Identification of Potential Water-Bearing Zones by the Use of Borehole Geophysics in the Vicinity of Keystone Sanitation Superfund Site Adams County, Pennsylvania and Carroll County, Maryland

by Randall W. Conger

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information
write to:

District Chief
U.S. Geological Survey
840 Market Street
Lemoyne, Pennsylvania 17043-1586

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.00006309	cubic meter per second

Vertical datum: 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

Between April 23, 1996, and June 21, 1996, the U.S. Environmental Protection Agency contracted Haliburton-NUS, Inc., to drill four clusters of three monitoring wells near the Keystone Sanitation Superfund Site. The purpose of the wells is to allow monitoring and sampling of shallow, intermediate, and deep water-bearing zones for the purpose of determining the horizontal and vertical distribution of any contaminated ground water migrating from the Keystone Site. Twelve monitoring wells, ranging in depth from 50 to 397.9 feet below land surface, were drilled in the vicinity of the Keystone Site. The U.S. Geological Survey conducted borehole-geophysical logging and determined, with geophysical logs and other available data, the ideal intervals to be screened in each well. Geophysical logs were run on four intermediate and four deep wells, and a caliper log only was run on shallow well CL-AD-173 (HN-1S). Interpretation of geophysical logs and existing data determined the placement of screens within each borehole.

INTRODUCTION

The Keystone Sanitation Superfund Site was an active landfill that accepted household, municipal, and some industrial and construction wastes from before 1966 until April 1990. In 1982, the Pennsylvania Department of Environmental Protection discovered volatile organic compounds (VOC's) in an on-site monitoring well and a nearby spring. Subsequent sampling by the U.S. Environmental Protection Agency (USEPA) in 1984 confirmed the presence of VOC's in off-site residential wells.

In 1987, the Keystone Site was added to the National Priorities List. The USEPA took the lead on the Remedial Investigation/Feasibility Study (RI/FS) in 1989. The purpose of the RI/FS was to evaluate the nature and extent of hazardous contamination and determine cost-effective remediation alternatives for the Keystone Site. In 1990, a Record of Decision (ROD) was signed by USEPA that specified a landfill cap and ground-water withdrawal and treatment as the remedies for contamination from the landfill site (Operable-Unit 1). In addition, the ROD provided for further study of off-site Operable-Unit 2 (OU-2) contamination. An RI/FS for OU-2 is currently being conducted by Haliburton-NUS, Inc. (NUS), to characterize the nature and extent of hazardous contamination and determine cost-effective remediation alternatives for off-site contamination.

Purpose and Scope

This report evaluates borehole geophysical-log data from nine boreholes in the vicinity of the Keystone Site. The borehole geophysical logs were run from April 23, 1996, to June 21, 1996. In 1996, the U.S. Geological Survey (USGS), in cooperation with the USEPA, conducted a geophysical investigation in vicinity of Keystone Sanitation Superfund Site. The purpose of this investigation is to identify potential water-bearing zones to screen and monitor in each borehole by the use of geophysical data and television camera surveys (borehole video logs). Caliper, natural-gamma (gamma), single-point-resistance, fluid-resistivity, fluid-temperature, and borehole-flow (heat-pulse-flowmeter) logs were collected in eight boreholes. Borehole video logs were collected in six boreholes. A caliper log only was collected in CL-AD-173.

Description of Study Area

The study area is located on the USGS, Littlestown, Maryland-Pennsylvania, 7.5-minute topographic quadrangle map. The Keystone Site is located on a 40-acre tract of land in Union Township, Adams County, Pa., less than 0.2 mi from the Maryland state line (fig. 1).

The Keystone Site and surrounding study area are situated in the Piedmont Upland Physiographic Section of the Piedmont Physiographic Province. The physiography of the area is characterized by broad, rolling uplands with some steep-sided valleys. The area is underlain predominantly by the Marburg Schist of pre-Cambrian to Cambrian age. These rocks are mapped as the Babylon Phyllite Member of the Marburg Formation in Maryland. The Marburg Schist is a muscovite-chlorite-albite-quartz schist, which is bluish-gray to silvery-green in appearance (Haliburton-NUS, Inc., written commun., 1995, p. 2-7). About 2,300 ft northwest of the Keystone Site, the area is underlain by the Antietam and Harpers Formations of Cambrian Age. These similar formations, which are mapped together, consist of quartzite, quartzose-schist, phyllite, and albite-mica schist (Haliburton-NUS, Inc., written commun., 1995, p. 2-9). The bedrock is overlain by a highly variable thickness of saprolitic, clayey regolith, which grades into competent bedrock. Average thickness of the regolith is about 45 ft (Haliburton-NUS, Inc., written commun., 1995, p. 2-9).

Ground water is in the pore spaces of the regolith and fractures of the bedrock. Preliminary investigations from NUS indicated that most ground water is stored at shallow depths (less than 45 ft) within the regolith because of its greater porosity compared to the fractured schist, phyllite, and quartzite bedrock. The saturated regolith and shallow, fractured bedrock are well connected hydraulically at the site as evidenced by water-level fluctuations caused by pumping (Haliburton-NUS, Inc., written commun., 1995); however, below depths of about 150 ft, a good connection between the water-bearing fractures and regolith is less certain. Most significant water-bearing zones are found within the bedrock at depths less than about 150 ft (Haliburton-NUS, Inc., written commun., 1995, p. 2-16).

The potential for ground-water movement is, in general, from topographic high areas to discharge areas in valleys (Haliburton-NUS, Inc., written commun., 1995, p. 2-16). Ground-water-flow paths are believed to be short; thus, most discharge should occur to local springs and streams. However, specific flow paths of ground water are more difficult to characterize because they can be affected greatly by the anisotropy of the foliated bedrock and the heterogeneity of the water-bearing zones.

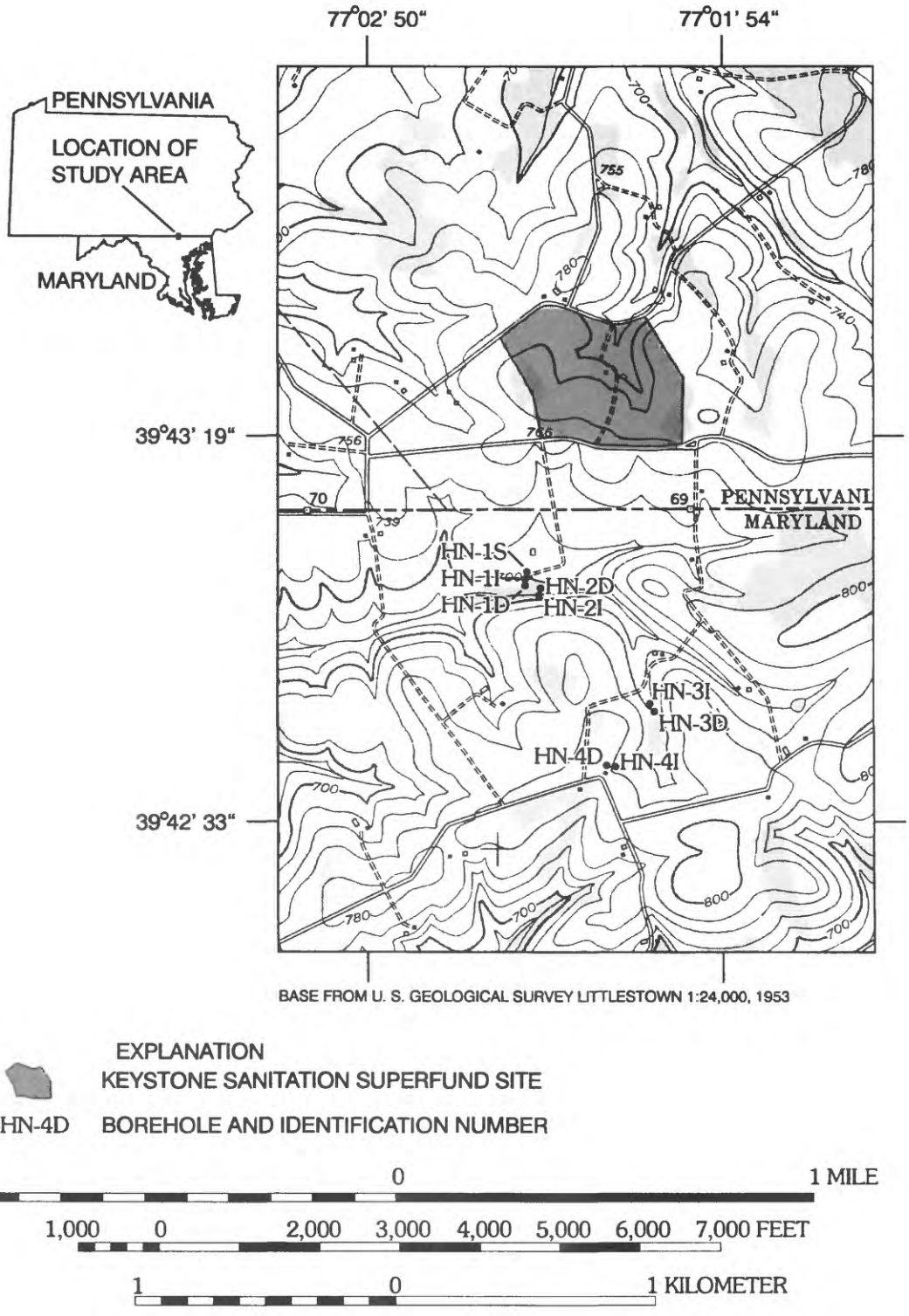

Figure 1. Location of Keystone Sanitation Superfund Site, Adams County, Pennsylvania, and Carroll County, Maryland.

BOREHOLE GEOPHYSICAL LOGGING

Geophysical Logs

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. Caliper logs are used to help correlate lithostratigraphy, identify fractures and possible water-bearing openings, and qualitatively correct other geophysical logs for changes in borehole diameter. Correlation of caliper logs with fluid-resistivity and fluid-temperature logs is used to identify fractures and water-producing and water-receiving zones and to measure fluid velocity.

The term fracture, used in association with caliper log interpretations, can have several different definitions. Those definitions include a bedding plane separation, lithologic contact, and water-producing or water-receiving zones. The term fracture also may simply indicate an enlargement of the borehole.

The natural-gamma or gamma log is a record of the amount of natural-gamma radiation emitted by rock material surrounding a borehole as a function of depth. Most gamma radiation from earth materials is emitted by potassium-40 and daughter products of the uranium and thorium decay series. The gamma log can be recorded through casing, but the readings are dampened. Generally, clay and shale emit higher gamma radiation than sandstone or carbonate rock. The primary uses of gamma logs are correlation of rock units and general lithologic identification (Keys, 1988).

Single-point-resistance logs record the electrical resistance between the borehole and an electrical ground at land surface in a water-filled open borehole. Generally, resistance increases with grain size and decreases with borehole diameter, density of water-bearing fractures, and increasing dissolved-solids concentration of borehole fluid. A fluid-filled borehole is required for single-point-resistance logs, and they are run only for the saturated part of the formation below the casing. Single-point-resistance logs are used to correlate lithostratigraphy and may help to identify the location of water-bearing zones (Keys and MacCary, 1971).

Fluid-resistivity logs measure the electrical resistance of fluid in the uncased section of the borehole. Fluid resistivity is the reciprocal of fluid conductivity. Fluid-resistivity logs reflect changes in the dissolved-solids concentration of the borehole fluid. Fluid-resistivity logs are used to identify water-producing and water-receiving zones and determine intervals of vertical borehole flow. Water-producing and water-receiving zones are identified by sudden changes in resistivity, and intervals of borehole flow are identified by little or no resistivity gradient between water-producing and water-receiving zones (Conger, 1996).

Fluid-temperature logs provide a continuous record of the temperature of the fluid in the uncased section of the borehole. Fluid-temperature logs are used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Intervals of vertical borehole flow are identified by little or no temperature gradient (Williams and Conger, 1990).

The direction and rate of borehole-fluid movement was determined by the use of a heat-pulse flowmeter. The heat-pulse flowmeter operates by heating a small sheet of water between two sensitive thermistors (heat sensors). A measurement of direction and rate is computed when a peak temperature is recorded by one of the thermistors. The range of flow measurement is about 0.01-1.0 gal/min in a 2- to 8-in.-diameter borehole (Conger, 1996).

The heat-pulse flowmeter can be used under both ambient and pumping conditions. After collecting borehole-flow measurements under ambient conditions, a pump can be lowered inside the water column and pumped at a small rate, usually less than 1 gal/min. After drawdown caused by pumping has stabilized, the flow can again be measured at the same depths as before pumping. The difference in the flow rate between ambient and pumping conditions identifies the zones in the borehole with the greatest water production.

Some heat-pulse flowmeter measurements may be influenced by (1) poor seal integrity between the borehole and heat-pulse flowmeter, and (2) contributions of water from storage within the borehole. If the seal between the borehole and flowmeter is not complete, some water can bypass the flowmeter, resulting in flow measurements that are less than the actual rate. When flowmeter measurements are conducted under pumping conditions, some measurements of flow rate may be affected if the water level in the borehole has not stabilized. When drawdown has not completely stabilized, a portion of the discharge water is contributed from storage within the borehole rather than from the aquifer. Although the heat-pulse flowmeter is a calibrated probe, the data are primarily used as a relative indicator to identify water-producing and water-receiving zones.

Video Logs

Earth Data, Incorporated, collected borehole video logs by lowering a waterproof camera down selected boreholes and recording the results on videotape. Where applicable, the video logs were used in the interpretation of the geophysical logs.

IDENTIFICATION OF POTENTIAL WATER-BEARING ZONES

The locations of nine boreholes in the vicinity of the Keystone Site in which geophysical-log data were collected for this study are shown on figure 1. A cross-reference between well numbers used by USGS and NUS are given in table 1. Geophysical logs were run in selected wells to determine the depth to install plastic screens at water-producing or water-receiving zones.

CL-AD-173 (HN-1S)

The caliper log shows that the total depth of the borehole is 50 ft. The caliper log shows fractures at 6-11, 13, 17, 23, 27-29, 32, 33, and 42-44 ft bls (below land surface) (fig. 2). Because the borehole was not water filled at the time of logging and because of time constraints, other logs were not run in the borehole. NUS installed 2-in.-diameter plastic screen in the borehole at 40-50 ft bls.

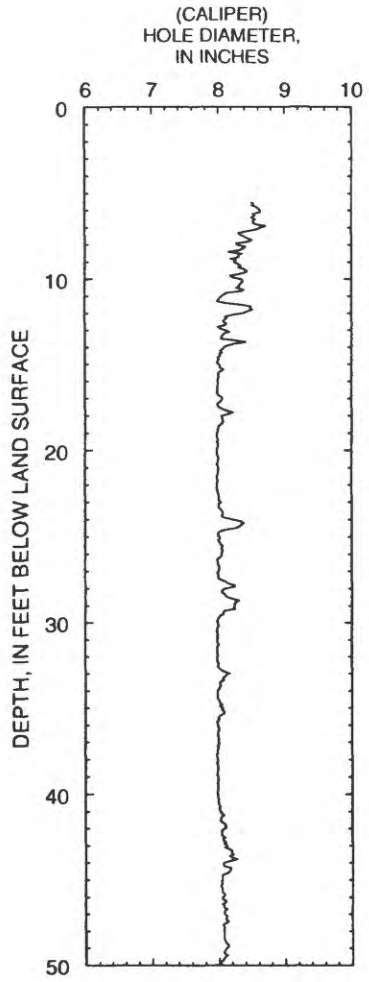

Figure 2. Borehole-geophysical log for borehole CL-AD-173 (HN-1S), Keystone Sanitation Superfund Site.

Table 1. *Boreholes logged at Keystone Sanitation Superfund Site*

[C, caliper log; G, natural-gamma log; R, single-point-resistance log; F, fluid-resistivity log; B, borehole video; T, fluid-temperature log; V, borehole-flow measurement]

U.S. Geological Survey well number	Haliburton-NUS well number	Depth logged (feet)	Geophysical logs run
CL-AD-173	HN-1S	50	C
CL-AD-174	HN-1I	149	C, G, R, F, B, T, V
CL-AD-175	HN-1D	398	C, G, R, F, B, T, V
CL-AD-177	HN-2I	148	C, G, R, F, B, T, V
CL-AD-178	HN-2D	393	C, G, R, F, B, T, V
CL-AD-180	HN-3I	147	C, G, R, F, B, T, V
CL-AD-181	HN-3D	397	C, G, R, F, B, T, V
CL-AD-183	HN-4I	146	C, G, R, F, T, V
CL-AD-184	HN-4D	393	C, G, R, F, T, V

CL-AD-174 (HN-1I)

The caliper log shows that the total depth of the borehole is 149 ft and that it is cased with 8-in.-diameter casing to 51 ft bls (fig. 3). The caliper log shows major fractures at 82-84 and 88-92 ft bls. The fluid-resistivity log shows a change in slope at 82 and 90 ft bls that correlates to fractures on the caliper log. The television survey shows an abrupt clearing of the borehole fluid at 85 ft bls, indicating a possible water-producing zone. Under ambient conditions, the heat-pulse flowmeter measured upward borehole flow at 57 and 70 ft bls and no flow at 100 ft bls (table 2). The geophysical logs and the heat-pulse-flowmeter data indicate water enters the borehole through fractures at 82-84 or 88-92 ft bls, moves upward, and exits the borehole through the fracture at 53 ft bls. Straddle-packer data indicate the zones at 78-86.8 and 87-95.8 ft bls are the major water-producing zones in the borehole. A screen placed at 82-92 ft bls would include the water-producing zones at 82-84 and 88-92 ft bls. A screen placed at 50-55 ft bls would include the water-receiving fracture at 53 ft bls. NUS installed 2-in.-diameter plastic well screen in the borehole at 78-93 ft bls.

Table 2. *Summary of heat-pulse-flowmeter measurements for borehole CL-AD-174 (HN-1I) at Keystone Sanitation Superfund Site*

[ft bls, feet below land surface; gal/min, gallon per minute]

Depth (ft bls)	Ambient conditions	
	Flow rate (gal/min)	Flow direction
57	0.12	Up
70	.09	Up
100	No flow	No flow

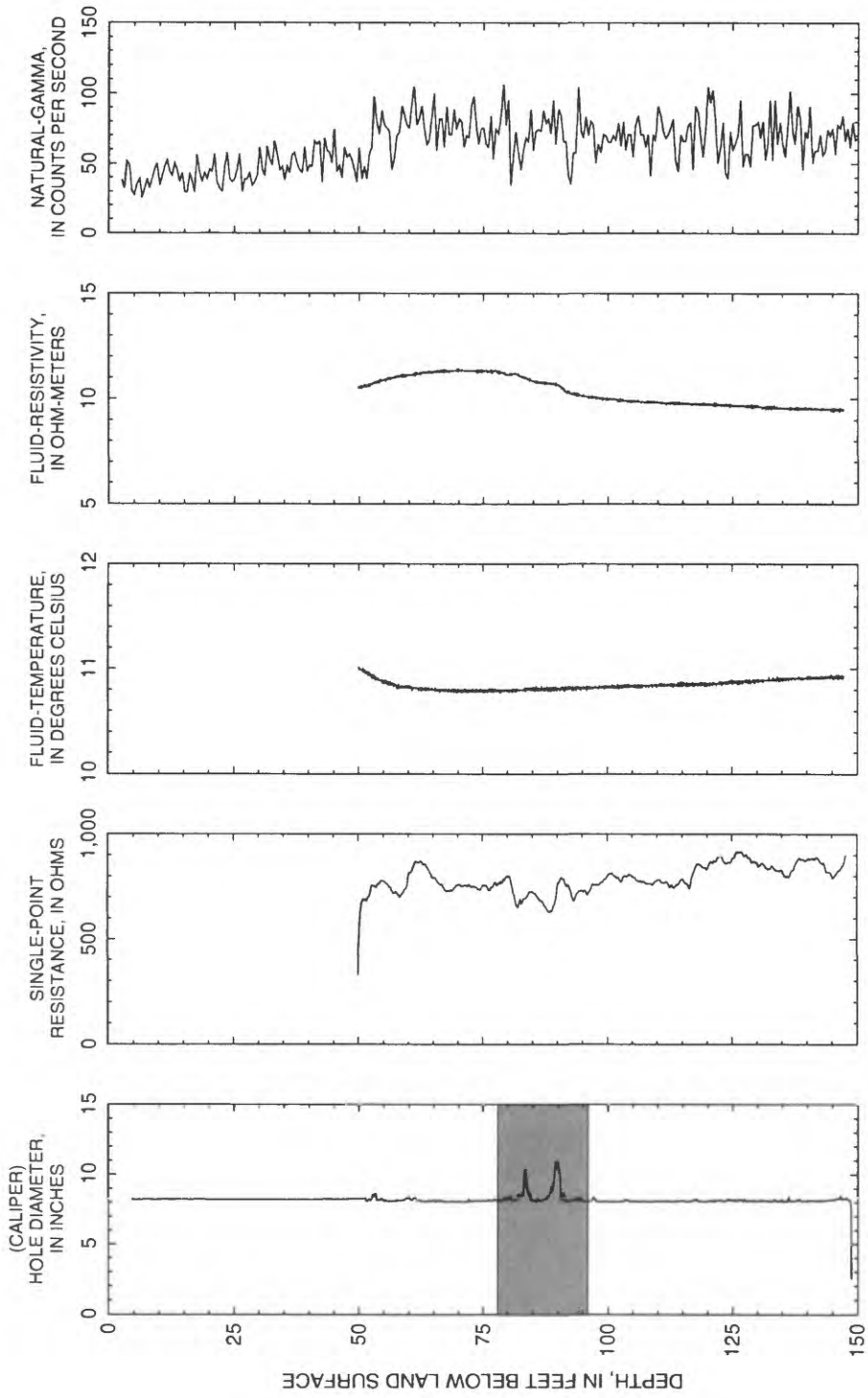

Figure 3. Borehole-geophysical logs for borehole CL-AD-174 (HN-1I), Keystone Sanitation Superfund Site. Shaded area on caliper log shows water-producing zone.

CL-AD-175 (HN-1D)

The caliper log shows that the total depth of the borehole is 397.9 ft and that it is cased with 8-in.-diameter casing to 49 ft bls (fig. 4). The caliper log shows major fractures at 123-126 and 184-186 ft bls plus numerous minor fractures throughout the borehole. The television survey shows an abrupt clearing of the borehole fluid at 89 ft bls, indicating a possible water-producing zone. Under ambient conditions, the heat-pulse-flowmeter measurements indicate no borehole flow at 142, 169, and 190 ft bls (table 3). A submersible pump was placed at 98 ft bls, and the borehole was pumped at a rate less than 1 gal/min. The water level in the borehole declined 3.06 ft after 16 minutes of pumping before beginning to stabilize. Under pumping conditions, the heat-pulse-flowmeter measurements showed no upward borehole flow at 115, 142, 169, and 190 ft bls. The suite of geophysical logs, television survey, heat-pulse flowmeter, and drilling data indicates the greatest water production is available from the interval between 54 and 89 ft bls. Screen(s) could be placed in the borehole such that one or more zones from 54 to 89 ft bls are isolated. NUS installed 2-in.-diameter plastic screen in the borehole at 151-166 ft bls.

Table 3. *Summary of heat-pulse-flowmeter measurements for borehole CL-AD-175 (HN-1D) at Keystone Sanitation Superfund Site*

[ft bls, feet below land surface; gal/min, gallon per minute]

Depth (ft bls)	Ambient conditions		Pumping conditions
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)
115	Not measured	Not measured	No flow
142	No flow	No flow	No flow
169	No flow	No flow	No flow
190	No flow	No flow	No flow

CL-AD-177 (HN-2I)

The caliper log shows that the total depth of the borehole is 148 ft and that it is cased with 8-in.-diameter casing to 50 ft bls (fig. 5). The caliper log shows fractures at 57, 73, 88, 98-103, and 123 ft bls plus several other minor fractures throughout the borehole. The fluid-resistivity and fluid-temperature logs show changes in slope near the bottom of casing at approximately 50 ft bls, which indicates no borehole flow. The fluid-temperature log shows a consistent increase in temperature with depth, indicating no vertical borehole flow. The geophysical logs, drilling, and the television survey do not identify water-producing zones within the borehole. This borehole could be left as an open-hole monitoring well. NUS installed 2-in.-diameter plastic screen at 66-76 ft bls.

CL-AD-178 (HN-2D)

The caliper log shows that the total depth of the borehole is 393 ft and that it is cased with 8-in.-diameter casing to 50 ft bls (fig. 6). The caliper log shows numerous very small fractures throughout the open borehole. Fine-grain sediment caused the caliper probe to respond abnormally near the bottom of the hole. The fluid-temperature log shows a consistent temperature gradient from 50 to 392 ft bls, indicating little or no vertical borehole flow. The fluid-resistivity log shows a change in slope at 74 ft bls that correlates to a small fracture on the caliper log. Changes in fluid resistivity from approximately 40 to 70 ft bls may be caused by slight water inflow from around the bottom of casing. Changes in slope in the fluid-resistivity log at 330-360 ft bls are

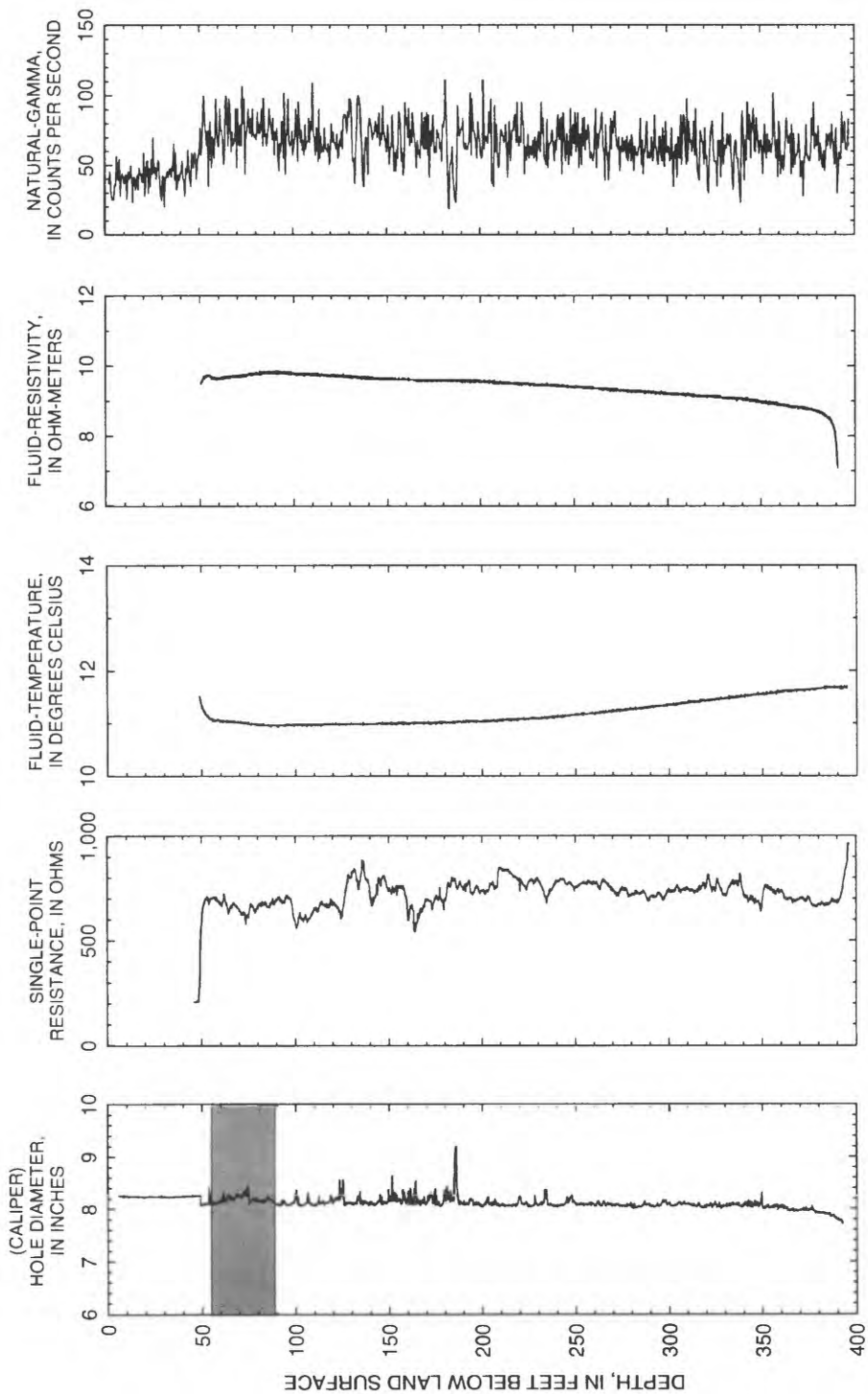

Figure 4. Borehole-geophysical logs for borehole CL-AD-175 (HN-1D), Keystone Sanitation Superfund Site. Shaded area on caliper log shows water-producing zone.

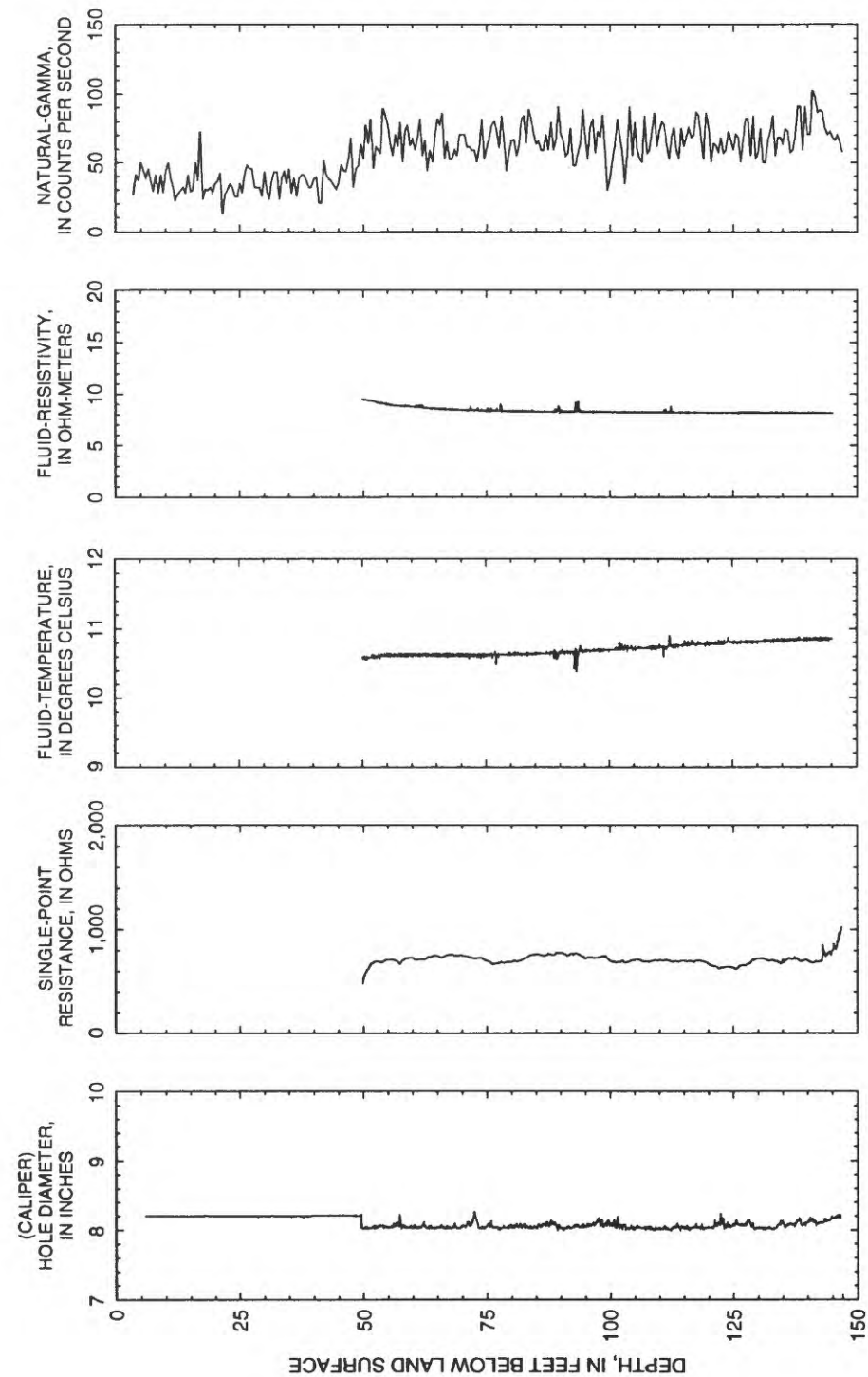

Figure 5. Borehole-geophysical logs for borehole CL-AD-177 (HN-2I), Keystone Sanitation Superfund Site.

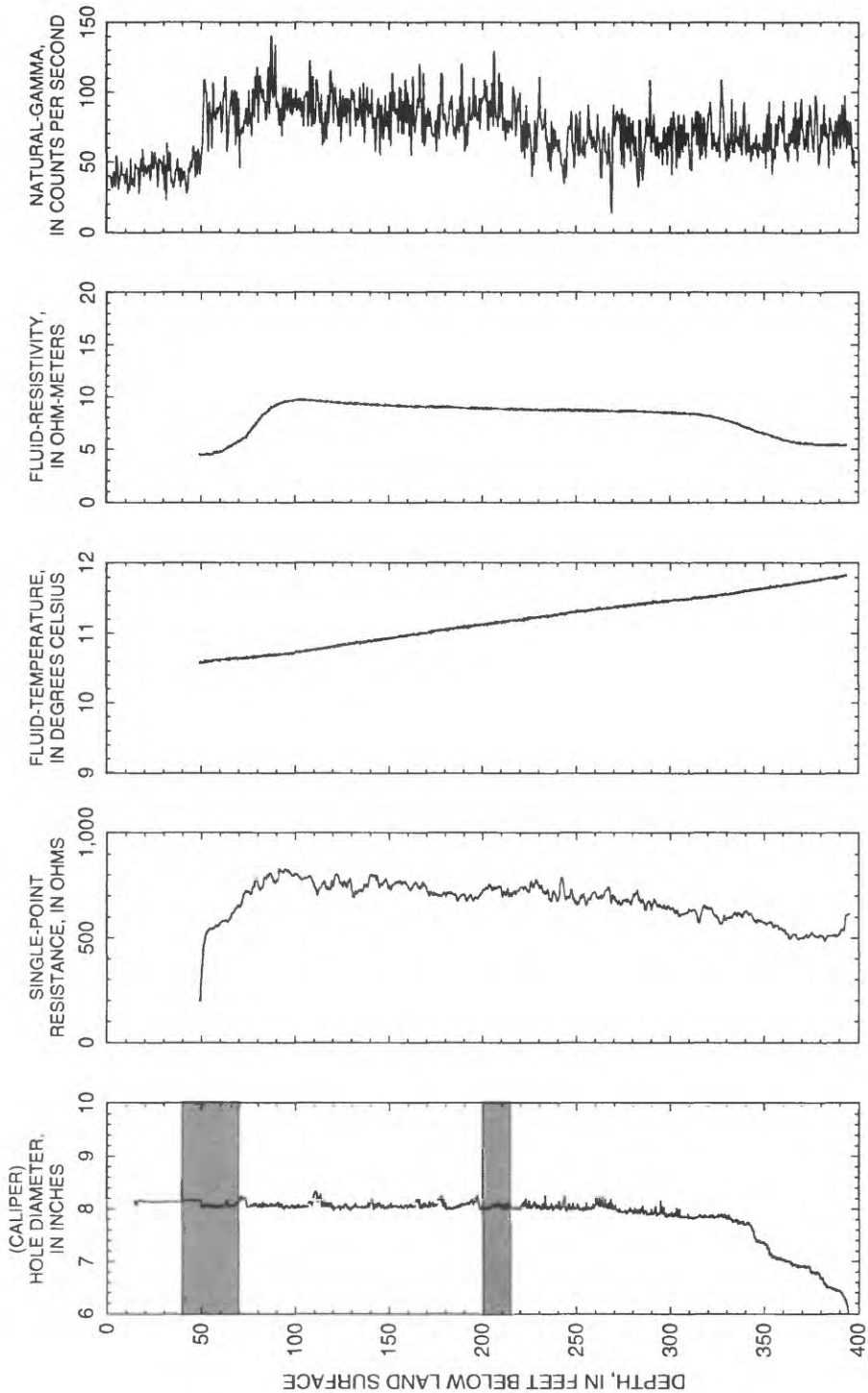

Figure 6. Borehole-geophysical logs for borehole CL-AD-178 (HN-2D), Keystone Sanitation Superfund Site. Shaded areas on caliper log show water-producing zones.

probably caused by the probe scraping the borehole wall during descent. Water-bearing zones reported on the drilling log were encountered at 18-20 and between 200 and 215 ft bls. The upper water-bearing zone was cased and grouted off; the lower water-bearing zone was reported on the drilling log to yield less than 0.5 gal/min. A screen placed in the borehole from 200 to 220 ft bls would include the water-producing zone reported on the drilling log at 215 ft bls. NUS installed 2-in.-diameter plastic screen in the borehole at 109-119 ft bls.

CL-AD-180 (HN-3I)

The caliper log shows that the total depth of the borehole is 147 ft and that it is cased with 8-in.-diameter casing to 59 ft bls (fig. 7). The caliper log shows minor fractures throughout the open borehole. Fine-grain sediment apparently obstructed the proper opening of the caliper-probe logs, causing the probe to respond abnormally. The fluid-temperature log shows a consistent increase in temperature with depth, indicating little or no vertical borehole flow. The fluid-resistivity log shows a minor change in slope at 60-90 ft bls that correlates with a fracture zone on the caliper log. The geophysical logs do not conclusively identify water-producing zones within the borehole. The straddle-packer data show a water-bearing zone between 80.5 and 89.5 ft bls. The drilling data show a water-bearing zone between 76 to 82 ft bls. A screen placed in the borehole from 70 to 90 ft bls would include the water-producing zones shown in the straddle packer data at 80.5-89.5 ft bls and the drilling log at 76-82 ft bls. NUS installed 2-in.-diameter plastic screen in the borehole at 80-90 ft bls.

CL-AD-181 (HN-3D)

The caliper log shows that the total depth of the borehole is 397 ft and that it is cased with 8-in.-diameter casing to 60 ft bls (fig. 8). The caliper log shows a major fracture at 69-74 ft bls plus additional smaller fractures throughout the borehole. From 250 to 400 ft bls, fine-grain sediment in the well caused the caliper probe to possibly react abnormally. The fluid-resistivity log shows a change in slope at 366 ft bls that is probably caused by the probe scraping the side of the borehole. Under ambient conditions, the heat-pulse-flowmeter measurements indicate upward borehole flow at 80 ft bls. The heat-pulse-flowmeter measurements indicated upward borehole flow at 130 ft bls initially, then no flow thereafter (table 4). The suite of geophysical logs and heat-pulse-flowmeter measurements indicate that water enters the borehole through fractures between 88-118 ft bls, moves upward, and exits the borehole through the fracture at 69-74 ft bls. Straddle-packer data indicate water-producing zones are located at 67.5-76.5 and 150.5-159.5 ft bls. A screen placed in the borehole from 65 to 80 ft bls and from 150 to 160 ft bls would include the water-producing zones at 67.5-76.5 ft bls and 150.5-159.5 ft bls. NUS installed 2-in.-diameter plastic screen in the borehole at 65-75 ft bls.

Table 4. *Summary of heat-pulse-flowmeter measurements for borehole CL-AD-181(HN-3D) at Keystone Sanitation Superfund Site*

[ft bls, feet below land surface; gal/min, gallon per minute]

Depth (ft bls)	Ambient conditions	
	Flow rate (gal/min)	Flow direction
80	0.14	Up
130	.095	Up[1]

[1] First measurement showed upward flow; thereafter, no flow was observed.

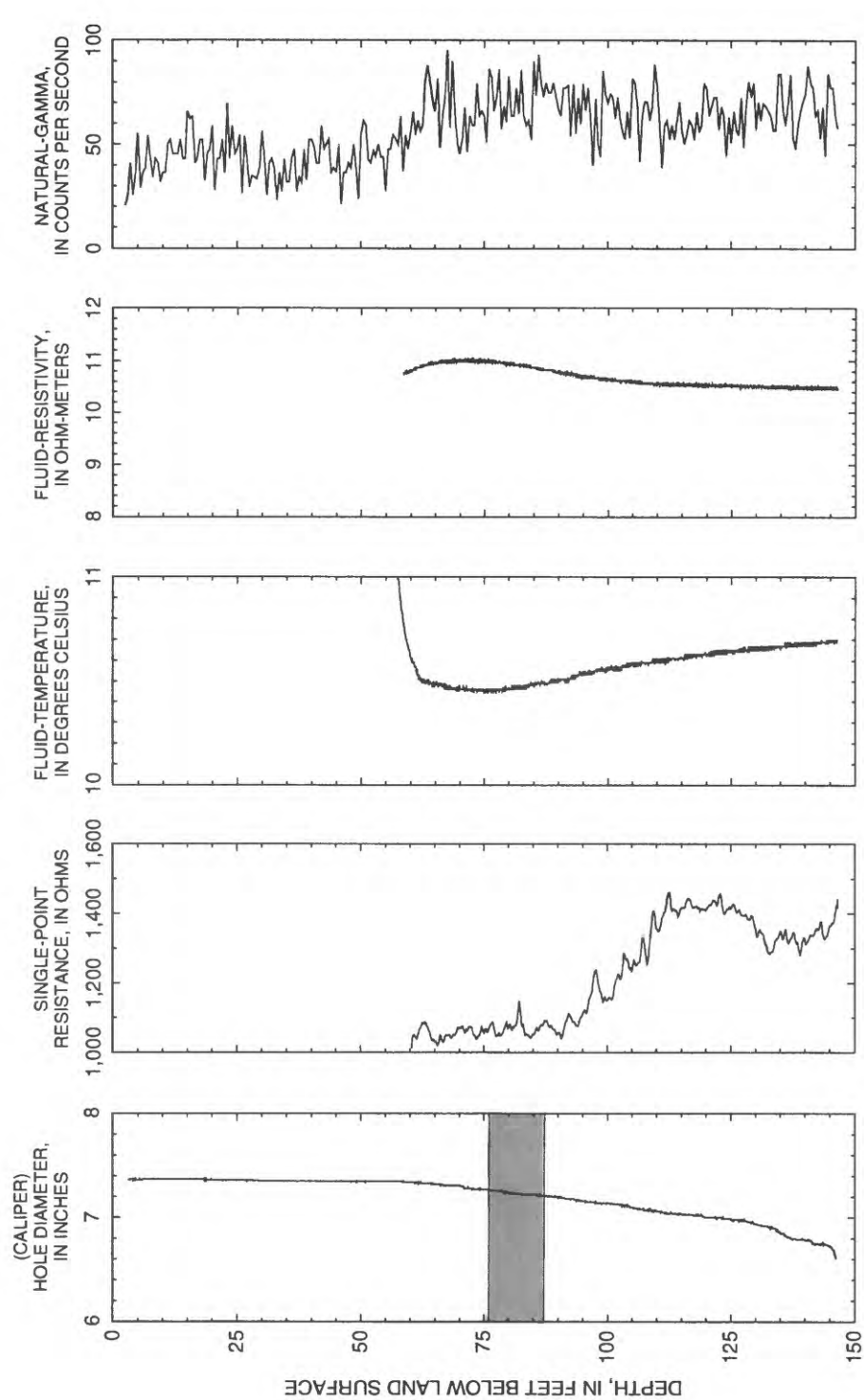

Figure 7. Borehole-geophysical logs for borehole CL-AD-180 (HN-3I), Keystone Sanitation Superfund Site. Shaded area on caliper log shows water-producing zone.

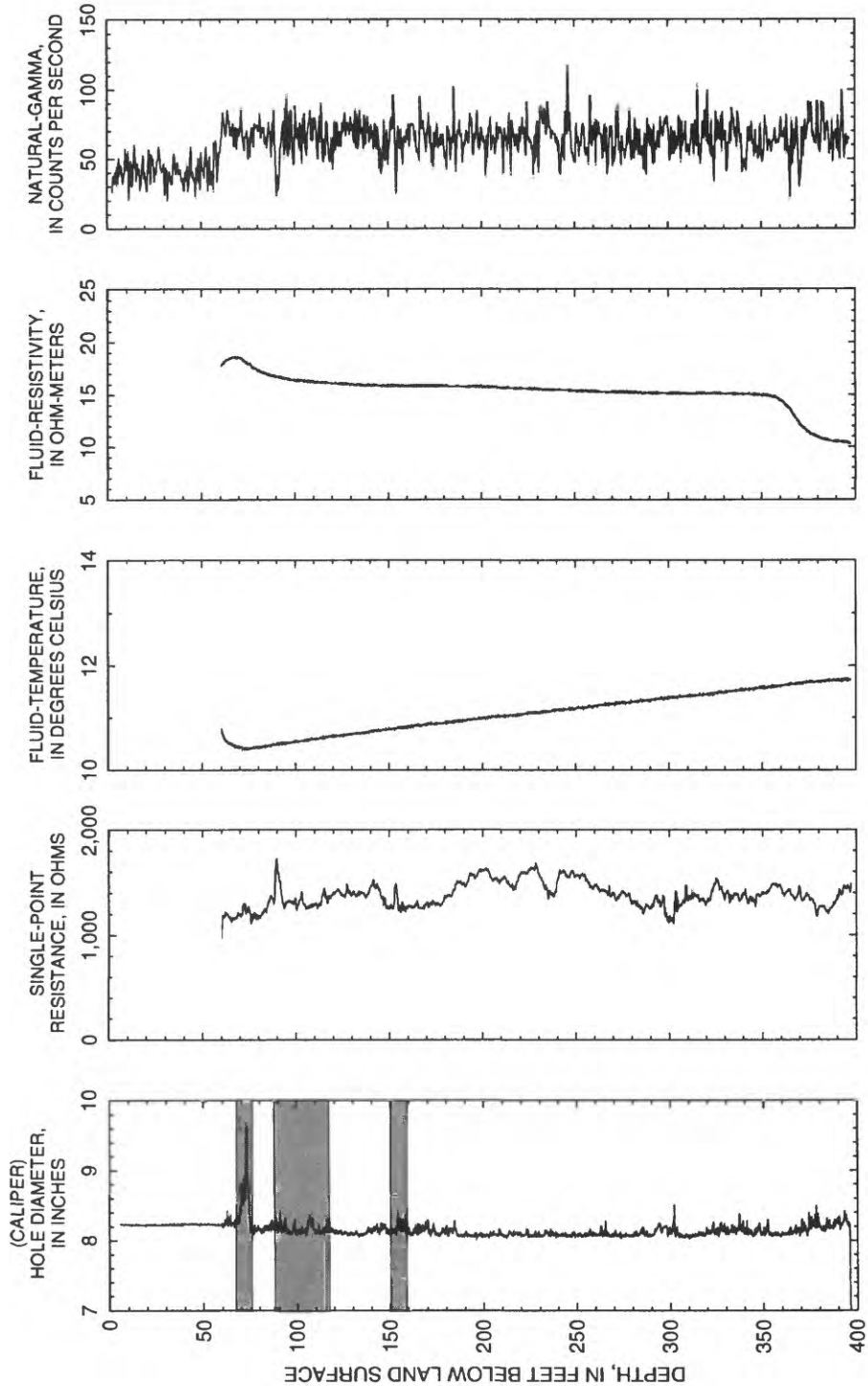

Figure 8. Borehole-geophysical logs for borehole CL-AD-181 (HN-3D), Keystone Sanitation Superfund Site. Shaded areas on caliper log show water-producing zones.

CL-AD-183 (HN-4I)

The caliper log shows that the total depth of the borehole is 146 ft and that it is cased with 8-in.-diameter casing to 65 ft bls (fig. 9). The caliper log shows fractures at 66-68, 80-82, 106-108, and 137-139 ft bls. The fluid-resistivity and fluid-temperature logs show minor changes in slope at 66-80 ft bls. The heat-pulse-flowmeter measurements indicate upward borehole flow at 75, 85, 102, and 130 ft bls. (table 5). The suite of geophysical logs and heat-pulse-flowmeter measurements indicate that water enters the borehole through the fractures at 137-139 ft bls, moves upward, and exits the borehole through the fracture at 66-68 ft bls. A screen placed at 134-144 ft bls would include the water-producing zone at 137-139 ft bls. A screen placed at 65-70 ft bls would include the water-receiving fracture at 66-68 ft bls. NUS installed 2-in.-diameter plastic screen in the borehole at 133-143 ft bls.

Table 5. *Summary of heat-pulse-flowmeter measurements for borehole CL-AD-183 (HN-4I) at Keystone Sanitation Superfund Site*

[ft bls, feet below land surface; gal/min, gallon per minute]

Depth (ft bls)	Ambient conditions	
	Flow rate (gal/min)	Flow direction
75	0.13	Up
85	.13	Up
102	.10	Up
130	.07	Up

CL-AD-184 (HN-4D)

The caliper log shows that the total depth of the borehole is 393 ft and that it is cased with 8-in.-diameter casing to 58 ft bls (fig. 10). The caliper log shows major fractures at 60-64 and 78-80 ft bls plus numerous smaller fractures throughout the borehole. The fluid-resistivity log shows a change in slope at 66, 90, 112, and 140 ft bls that approximately correlates to fractures shown on the caliper log. The heat-pulse-flowmeter measurements indicate no borehole flow at 68, 74, 94, and 114 ft bls (table 6). The drilling-log data indicate water-bearing zones at 75 and 80-82 ft bls that are in proximity to fractures seen on the caliper log at 61-63 and 78-80 ft bls. A screen placed at 58-68 ft bls would include the water-producing zone at 61-63 ft bls. A screen placed at 77-92 ft bls would include the water-producing fracture at 78-80 ft bls and the possible water-producing zone at approximately 89 ft bls. NUS installed 2-in.-diameter plastic screen in the borehole at 78-88 ft bls.

Table 6. *Summary of heat-pulse-flowmeter measurements for borehole CL-AD-184 (HN-4D) at Keystone Sanitation Superfund Site*

[ft bls, feet below land surface; gal/min, gallon per minute]

Depth (ft bls)	Flow rate under ambient conditions (gal/min)
68	No flow
74	No flow
94	No flow
114	No flow

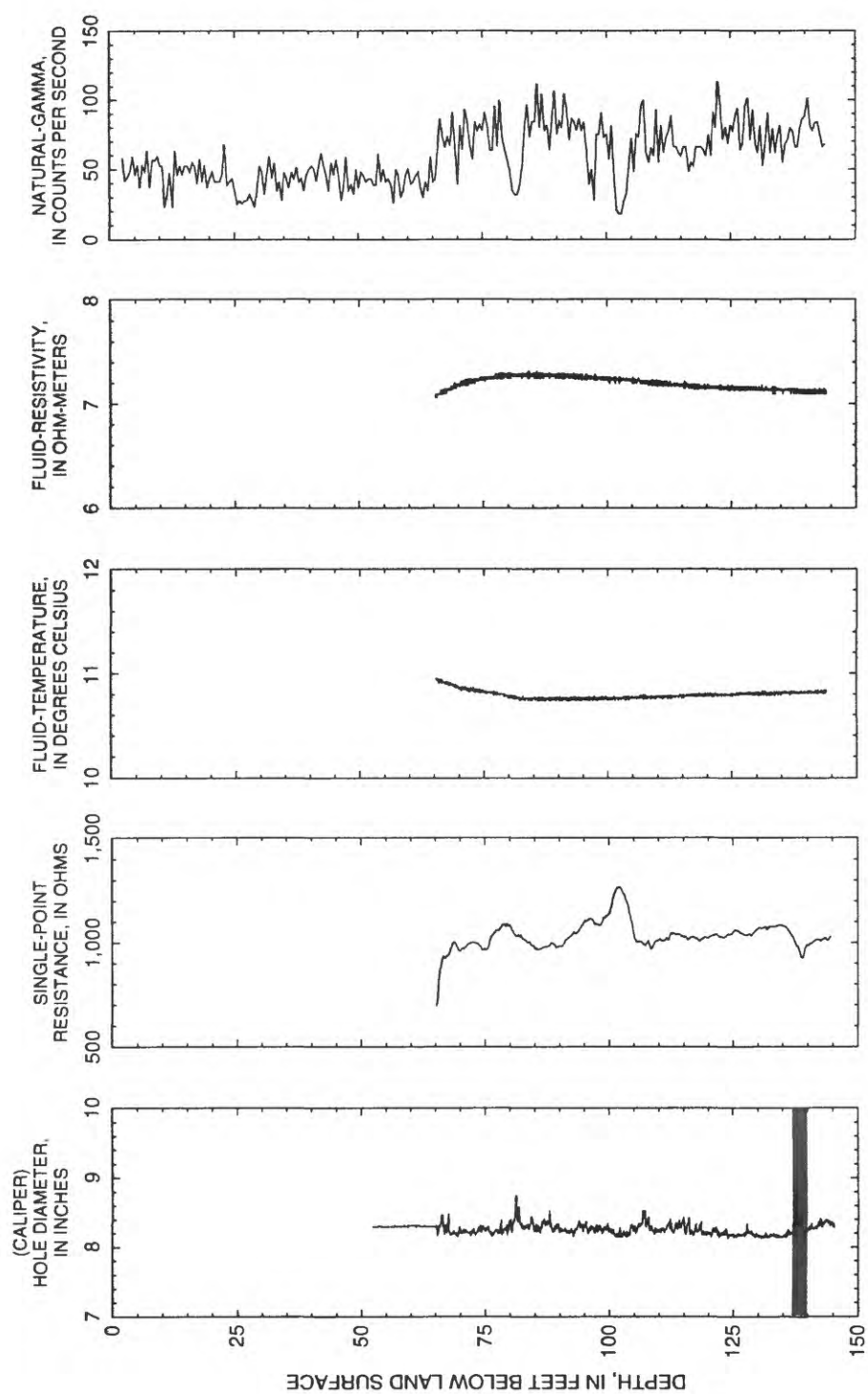

Figure 9. Borehole-geophysical logs for borehole CL-AD-183 (HN-4I), Keystone Sanitation Superfund Site. Shaded area on caliper log shows water-producing zone.

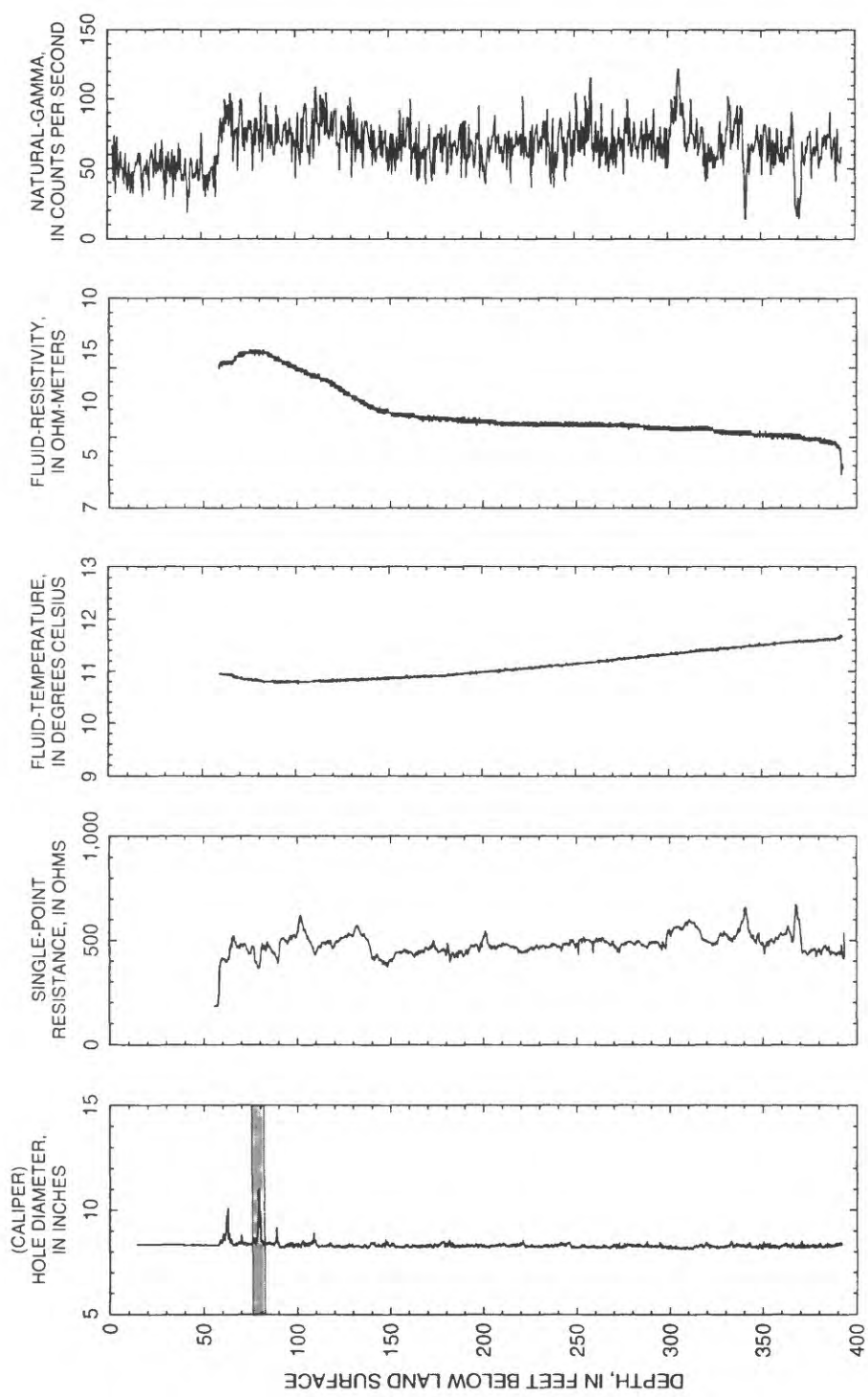

Figure 10. Borehole-geophysical logs for borehole CL-AD-184 (HN-4D), Keystone Sanitation Superfund Site. Shaded area on caliper log shows water-producing zone.

SUMMARY

Only boreholes CL-AD-174, CL-AD-175, CL-AD-181, and CL-AD-183 show ambient vertical borehole flow. In these boreholes, water is produced through fractures between 82-139 ft bls, moves upward, and exits the borehole through fractures between 50-75 ft bls. Specifically, water-producing zones in all intermediate and deep boreholes yield 5 gal/min or less, except for CL-AD-174 and CL-AD-175, which intersect major fractures. Driller reported yields for wells CL-AD-174 and CL-AD-175 are about 12 and 15 gal/min, respectively.

Generally, water is more available in the weathered overburden and decreases with depth. All major water-bearing zones are less than 150 ft bls, and ambient borehole flow does not occur at depths greater than 140 ft bls.

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