	Sand, 10 YR 8/2, very fine to medium, some broken gravel.
10.5-15.5		Chatter at 11.5, 12.5, and 14 to 15.5 feet.
15.5-20.5	C	Same as hole 8, grinding at 17.5 feet. Darker, 1/4- to 1/2-inch gravel at 19 feet.
20.5-22.0	C	Same.
22.0-25.5	C	Gravel, 1/2- to 2-inch, clean.
25.5-30.5	C	No chatter, in sand(?), returning gravel.
30.5-35.5	C	Sand, silty to coarse, dry, gray.
35.5-40.5	C	Chatter at 38 feet, gravel?
40.5-45.5	C	Clay, light-olive-gray.
45.5-47.5:	S (70%)	
45.5-46.5		Clay, 5 Y 3/2, tight, unstructured.
46.5-46.7		Clay, 10 Y 4/2.
46.7-46.9		Clay, 5 GY 5/2, tight, some structure, platy, no odor.
47.5-49.5	S (unknown)	Kept for analysis. Lignite on end.
49.5-50.5	S (100%)	Auger refused at 50.5 feet. Black lignite to 50.5 feet. Sand grains embedded in base of sample. Abandoned hole. Plugged with 25 pounds of bentonite at 2 feet.

Table 6. Geologic logs of holes - **Continued**

Hole number:	10	Date started:	January 28, 1987
Hydrologist:	Peter	Date finished:	January 28, 1987
Drillers:	Nichols, Shanahan, Rider		
Location:	29N.12W.22.3133		
Land-surface elevation:	5,418.7 feet		

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 2.5	C	Silt, clayey. Chattering.
2.5- 5.5	C	Sand, 10 YR 7/4, very fine to very coarse.
5.5-10.5	C	Silt to 1/4-inch pebbles, chatter, 10 YR 7/4, no odor, dry.
10.5-12.5:	S (75%)	
10.5-10.6		Silt to coarse sand, 10 YR 8/2.
10.6-11.6		Clay and silt, 10 YR 5/4, moist.
11.6-12.1		Clay and coarse sand. White streaks horizontally. No odors, no staining.
12.5-15.5	C	Sand, 10 YR 5/4, very fine, and 1/4- to 1/2-inch gravel. Slightly moist.
15.5-18.5	C	Silt, clayey, return as 1/2- to 1-inch clods. 1/2-inch pieces of tight clay, 5 Y 5/2. Tightened at 17.5 feet.
18.5-19.6:	S (100%)	Refused at 19.5 feet.
18.5-19.1		Silt and clay, 5 Y 7/2, tough and dry.
19.1-19.6		Clay, 10 R 7/2, streaked through silt, 5 Y 7/2. Abandoned. Left open for use by seismic crew.

Table 6. Geologic logs of holes - Continued

Hole number: 11
Hydrologist: Mason
Drillers: Eddy, Shanahan, Rider
Location: 29N.12W.22.1331
Land-surface elevation: 5,445.6 feet

Date started: February 2, 1987
Date finished: February 2, 1987

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0-13.0	C	Sand, 10 YR 5/4, coarse with some medium gravel. Moist.
13.0-15.5	C	Sand, 10 YR 5/4, fine to medium, silty, less gravel, drier.
15.5-20.5	C	Sand, 10 YR 5/4, fine to medium, silty.
20.5-22.5	S (45%)	0.4 foot - sand, 10YR 7/4, fine to coarse, silty, mostly fine to medium. 0.5 foot - same as top of sample, with less silt.
22.5-25.5	C	Sand, 10 YR 6/2, fine to coarse, silty. Dry. No gravel.
25.5-30.5	C	Sand, 10 YR 6/2, coarse, some silt. Rock at 29 feet.
30.5-32.5	S (75%)	1.0 foot - sand, 10 YR 5/4, mostly coarse, some fine to medium. No silt. Mostly quartz. 0.5 foot - sand, 10 YR 5/4, mostly coarse, some fine to medium. More cohesive, possibly from sampling.
32.5-40.5	C	Slow, no return. Clay balls at two different times (two layers?). Sample from teeth of plug: clay, 10 YR 5/4, with fine-grained sand. Moist.
40.5-42.5	S (100%)	Water at 40 feet. Saved for test. Bottom is clay, 10 YR 5/4, and fine-grained sand.
42.5-45.5	C	Clay balls return.
45.5-50.5	C	Rock at 46 feet. Slow until 50 feet. Chatter at 49 feet. Clay balls return. Sample from teeth of plug: sand, 10 YR 5/4, fine, silty. Wet.
50.5-52.5	S (100%)	Hard at 52 feet. Sample saved for testing. Sample from bottom auger flight: clay, 10 YR 2/2, tight with some coarse-grained material.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 40-foot casing. Sand not tagged. Bentonite, 25 pounds, 1/4-inch pellets.

Table 6. Geologic logs of holes - Continued

Hole number: 12
Hydrologist: Mason
Drillers: Eddy, Rider
Location: 29N.12W.21.4422
Land-surface elevation: 5,409.8 feet

Date started: February 6, 1987
Date finished: February 6, 1987

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.5	C	Sand, 10 YR 5/4, fine to very coarse, mostly coarse. Intermittent gravel beneath 2.5 feet. Moist.
5.5-10.5	C	Sand, 10 YR 5/4, fine to very coarse, mostly coarse. Clay, 10 YR 4/2, moist, beneath 7 feet. Drilling easier at 9 feet.
10.5-15.5	C	Clay, 10 YR 4/2, drier and tighter beneath 12 feet. Some gravel, possibly from upper layers.
15.5-17.5	S (65%)	0.2 foot - clay, 10 YR 4/2, and fine-grained sand. 0.8 foot - sand, 10 YR 5/4, fine to coarse, some silt, mostly fine to medium. Dry. 0.3 foot - sand, 10 YR 5/4, fine to medium, silty, may be compacted. Dry.
17.5-20.5	C	Clay, 10 YR 4/2, fine to medium sand. Dry. Rock at 18.5 feet. Slow and tight.
20.5-25.0	C	Same material. Tight to 22 feet.
25.0-27.0	S (65%)	1.0 foot - sand, 10 YR 5/4, fine to coarse, mostly fine to medium. Wet. 0.3 foot - sand, 10 YR 5/4, fine to medium with minor amount of silt.
27.0-30.0	C	No return, easy drilling. Water table?
30.0-35.0	C	Sand, 10 YR 5/4, silty, fine to coarse. Wet.
35.0-37.0	S (100%)	Saved for testing. Top of sample is sand, 10 YR 5/4, silty and very fine. Rock at 37 feet, damaged end of tube.
37.0-40.0	C	Gravel zone to 38.0 feet. Tight at 40 feet.
40.0-43.5	C	Hard clays. Very slow and tight. Auger refused.

Completion:
Casing - 5-foot blank, with plug, 5-foot 10-slot screen, 35-foot casing.
Sand tagged at 30.5 feet.
Bentonite, 25 pounds, 1/4-inch pellets, tagged at 27 feet.

Table 6. Geologic logs of holes - Concluded

Hole number:	13	Date started:	February 7, 1987
Hydrologist:	Mason	Date finished:	February 7, 1987
Drillers:	Eddy, Rider		
Location:	29N.12W.21.4444		
Land-surface elevation:	5,399.2 feet		

Depth (feet below land surface)	Sampling method C - cuttings, SS - split spoon, S - shelby tube (percent recovery)	Description
0.0- 5.0	C	Sand, 10 YR 5/4, fine to coarse, mostly fine to medium, minor gravel. Moist.
5.0-10.0	C	Sand, 10 YR 5/4, fine to very coarse, mostly coarse. Moist. Minor gravel.
10.0-15.0	C	Sand, 10 YR 5/4, fine to very coarse, mostly coarse to very coarse. Gravel from 10.5 to 12 feet, cobbles to as much as 2 inches. Moist.
15.0-21.0	C	Sand, 10 YR 5/4, fine to very coarse, mostly coarse to very coarse. Thin gravel zones.
21.0-25.0	C	Clay, 10 YR 4/2, soft, no sand. Fast drilling.
25.0-27.0	S (70%)	0.2 foot - clay, 10 YR 4/2, fine to medium sand. 1.2 feet - clay, 10 YR 4/2, minor amounts of sand. Soft and not plastic.
27.0-37.0	C	Clay, 10 YR 4/2, minor amounts of sand. Easy drilling.
37.0-39.0	C	Easy drilling, very soft. Water table?
39.0		Hard drilling. Gravel?
39.0-40.0		Clay, 10 YR 4/2, fine to medium sand. Wet. Soft, auger sank in when disconnected, couldn't sample. After backing out, then returning to 40.0 feet, return is liquid clay-sand mixture, 10 YR 5/4.
40.0-50.0	C	Liquid clay-sand mixture, 10 YR 5/4. Easy drilling. Slight increase in pressure at 43.0 feet. Tighter at 50.0 feet.
50.0-55.0	C	Gravel at 51 feet. Hard clay at 54.5 feet.
55.0-57.0	C	Hard clay. Stopped.

Completion:
Casing - 5-foot 10-slot screen with bottom plug, 30-foot casing.

Table 7. Terrain-conductivity data

Transmit location (meters)	Receive location (meters)	Reading (milli-siemens per meter)	Sensi-tivity	Terrain conduc-tivity (milli-siemens per meter)	Remarks
		Well 3 to well 11 (Horizontal dipole)			
0	20	0.938	30	28	Transmitter at well 3.
0	40	.381	100	38	
20	40	.318	100	32	
20	60	.400	100	40	
40	60	.320	100	32	
40	80	.439	100	44	
60	80	.359	100	36	
60	100	.440	100	44	
80	100	.380	100	38	
80	120	.465	100	46	
100	120	.385	100	38	
100	140	.465	100	46	
120	140	.418	100	42	
120	160	.442	100	44	
140	160	.400	100	40	
140	180	.458	100	46	
160	180	.410	100	41	
160	200	.465	100	46	
180	200	.435	100	44	
180	220	.475	100	48	
200	220	.439	100	44	
200	240	.450	100	45	
220	240	.380	100	38	
220	260	.419	100	42	
240	260	.319	100	32	
240	280	.380	100	38	
260	280	.298	100	30	Receiver at well 11.
		Well 11 to well 6 (Horizontal dipole)			
0	20	0.280	100	28	Transmitter at well 11.
0	40	.340	100	34	
20	40	.280	100	28	
20	60	.340	100	34	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Well 11 to well 6 (Horizontal dipole)			
40	60	0.270	100	27	
40	80	.340	100	34	
60	80	.280	100	28	
60	100	.330	100	33	
80	100	.260	100	26	
80	120	.330	100	33	
100	120	.260	100	26	
100	140	.320	100	32	
120	140	.250	100	25	
120	160	.320	100	32	Receiver about 6 feet north of well 6.
140	160	.250	100	25	
		Well 6 to well 8 (Horizontal dipole)			
0	20	0.820	30	25	Transmitter at well 6.
0	40	.300	100	30	
20	40	.781	30	23	
20	60	.305	100	30	
40	60	.830	30	25	
40	80	.290	100	29	
60	80	.882	30	26	
60	100	.320	100	32	
80	100	.862	30	26	
80	120	.330	100	33	
100	120	.935	30	28	
100	140	.325	100	32	
120	140	.920	30	28	
120	160	.320	100	32	
140	160	.825	30	25	
140	180	.310	100	31	
160	180	.839	30	25	
160	200	.320	100	32	
180	200	.900	30	27	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Well 6 to well 8 (Horizontal dipole)			
180	220	0.350	100	35	
200	220	.305	100	30	
200	240	.380	100	38	
220	240	.339	100	34	
220	260	.415	100	42	
240	260	.380	100	38	
240	280	.420	100	42	
260	280	.390	100	39	
260	300	.440	100	44	
280	300	.381	100	38	
280	320	.425	100	42	
300	320	.358	100	36	
300	340	.420	100	42	
320	340	.360	100	36	
320	360	.381	100	38	
340	360	.340	100	34	Receiver at well 8.
		Well 8 to well 12 (Horizontal dipole)			
0	20	0.900	30	27	Transmitter at well 8.
0	40	.240	100	24	
20	40	.780	30	23	
20	60	.220	100	22	
40	60	.740	30	22	
40	80	.960	30	29	
60	80	.770	30	23	
60	100	.940	30	28	
80	100	.900	30	27	
80	120	.240	100	24	
100	120	.880	30	26	
100	140	.260	100	26	Receiver 10 feet north of well 12.
120	140	.280	100	28	
120	160	.260	100	26	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (milli-siemens per meter)	Sensi-tivity	Terrain conduc-tivity (milli-siemens per meter)	Remarks
		Well 12 to well 13 (Horizontal dipole)			
0	20	0.300	100	30	Transmitter at well 12.
0	40	.280	100	28	
20	40	.290	100	29	
20	60	.290	100	29	
40	60	.330	100	33	
40	80	.300	100	30	
60	80	.390	100	39	
60	100	.320	100	32	
80	100	.350	100	35	
80	120	.330	100	33	
100	120	.330	100	33	
100	140	.310	100	31	
120	140	.340	100	34	
120	160	.320	100	32	
140	160	.340	100	34	
140	180	.320	100	32	
160	180	.330	100	33	
160	200	.320	100	32	
180	200	.320	100	32	
180	220	.330	100	33	
200	220	.340	100	34	
200	240	.330	100	33	Receiver 13 feet north of well 13.
220	240	.360	100	36	
220	260	.320	100	32	
240	260	.320	100	32	
		Well 13 to section corner (Horizontal dipole)			
0	20	0.340	100	34	Transmitter at well 13.
0	40	.310	100	31	
20	40	.300	100	30	
20	60	.300	100	30	
40	60	.300	100	30	

Table 7. **Terrain-conductivity data** - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Well 13 to section corner (Horizontal dipole)			
40	80	0.280	100	28	Receiver 12 feet north of corner.
60	80	.290	100	29	
60	100	.280	100	28	
80	100	.270	100	27	
		Section corner to U.S. Highway 64 (Horizontal dipole)			
0	20	0.860	30	26	Transmitter at section corner.
0	40	.260	100	26	
20	40	.280	100	28	
20	60	.275	100	28	
40	60	.295	100	30	
40	80	.275	100	28	
60	80	.280	100	28	
60	100	.275	100	28	
80	100	.279	100	28	
80	120	.290	100	29	
100	120	.260	100	26	
100	140	.260	100	26	
120	140	.860	30	26	
120	160	.255	100	26	
140	160	.800	30	24	
140	180	.980	30	29	
160	180	.790	30	24	
160	200	.920	30	28	Drifting from 0.90 to 0.94.
180	200	.700	30	21	
180	220	.880	30	26	Drifting from 0.86 to 0.90.
200	220	.620	30	19	
200	240	.840	30	25	Drifting from 0.82 to 0.88.
220	240	.642	30	19	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Section corner to U.S. Highway 64 (Horizontal dipole)			
220	260	0.920	30	28	Drifting from 0.72 to 1.0.
240	260	.725	30	22	
240	280				No reading; receiver about 30 feet from east end of culvert.
		Hole 1 to well 3 to hole 4 (Horizontal dipole)			
0	10	0.630	30	19	Transmitter at hole 1.
0	20	.260	100	26	
0	40	.300	100	30	
10	20	.582	30	17	
20	30	.505	30	15	
20	40	.240	100	24	
20	60	.340	100	34	
30	40	.490	30	15	
40	50	.470	30	14	Receiver 15 feet west of well 3.
40	60	.240	100	24	
40	80	.280	100	28	
50	60	.500	30	15	
60	70	.520	30	16	
60	80	.260	100	26	
60	100	.340	100	34	
70	80	.530	30	16	
80	90	.530	30	16	
80	100	.280	100	28	
80	120	.340	100	34	
90	100	.480	30	14	
100	110	.522	30	16	
100	120	.260	100	26	

Table 7. **Terrain-conductivity data** - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Hole 1 to well 3 to hole 4 (Horizontal dipole)			
100	140	0.360	100	36	
110	120	.575	30	17	
120	130	.575	30	17	
120	140	.310	100	31	
120	160	.380	100	38	
130	140	.640	30	19	
140	150	.705	30	21	
140	160	.320	100	32	Receiver at hole 4.
150	160	.641	30	19	
160	170	.580	30	17	
		(Vertical dipole)			
0	10	0.712	30	21	Transmitter at hole 1.
10	20	.720	30	22	
20	30	.640	30	19	
30	40	.675	30	20	
40	50	.675	30	20	Receiver 15 feet west of well 3.
50	60	.690	30	21	
60	70	.675	30	20	
70	80	.815	30	24	
80	90	.715	30	21	
90	100	.700	30	21	
100	110	.721	30	22	
110	120	.835	30	25	
120	130	.920	30	28	
130	140	.830	30	25	
140	150	.850	30	26	
150	160	.865	30	26	Receiver at hole 4.
160	170	.845	30	25	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (milli-siemens per meter)	Sensi-tivity	Terrain conduc-tivity (milli-siemens per meter)	Remarks
		Temporary reference point to well 8 to hole 10 (Horizontal dipole)			
0	10	0.961	30	29	Transmitter about 170 feet west of well 8.
0	20	.381	100	38	
0	40	.341	100	34	
10	20	.959	30	29	
10	30	.355	100	36	
10	50	.320	100	32	
20	30	.870	30	26	
20	40	.340	100	34	
20	60	.305	100	30	Receiver 10 feet west of well 8.
30	40	.762	30	23	
30	50	.310	100	31	
30	70	.300	100	30	
40	50	.720	30	22	
40	60	.290	100	29	
40	80	.299	100	30	
50	60	.655	30	20	
50	70	.280	100	28	
50	90	.295	100	30	
60	70	.645	30	19	
60	80	.290	100	29	
60	100	.295	100	30	
70	80	.700	30	21	
70	90	.300	100	30	
70	110	.295	100	30	
80	90	.780	30	23	
80	100	.300	100	30	
80	120	.280	100	28	
90	100	.745	30	22	
90	110	.299	100	30	
90	130	.305	100	30	
100	110	.700	30	21	
100	120	.270	100	27	
100	140	.299	100	30	

Table 7. **Terrain-conductivity data** - Continued

Transmit location (meters)	Receive location (meters)	Reading (milli-siemens per meter)	Sensi-tivity	Terrain conduc-tivity (milli-siemens per meter)	Remarks
		Temporary reference point to well 8 to hole 10 (Horizontal dipole)			
110	120	0.640	30	19	
110	130	.300	100	30	
110	150	.300	100	30	
120	130	.705	30	21	
120	140	.318	100	32	
120	160	.350	100	35	Receiver 5 feet west of landfill fence.
130	140	.715	30	21	
130	150	.339	100	34	
130	170				Landfill fence.
140	150	.760	30	23	
140	160	.360	100	36	
150	160	.330	100	33	
		Restart line at landfill fence			
0	10	0.425	100	42	Transmitter at landfill fence.
0	20	.420	100	42	
0	40				Meter would not sta-bilize.
10	20	.280	100	28	
10	30	.400	100	40	
10	50				Landfill fence.
20	30	.320	100	32	
20	40	.435	100	44	
30	40	.380	100	38	
30	50	.405	100	40	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		(Vertical dipole)			
0	10	0.441	100	44	Transmitter about 170 feet west of well 8.
0	20	.420	100	42	
0	40	.385	100	38	
10	20	.310	100	31	
10	30	.370	100	37	
10	50	.270	100	27	
20	30	.370	100	37	
20	40	.390	100	39	
20	60	.315	100	32	Receiver 10 feet west of well 8.
30	40	.299	100	30	
30	50	.360	100	36	
30	70	.300	100	30	
40	50	.310	100	31	
40	60	.360	100	36	
40	80	.239	100	24	
50	60	.300	100	30	
50	70	.400	100	40	
50	90	.290	100	29	
60	70	.310	100	31	
60	80	.360	100	36	
60	100	.279	100	28	
70	80	.300	100	30	
70	90	.325	100	32	
70	110	.240	100	24	
80	90	.320	100	32	
80	100	.320	100	32	
80	120	.275	100	28	
90	100	.319	100	32	
90	110	.370	100	37	
90	130	.275	100	28	
100	110	.335	100	34	
100	120	.381	100	38	
100	140	.360	100	36	
110	120	.320	100	32	

Table 7. **Terrain-conductivity data** - Continued

Transmit location (meters)	Receive location (meters)	Reading (milli-siemens per meter)	Sensi-tivity	Terrain conduc-tivity (milli-siemens per meter)	Remarks
		(Vertical dipole)			
110	130	0.420	100	42	
110	150	.465	100	46	
120	130	.320	100	32	
120	140	.445	100	44	
120	160	.975	100	98	
130	140	.339	100	34	
130	150	.515	100	52	
130	170				Landfill fence.
140	150	.340	100	34	
140	160	.360	300	108	
150	160	.805	100	80	
		Restart line at landfill fence			
0	10	0.430	300	129	Transmitter at landfill fence.
0	20	.635	300	190	
0	40	.400	300	120	
10	20	.490	100	49	
10	30	.699	100	70	
10	50				Landfill fence.
20	30	.440	100	44	
20	40	.560	100	56	
30	40	.545	100	54	
30	50	.695	100	70	
		Temporary reference point to well 13 to well GBR-17 (Horizontal dipole)			
0	10	0.341	100	34	Transmitter about 180 feet west of well 13.
0	20	.339	100	34	
0	40	.300	100	30	
10	20	.265	100	26	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Temporary reference point to well 13 to well GBR-17 (Horizontal dipole)			
10	30	0.305	100	30	
10	50	.290	100	29	
20	30	.755	30	23	
20	40	.305	100	30	
20	60	.275	100	28	Receiver 4 feet west of well 13.
30	40	.750	30	22	
30	50	.282	100	28	
30	70	.295	100	30	
40	50	.705	30	21	
40	60	.300	100	30	
40	80	.318	100	32	
50	60	.710	30	21	
50	70	.300	100	30	
50	90	.300	100	30	
60	70	.750	30	22	
60	80	.300	100	30	
60	100	.285	100	28	
70	80	.860	30	26	
70	90	.340	100	34	
70	110	.305	100	30	
80	90	.845	30	25	
80	100	.340	100	34	
80	120	.305	100	30	
90	100	.825	30	25	
90	110	.320	100	32	
90	130	.298	100	30	Receiver 5 feet east of well GBR-17.
100	110	.850	30	26	
100	120	.340	100	34	
100	140	.295	100	30	
110	120	.845	30	25	
110	130	.320	100	32	
110	150	.285	100	28	
120	130	.900	30	27	
120	140	.320	100	32	

Table 7. Terrain-conductivity data - Continued

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		Temporary reference point to well 13 to well GBR-17 (Horizontal dipole)			
120	160	0.260	100	26	Receiver 10 feet west of underground cable.
130	140	.820	30	25	
130	150	.319	100	32	
		(Vertical dipole)			
0	10	0.430	100	43	Transmitter about 180 feet west of well 13.
0	20	.400	100	40	
0	40	.330	100	33	
10	20	.340	100	34	
10	30	.380	100	38	
10	50	.330	100	33	
20	30	.300	100	30	
20	40	.300	100	30	
20	60	.310	100	31	Receiver 4 feet west of well 13.
30	40	.840	30	25	
30	50	.300	100	30	
30	70	.260	100	26	
40	50	.340	100	34	
40	60	.460	100	46	
40	80	.250	100	25	
50	60	.350	100	35	
50	70	.330	100	33	
50	90	.910	30	27	
60	70	.340	100	34	
60	80	.340	100	34	
60	100	.530	30	16	
70	80	.430	100	43	
70	90	.390	100	39	
70	110	.250	100	25	

Table 7. **Terrain-conductivity data** - Concluded

Transmit location (meters)	Receive location (meters)	Reading (millisiemens per meter)	Sensitivity	Terrain conductivity (millisiemens per meter)	Remarks
		(Vertical dipole)			
80	90	0.330	100	33	
80	100	.840	30	25	
80	120	.840	30	25	
90	100	.320	100	32	
90	110	.360	100	36	
90	130	.250	100	25	Receiver 5 feet east of well GBR-17.
100	110	.430	100	43	
100	120	.430	100	43	
100	140	.330	100	33	
110	120	.340	100	34	
110	130	.340	100	34	
110	150	.900	30	27	
120	130	.360	100	36	
120	140	.360	100	36	
120	160	.270	100	27	Receiver 10 feet west of underground cable.
130	140	.360	100	36	
130	150	.340	100	34	
130	170				Underground cable.

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