U.S. Department of the Interior
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EVALUATION OF GEOPHYSICAL LOGS, PHASE II, NOVEMBER 1998 TO MAY 1999, AT CROSSLEY FARMS SUPERFUND SITE, BERKS COUNTY, PENNSYLVANIA

by Randall W. Conger

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U.S. DEPARTMENT OF THE INTERIOR

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CONTENTS

Page

ILLUSTRATIONS

Page

ILLUSTRATIONS—Continued

Page

TABLES

Page

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile	1.609	kilometer
gallon per minute (gal/min)	0.00006309	cubic meter per second

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

Abbreviated water-quality units used in report:

µg/L, micrograms per liter

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ABSTRACT

Between November 1998 and May 1999, geophysical logging was conducted in 29 boreholes at the Crossley Farms Superfund Site, Hereford Township, Berks County, Pa., to determine the fluid-producing zones, fluid-receiving zones, zones of vertical borehole flow, and casing depth. The wells range in depth from 96 to 500 feet below land surface. Gamma logs only were collected in three bedrock wells. The geophysical logging determined the placement of well screens and packers, which allow monitoring and sampling of water-bearing zones in the fractured bedrock so that the horizontal and vertical distribution of contaminated ground water migrating from known sources could be determined. Geophysical logging included collection of caliper, video, fluid-temperature, fluid-resistivity, single-point-resistance, natural-gamma, fluid-flow, and acoustic-televiewer logs. Caliper and video logs were used to locate fractures, joints, and weathered zones. Inflections on fluid-temperature and fluid-resistivity logs indicated possible water-bearing fractures, and flowmeter measurements verified these locations. Single-point-resistance and natural-gamma logs provided information on stratigraphy. After interpretation of geophysical, video logs, and drillers notes, 24 of the wells were reconstructed such that water levels can be monitored and water samples collected from discrete water-bearing fractures in each well.

INTRODUCTION

Commercial hazardous wastes were reportedly disposed of during the mid-1960's to the mid-1970's at the abandoned quartzite quarry and nearby areas on Blackhead Hill at the Crossley Farms Superfund Site[1] (Halliburton NUS, 1995). The site is about 20 mi northeast of Reading, Pa., in the community of Huffs Church in Hereford Township, Berks County (fig. 1).

In the early 1980's, homeowners near the Crossley Farms Superfund Site complained about the quality of their well water. In 1983, ground-water samples collected by the Pennsylvania Department of Environmental Resources and Roy F. Weston, Inc. indicated some residential wells were contaminated with trichloroethylene (TCE) and tetrachloroethene (PCE). Additional sampling identified TCE as the principal contaminant at concentrations as great as 22,800 µg/L in residential well water. Currently, about 50 residential wells that have been affected are equipped with carbon filters at the point of use (Roy Schrock, U.S. Environmental Protection Agency, oral commun., 2000).

In 1987-88, a hydrogeologic assessment was conducted at the Crossley Farms Superfund Site by Roy F. Weston, Inc., and IT Corporation (Roy F. Weston/IT, 1988). Weston conducted soil-gas surveys and drilled 21 monitor wells in proximity to the site and concluded that the source of the TCE was from the top of Blackhead Hill, probably near the abandoned quarry and borrow-pit area. To delineate the extent of ground-water contamination, a Focused Feasibility Study (FFS) and Remedial Investigation/Feasibility Study (RI/FS) currently are being conducted by Tetra Tech NUS Inc. (TTNUS), to better characterize the nature and extent of hazardous contamination and evaluate remedial options for the contaminated residential wells. The USGS used borehole geophysics to identify water-producing zones, water-receiving zones, and intervals of vertical flow in each well. This effort helped to characterize local geology and hydrology and aided well reconstruction so that water samples may be collected from discrete intervals.

[1] The boundaries of the Crossley Farms Superfund Site are not delineated but are assumed to be coincident with the extent of the plume of contaminated ground water near Blackhead Hill described in Halliburton NUS (1995).

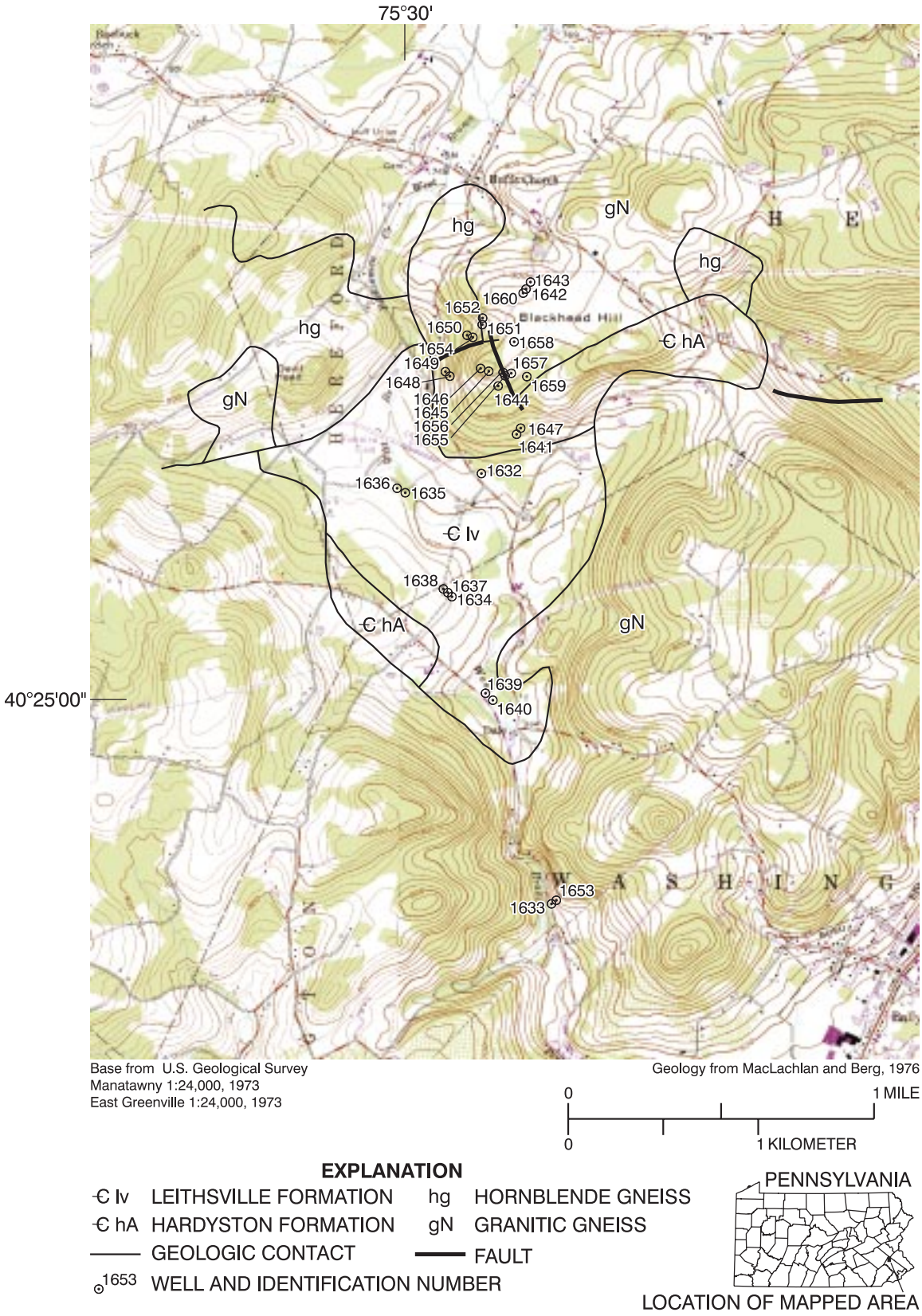

Figure 1. Location of boreholes logged at Crossley Farms Superfund Site, Berks County, Pennsylvania.

Purpose and Scope

This report evaluates borehole geophysical and video logs collected by the USGS in 29 wells at and near Crossley Farms Superfund Site (table 1 and fig. 1). This report identifies one or more water-producing and water-receiving zones in each well on the basis of geophysical and video-log data. The purpose of the logging was to determine the placement of a well screen, so that discrete intervals can be sampled. Borehole-video logs were collected in 15 of the 29 wells. Caliper, natural-gamma, single-point-resistance, fluid-resistivity, fluid-temperature, and borehole-flow (heatpulse flowmeter) logs were collected in 27 of the 29 wells. A natural-gamma log only was collected in three wells and caliper and natural-gamma logs were collected in one well.

Table 1. *Boreholes logged at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[-Clv, Leithsville Formation, gN, granitic gneiss; -ChA, Hardyston Formation; hg, hornblende gneiss; A, acoustic televiewer; B, borehole video; C, caliper log; G, natural-gamma log; R, single-point-resistance log; F, fluid-resistivity log; T, fluid-temperature log; V, borehole-flow measurement; gal/min, gallons per minute]

U.S. Geological Survey borehole-identification number	Tetra Tech NUS identification number	Depth logged (feet)	Open (O) or screened (S) interval below land surface (feet)	Depth to water below land surface (feet)	Date water level measured	Geologic unit	Geophysical logs collected
BE-1632	HN-07-D	300	230-240 (S)	51.62	11/10/98	-Clv	B,C,G,R,F,T,V
BE-1633	HN-17-I	149	68-78 (S)	5.80	11/19/98	gN	B,C,G,R,F,T,V
BE-1634	HN-14-D	374	344-354 (S)	78.11	11/20/98	-Clv	B,C,G,R,F,T,V
BE-1635	HN-13-D	373	360-370 (S)	12.95	12/3/98	-Clv	C,G,R,F,T,V
BE-1636	HN-13-I	200	35-45 (S)	12.59	12/4/98	-Clv	C,G,R,F,T,V
BE-1637	HN-14-S	96	80-100 (S)	73.82	12/4/98	-Clv	G
BE-1638	HN-14-I	151	137-150 (S)	74.80	12/4/98	-Clv	G
BE-1639	HN-16-D	203	196-206	16.51	12/14/98	-Clv	C,G
BE-1640	HN-16-I	149	150-170	17.00	12/14/98	-Clv	G
BE-1641	HN-15-D	299	259-269 (S)	51.87	12/14/98	-ChA	B,C,G,R,F,T,V
BE-1642	HN-9-I	148	75-85 (S)	39.96	1/5/99	gN	C,G,R,F,T,V
BE-1643	HN-9-S	100	45-60 (S)	40.37	1/5/99	gN	C,G,R,F,T,V
BE-1644	HN-01-D	262	West Bay[1]	33.35	1/6/99	-ChA	B,C,G,R,F,T,V
BE-1645	HN-12-I	148	118-138 (S)	47.70	1/26/99	-ChA	C,G,R,F,T,V
BE-1646	HN-12-D	304	275-304 (S)	101.20	1/27/99	-ChA	B,C,G,R,F,T,V
BE-1647	HN-15-I	204	184-204 (S)	41.88	2/10/99	-ChA	B,C,G,R,F,T,V
BE-1648	HN-11-I	150.5	114-119 (S)	46.21	1/29/99	-ChA	B,C,G,R,F,T,V
BE-1649	HN-11-D	299	West Bay[1]	45.82	1/29/99	-ChA	A,B,C,G,R,F,T,V
BE-1650	HN-10-D	300	247-257 (S)	7.08	2/5/99	hg	B,C,G,R,F,T,V
BE-1651	HN-18-D	500	West Bay[1]	87.91	2/17/99	gN	A,B,C,G,R,F,T,V
BE-1652	HN-18-I	150	35-150 (O)	84.35	2/19/99	gN	A,B,C,G,R,F,T,V
BE-1653	HN-17-V	463	West Bay[1]	Flowing (0.22 gal/min)	3/3/99	gN	B,C,G,R,F,T,V
BE-1654	HN-10-I	145	71-81 (S) 112-122 (S)	15.36	3/22/99	hg	C,G,R,F,T,V
BE-1655	HN-19-I	168	90-100 (S)	20.63	3/25/99	gN	C,G,R,F,T,V
BE-1656	HN-20-I	194	110-120 (S)	26.50	4/1/99	-ChA	C,G,R,F,T,V
BE-1657	HN-21-I	193	110-120 (S)	23	4/12/99	gN	B,C,G,R,F,T,V
BE-1658	HN-22-I	151	68-78 (S) 132-142 (S)	26.07	4/7/99	gN	C,G,R,F,T,V
BE-1659	HN-23-I	130	100-125 (S)	6.11	4/15/99	gN	C,G,R,F,T,V
BE-1660	HN-9-D	360	150-360 (O)	59.30	6/4/99	gN	A,B

[1] West Bay, a brand name multi-port permanent packer system installed so that numerous intervals could be sampled in a single borehole indefinitely, is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Hydrogeologic Setting

The Crossley Farms Site is located in the Reading Prong Section of the New England Physiographic Province (Fenneman, 1938). The upland area of Blackhead Hill is underlain by Precambrian gneiss and Cambrian quartzite of the Hardystown Formation (MacLachlan and Berg, 1981). The adjacent valley to the south and west is underlain mainly by Cambro-Ordovician dolomite of the Leithsville Formation. Bedrock is overlain by 30 to 120 ft of unconsolidated regolith (Weston/ IT, 1988).

Ground water occurs and moves through secondary openings in the regolith, fractures, joints, and cleavage planes in the bedrock. The water table in the shallow part of the regolith is saturated at many locations. Maps of the water table in the regolith indicate shallow ground water probably moves radially from the summit of Blackhead Hill to the south and west. Potentiometric-surface maps of the water table in the bedrock indicate a potential for ground-water movement from the quarry area to the south and east (Weston/IT 1988). Within the Leithsville Formation, secondary openings have been enlarged by dissolution and weathering of the dolomite. Hydraulic gradients are less steep in the Leithsville Formation than in the crystalline bedrock. In the fractured bedrock, ground water moves from Blackhead Hill radially toward the valley. Specific flow paths, however, are difficult to characterize because they can be affected by the anisotropy of the regolith and fractured bedrock and heterogeneity of water-producing and water-receiving zones.

Borehole Geophysical Logs

Geophysical logs provide information on location of fractures (caliper and video logs) and water-producing and water-receiving zones, intervals of vertical borehole flow (fluid-resistivity and fluid-temperature logs), quantification of borehole flow (heatpulse-flowmeter measurements), lithologic correlation (gamma and single-point-resistance logs), and data on well construction (caliper and single-point-resistance logs) where unknown.

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. Caliper logs are used to identify fractures and possible water-producing and water-receiving zones and 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, water-producing zones, water-receiving zones, and zones of vertical borehole flow.

The natural-gamma or gamma log measures the natural-gamma radiation (photons) emitted from all rocks. The most common emitters of gamma radiation are uranium-238, thorium-232, their daughter elements, and potassium-40. These radioactive elements are concentrated in clays by adsorption, precipitation, and ion exchange. Fine-grained sediments such as shale or siltstone usually emit more gamma radiation than sandstone, limestone, or dolomite. Gamma log data can be collected in or out of water or casing. However, casing does reduce the gamma response. The gamma log is used to correlate geologic units between wells (Keys, 1990).

The single-point-resistance log records the electrical resistance of a formation between the probe in a water filled borehole below casing and an electrical ground at land surface. Generally, electrical resistance increases with formation grain size and decreases with borehole diameter, water-bearing fractures, and increasing dissolved-solids concentration of borehole water fluid. The single-point-resistance log is used to correlate geology between wells and may help identify formation water-bearing zones. (Keys 1990).

Fluid resistivity is the inverse of fluid conductivity. The fluid-resistivity log measures the electrical resistivity of the water column in the well. The fluid-resistivity probe measures the resistivity of borehole water between electrodes in the probe. Fluid-resistivity logs reflect changes in the dissolved-solids concentration of the well water. Fluid-resistivity logs are used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones are usually identified by distinct changes in resistivity.

Intervals of vertical borehole flow are usually identified by a low-resistivity gradient between a water-producing and a water-receiving zone. Also, some types of contaminant plumes can be identified.

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

The direction and rate of borehole-water movement was determined by the use of a heatpulse flowmeter. The heatpulse flowmeter operates by heating a small volume 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 0.01-1.2 gal/min in a 2- to 10-in.-diameter borehole (Conger, 1996).

Some heatpulse-flowmeter measurements may be influenced by (1) poor seal integrity between the borehole and heatpulse 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 measurements of flow that are less than the actual rate. Although the heatpulse flowmeter is a calibrated probe, the data are primarily used as a relative indicator to identify water-producing zones.

The borehole acoustic televiewer log is a magnetically oriented, 360-degree photograph-like image of the acoustic reflection of the borehole wall. The acoustic televiewer is an ultrasonic imaging tool operating at a frequency of about 1 megahertz that scans the borehole wall with an acoustic beam generated by a pulsed piezoelectric source rotating at about 3 revolutions per second as the tool is moved up the borehole at 5 ft per minute. Digital images of a 3- to 9-in.-diameter, water-filled uncased borehole are recorded by a computer collecting the data. The log is represented in two dimensions by splitting the image vertically along the north axis and lain flat. A smooth and hard borehole wall produces a uniform reflection pattern. The intersection of a fracture, bedding, joints, and cleavage planes with the borehole wall scatters the acoustic waves, producing dark, linear features. Because the image is magnetically oriented, the dip and strike of the fracture can be determined.

Borehole deviation logs, also called dipmeter logs, record the deviation of a borehole from true vertical. Deviation of boreholes from the vertical is common, and deviation logs are used to calculate true vertical depth of features of interest and to correct the strike and dip of fractures or bedding obtained from acoustic televiewer logs.

Borehole television logging or video logging was conducted by lowering a waterproof camera down the borehole and recording the image on video tape. The depth indicated on the video log is typically within plus or minus 1.0 ft of the geophysical logs because of some minor slippage of the television cable and is corrected by comparison with other geophysical logs.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS

The locations of boreholes logged are shown on figure 1. The reference measuring point for all geophysical and video logs is land surface. Depth of wells, casing lengths, and water levels at the time of logging are given in feet below land surface (bls). A cross-reference between USGS borehole-identification numbers and TTNUS borehole-identification numbers are shown in table 1.

BE-1632 (HN-07-D)

Well BE-1632 was drilled in the Leithsville Formation. The caliper log shows the total depth of the borehole is 300 ft, and it is cased with 6.5-in.-diameter casing to 149.5 ft bls (fig. 2). The static water level at the time of logging was 51.62 ft bls. The caliper log indicates the borehole was reamed for casing to 154 ft bls. The caliper log shows minor fractures at 154.5, 192, and 234-237 ft bls. The gamma log indicates a lithologic contact between the Leithsville Formation and the underlying Hardyston Formation at 89 ft bls; a probable fault zone from 170 to 220 and 270 to 300 ft bls, that correlates with high and low resistance, respectively, is shown on the single-point-resistance log. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 140, 158, 176, 210, and 230 ft bls and no flow at 240, 250, and 276 ft bls (table 2). The video log shows what appears to be iron bacteria in the borehole water below 52 ft bls that decreases in abundance with depth and is not seen below 154 ft bls. The video log generally shows that high angle fractures (greater than 45°) dip to the northwest and shallow angle fractures dip to the southeast. The video log also shows that the water-receiving zone at 154 ft bls strikes northeast-southwest and dips southeast. The water-producing zone at 234-237 ft bls strikes northeast-southwest but dips to the northwest. The caliper and fluid-temperature logs and the heatpulse-flowmeter measurements indicate water enters the borehole through the fractures at 234-237 ft bls, moves upward, and exits the borehole through the fracture at 154.5 ft bls and at a break in casing above 140 ft bls. The borehole was backfilled from 300 ft bls to 252 ft bls. A screen was placed at 230 to 240 ft bls with the sand pack placed at 225-252 ft bls, to include the water-producing fractures at 234-237 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

Table 2. *Summary of heatpulse-flowmeter measurements for borehole BE-1632 (HN-07-D) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallons per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
140	0.5	up
158	1.0	up
176	1.0	up
210	.95	up
230	.90	up
240	no flow	--
250	no flow	--
276	no flow	--

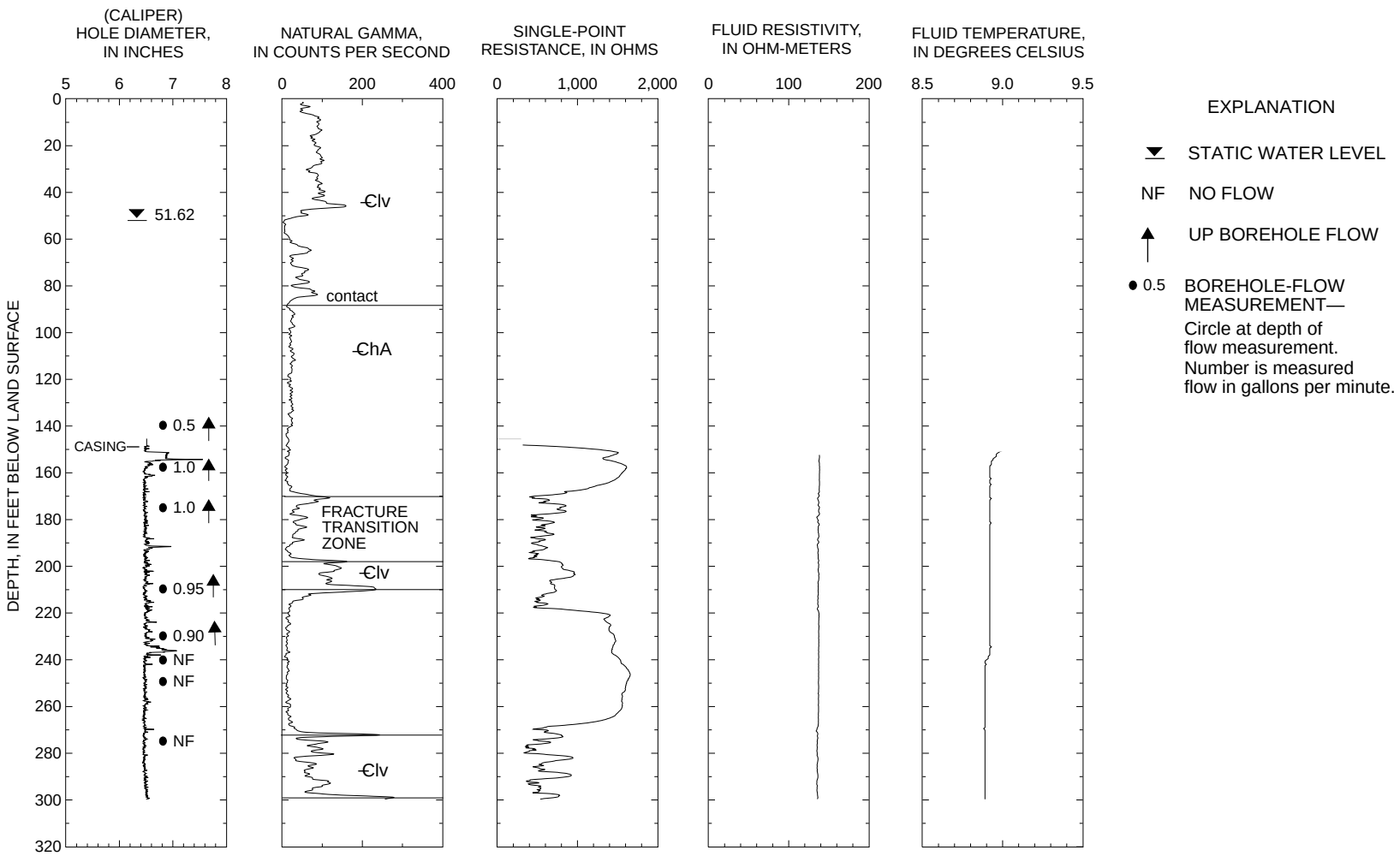

Figure 2. Borehole geophysical logs for borehole BE-1632 (HN-07-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1633 (HN-17-I)

Well BE-1633 was drilled in the Precambrian granitic gneiss. The caliper log shows the total depth of the borehole is 149 ft, and it is cased with 6.5-in.-diameter casing to approximately 50 ft bls (fig. 3). The static water level at the time of logging was 5.80 ft bls. The caliper log shows minor fractures throughout the open-hole interval. The gamma log shows high gamma spikes below 88 ft bls that are probably due to higher concentrations of potassium feldspar within the granite-gneiss. The fluid-resistivity and fluid-temperature logs show changes in slope at approximately 74 and 77 ft bls, respectively, that approximately correlate to a fracture zone shown on the caliper log at 70-74 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 67, 78, 100, and 124 ft bls. The single-point-resistance log shows a low resistance peak at 59 ft bls that suggests an additional water-producing zone. The borehole video log shows iron bacteria in the borehole water and very poor visibility that decreases with depth. The geophysical logs and the drilling data indicate water may be produced through fractures at 70-74 and possibly 59 ft bls. A screen was placed at 68-78 ft bls with a sand pack placed at 65-85 ft bls to include the probable water-producing fractures at 70-74 ft bls. (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

BE-1634 (HN-14-D)

Well BE-1634 was drilled in the Leithsville Formation. The caliper log shows the total depth of the borehole is 374 ft, and it is cased with 6.5-in.-diameter casing to 282 ft bls (fig. 4). The static water level at the time of logging was 78.11 ft bls. The caliper log shows major fractures at 283, 300, 347, 353-357, 360-364, 366, and 369 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 319, 330, and 342 ft bls and no flow at 292, 306, and 350 ft bls (table 3). The borehole video shows considerable iron bacteria in the borehole water and on the sides of the casing. The open borehole is rough, very fractured, and appears to be out of plumb. Bedding is high angle (greater than 45°) and dips to the southwest. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through the fractures at 312 ft bls, moves downward, and exits the borehole through the fracture at 347 ft bls. A screen was placed at 344-354 ft bls with a sand pack placed at 334-374 ft bls to include the water-receiving fracture at 347 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

Table 3. *Summary of heatpulse-flowmeter measurements for borehole BE-1634 (HN-14-D) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
292	no flow	--
306	no flow	--
319	0.04	down
330	.03	down
342	.03	down
350	no flow	--

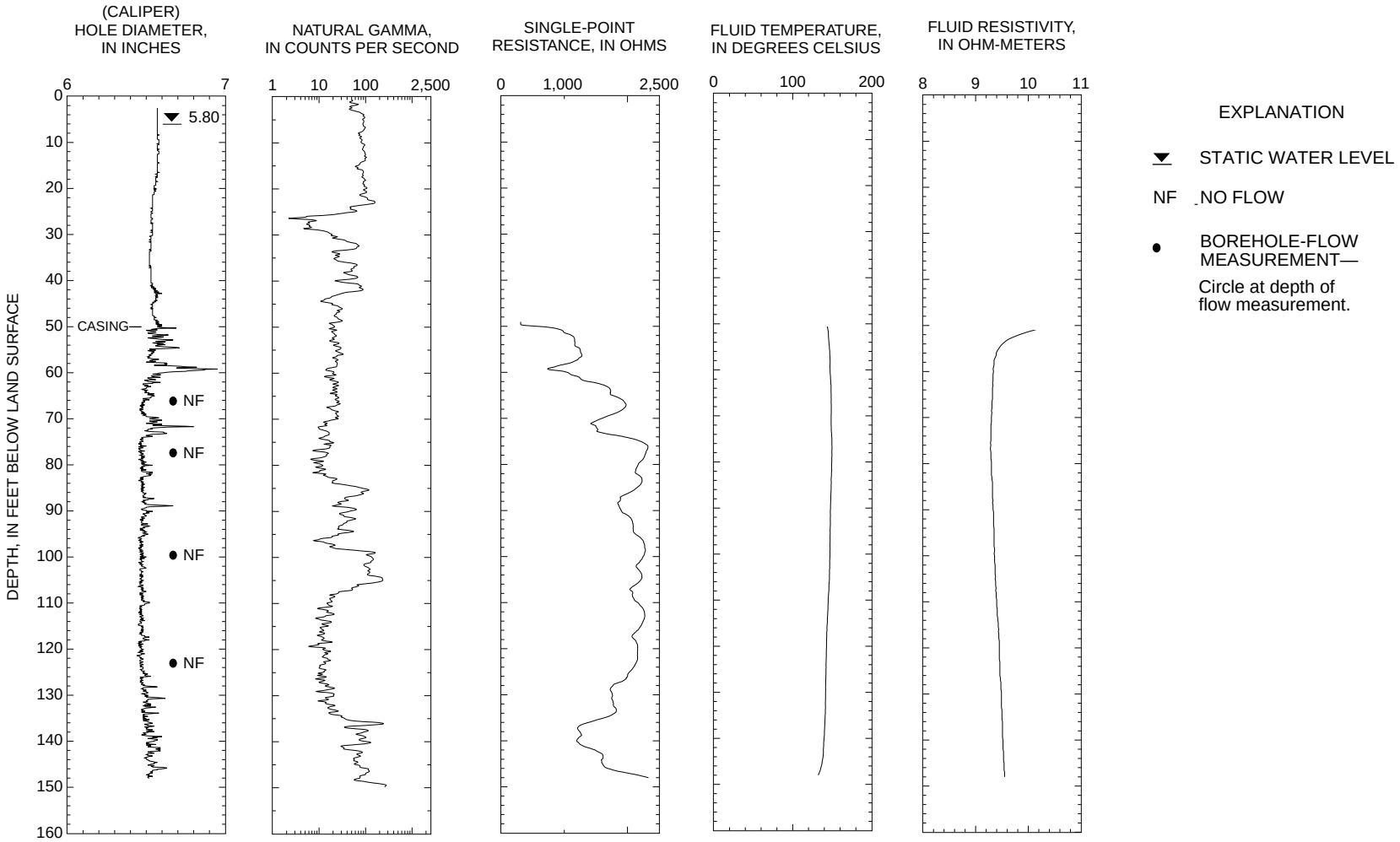

Figure 3. Borehole geophysical logs for borehole BE-1633 (HN-17-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

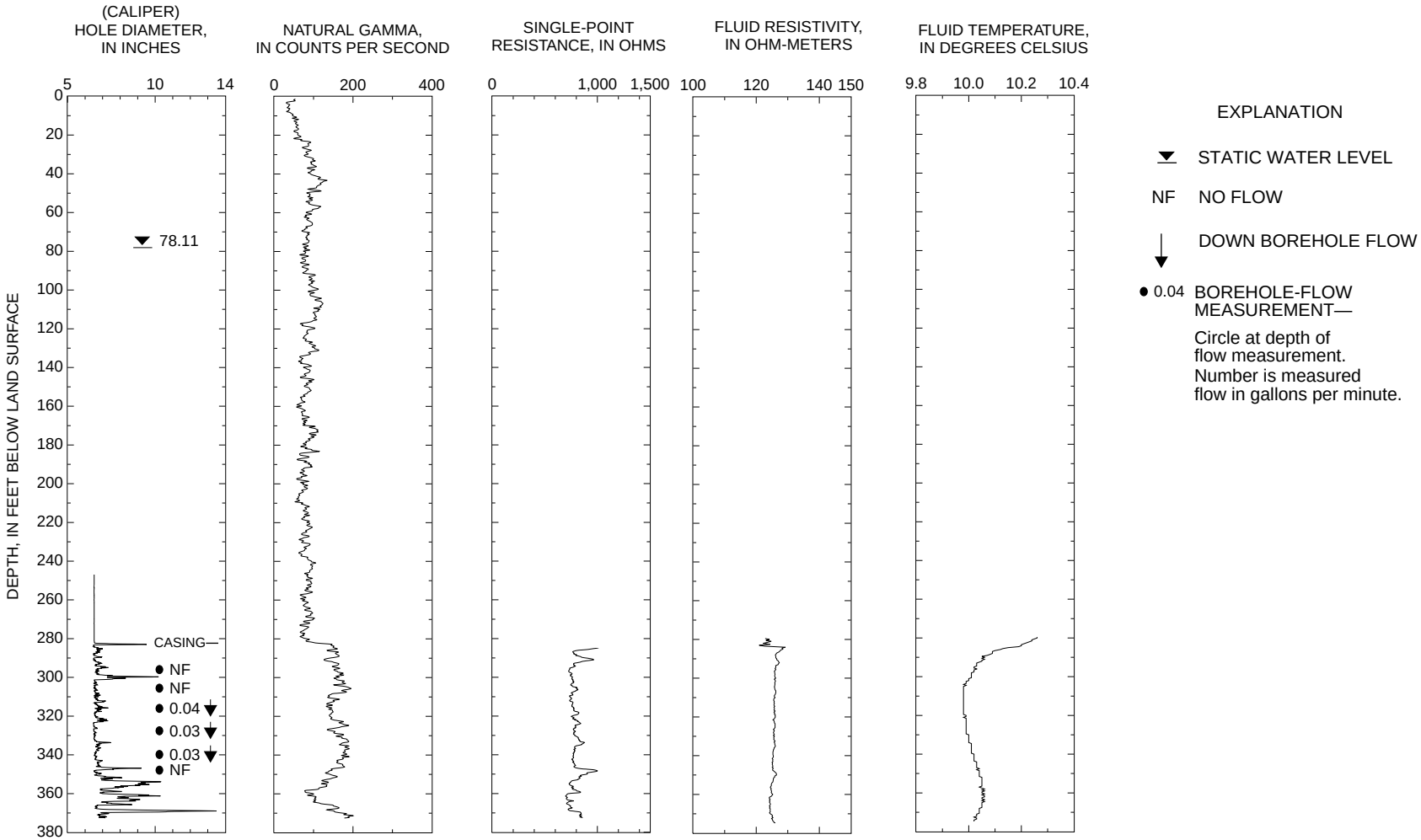

Figure 4. Borehole geophysical logs for borehole BE-1634 (HN-14-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1635 (HN-13-D)

Well BE-1635 was drilled in the Leithsville Formation. The caliper log shows the total depth of the borehole is 373 ft, and it is cased with 6.5-in.-diameter casing to 151 ft bls (fig. 5). The static water level at the time of logging was 12.95 ft bls. The caliper log shows the borehole has 4 ft of sediment on the bottom. The caliper log shows fractures at 361-368 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 174, 224, 280, and 352 ft. The driller's log reports the total yield of the borehole is approximately 15 gal/min and this water was produced near the bottom of the borehole (Robert Good, Tetra Tech NUS, Inc., written commun., 1999). A screen was placed at 360-370 ft bls and a sand pack was placed at 338-373 ft bls, to include the water-producing fractures at 360-368 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

BE-1636 (HN-13-I)

Well BE-1636 was drilled in the Leithsville Formation. The caliper log shows the total depth of the borehole is 200 ft, and it is cased with 6.5-in.-diameter casing to 30 ft bls (fig. 6). The static water level at the time of logging was 12.59 ft bls. The caliper log shows fractures at 30.5, 32-34, and 36 ft bls. The fluid-temperature log shows a sudden change in temperature at 34 ft bls indicating the only potential water-producing zone in the borehole. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 50, 100, and 154 ft bls. A screen was placed at 35-45 ft bls with the sand pack placed at 33-55.5 ft bls to include the potential water-producing zone at 32-34 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

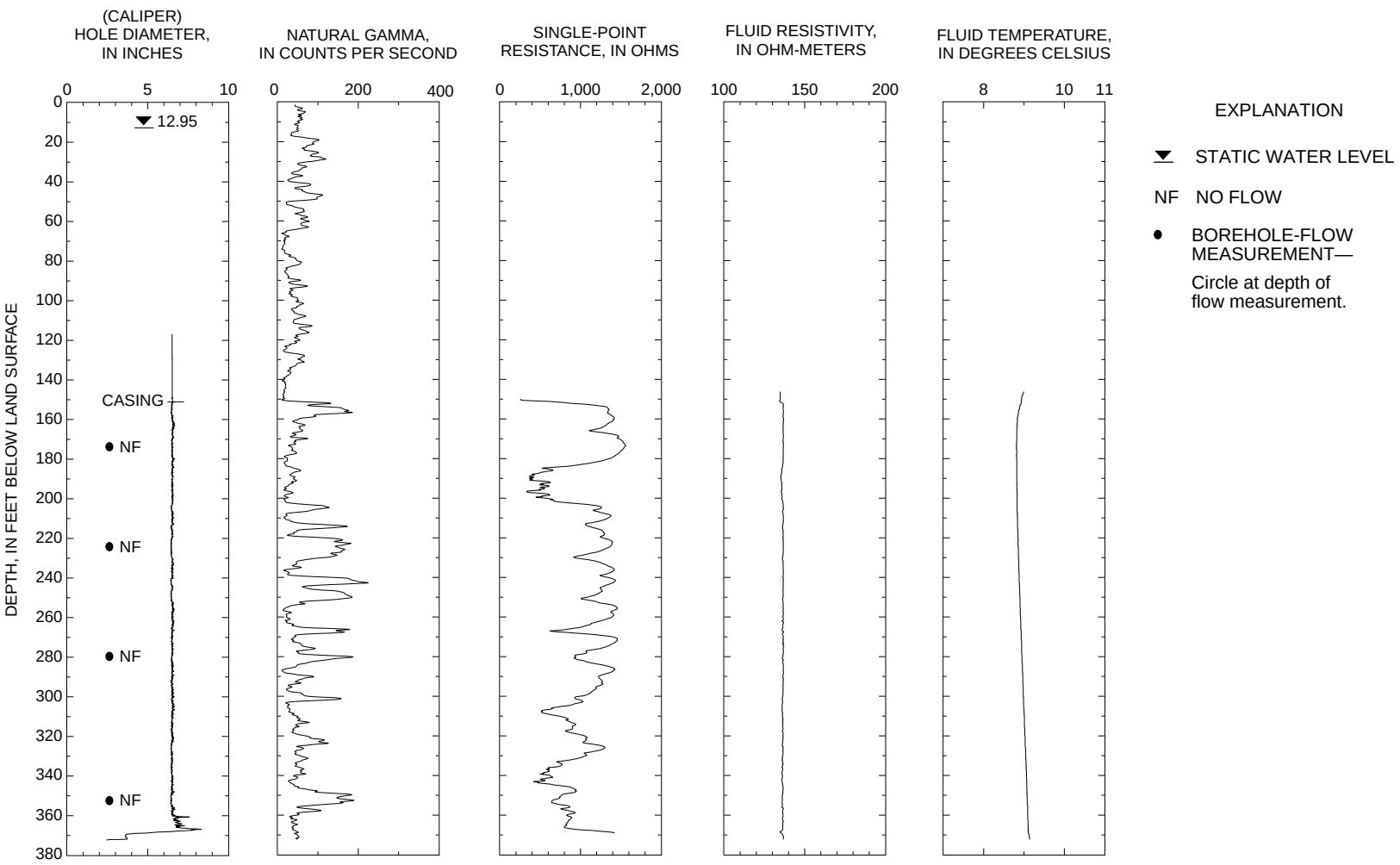

Figure 5. Borehole geophysical logs for borehole BE-1635 (HN-13-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

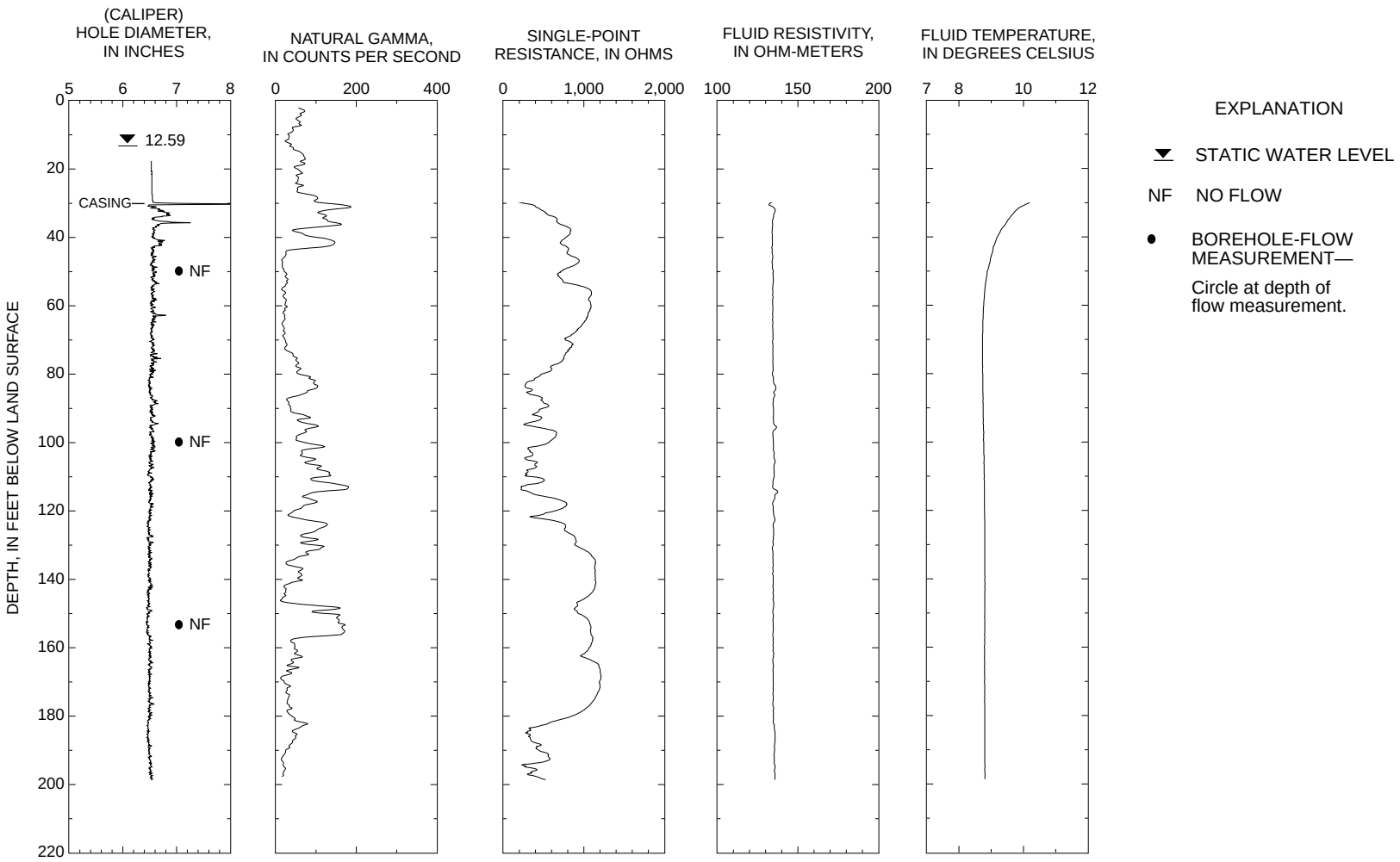

Figure 6. Borehole geophysical logs for borehole BE-1636 (HN-13-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1637 (HN-14-S)

Well BE-1637 was drilled in the Leithsville Formation. The natural-gamma log only was collected on this well for lithologic evaluation and possible correlation with nearby boreholes (fig. 7). The borehole was already screened at the time of logging. The gamma log shows the total depth of the borehole is 96 ft. The static water level at the time of logging was 73.82 ft bls. A 2-in.-diameter PVC screen was installed at 80-100 ft bls and a sand pack was extended from 77 to 100.5 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

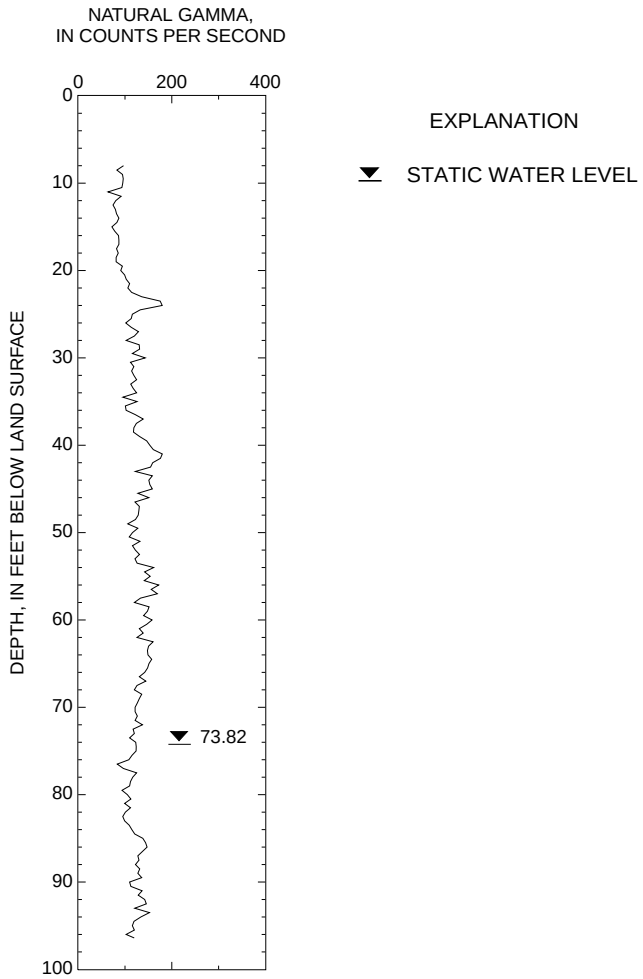

Figure 7. Natural-gamma log for borehole BE-1637 (HN-14-S) Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1638 (HN-14-I)

Well BE-1638 was drilled in the Leithsville Formation. The natural-gamma log only was collected on this well for lithologic evaluation and possible correlation with nearby boreholes (fig. 8). The borehole was already screened at the time of logging. The gamma log shows the total depth of the borehole is 151 ft. The static water level at the time of logging was 74.80 ft bls. The driller's log reports a yield of approximately 20-40 gal/min at 145 ft bls. A screen was installed at 137-152 ft bls and a sand pack was extended from 134-152.5 ft bls to include the water-producing zone at 145 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

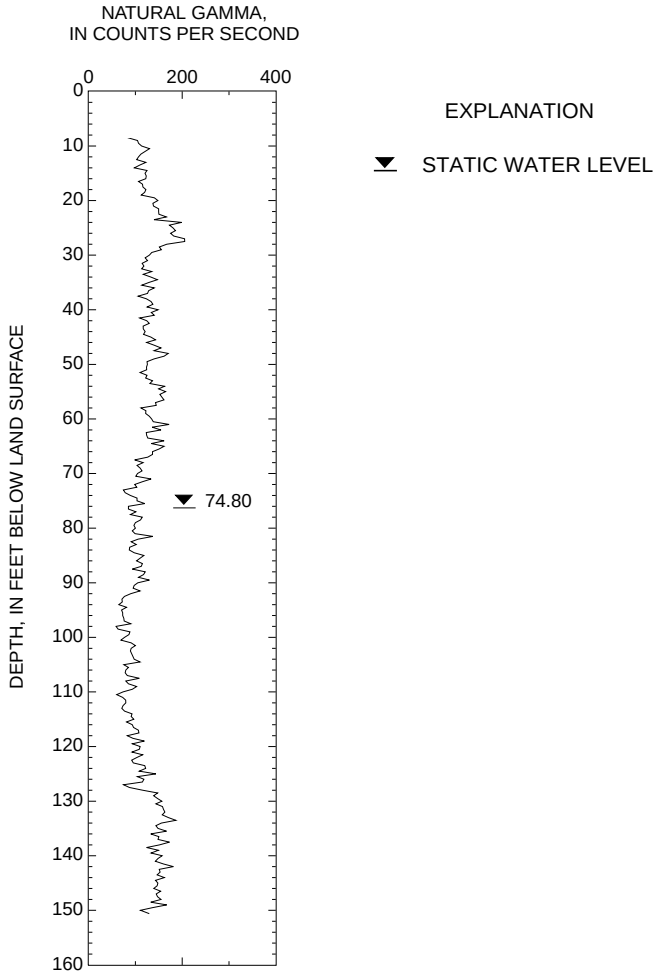

Figure 8. Natural-gamma log for borehole BE-1638 (HN-14-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1639 (HN-16-D)

Well BE-1639 was drilled in the Leithsville Formation. The caliper log shows the total depth of the borehole is 203 ft and it is cased with 6.5-in.-diameter casing to 198.5 ft bls (fig. 9). The static water level at the time of logging was 16.51 ft bls. The caliper log shows large fractures at 197 and 200-202 ft bls. The driller's log reports 100 gal/min of water enters the borehole through the fractures at 197-202 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999). A screen was placed at 193-203 ft bls and a sand pack was placed at 176-203 ft bls to include the water-producing fractures at 197-202 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

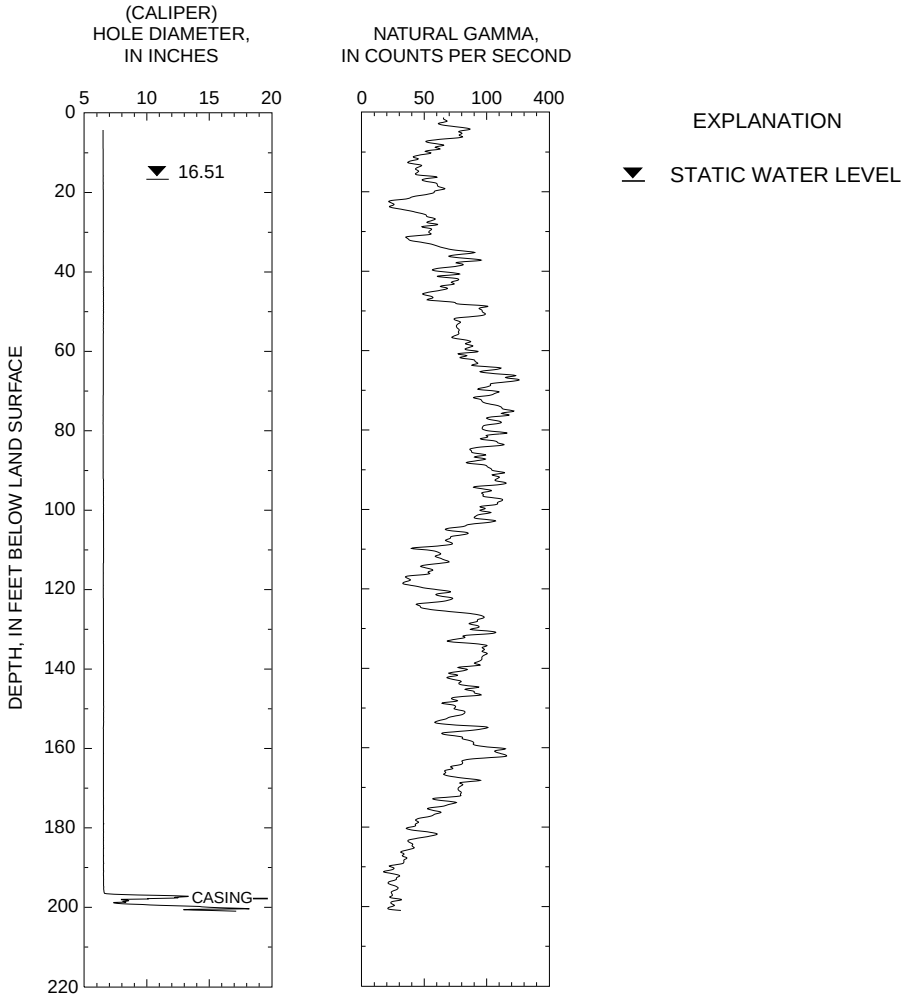

Figure 9. Borehole geophysical logs for borehole BE-1639 (HN-16-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1640 (HN-16-I)

Well BE-1640 was drilled in the Leithsville Formation. The gamma log only was collected on this borehole for lithologic evaluation and possible correlation with nearby boreholes (fig. 10). The gamma log shows the total depth of the borehole is 149 ft. The static water level at the time of logging was 17.00 ft bls. A screen was placed at 150-170 ft bls with a sand pack placed at 144.5-170 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

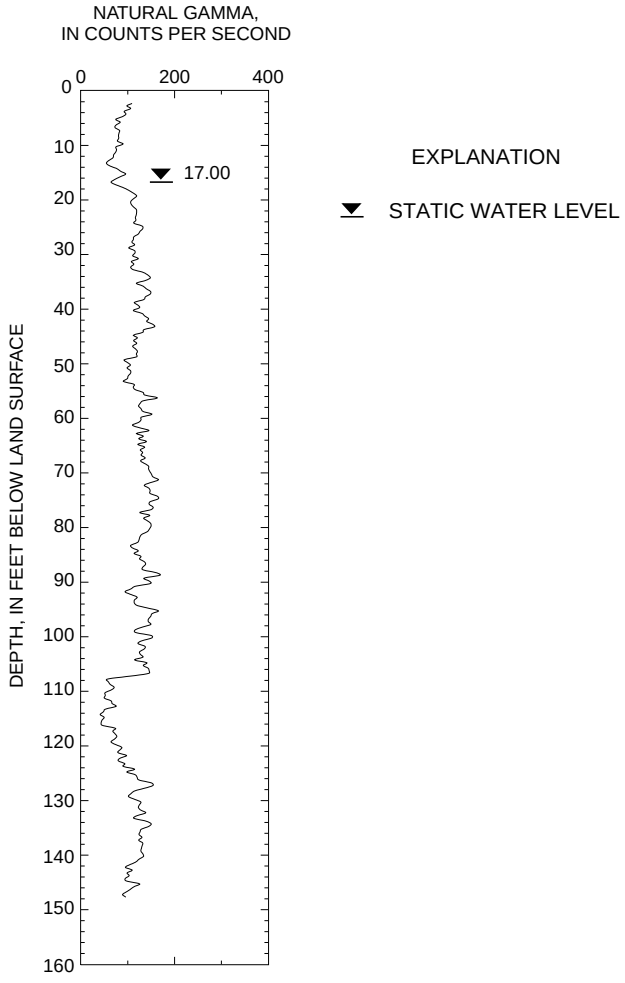

Figure 10. Natural-gamma logs for borehole BE-1640 (HN-16-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1641 (HN-15-D)

Well BE-1641 was drilled in the Cambrian Hardyston Formation. The caliper log shows the total depth of the borehole is 299 ft, and it is cased with 6.5-in.-diameter casing to 150.5 ft bls (fig. 11). The static water level at the time of logging was 51.87 ft bls. The caliper log shows minor fractures throughout the open-hole interval. The driller's log reports 2-3 gal/min of water is produced above 260 ft bls and an additional 1-2 gal/min at 280 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999). These water-producing zones correspond to fracture zones shown on the caliper log at 232-240 and 264 ft bls, respectively. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 140, 170, 190, 216, 250, 270, and 280 ft bls. The borehole video shows a vertical fracture at 173 ft bls. A thrust fault contact between the overlying Hardyston Formation and the basal Precambrian granite gneiss is evident at 208 ft bls. Because of an increase in sediment, there was no visibility below 271 ft bls. The approximate contact of the thrust fault is confirmed by the driller's log and is described as a transition from a quartzite to a hornblende gneiss from 190 to 210 ft bls (Robert Good, Tetra Tech NUS, Inc., written commun., 1999). A screen was placed at 259-269 ft bls with a sand pack at 244-281 ft bls to include the water-producing fracture at 264 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

BE-1642 (HN-9-I)

Well BE-1642 was drilled in the Precambrian granite gneiss. The caliper log shows the total depth of the borehole is 148 ft and it is cased with 6.5-in.-diameter casing to approximately 42 ft bls (fig. 12). The static water level at the time of logging was 39.96 ft bls. The caliper log shows minor fractures throughout the open-hole interval. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 63, 88, and 122 ft bls. The single-point-resistance log shows a low resistance at 46, 56, 81, and 125-135 ft bls that correlate to minor diameter changes (possible fractures) shown on the caliper log and may indicate water-producing zones. The driller reported that water was produced at 81 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999). A screen was placed at 75-85 ft bls to include the water-producing fractures at 75-85 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

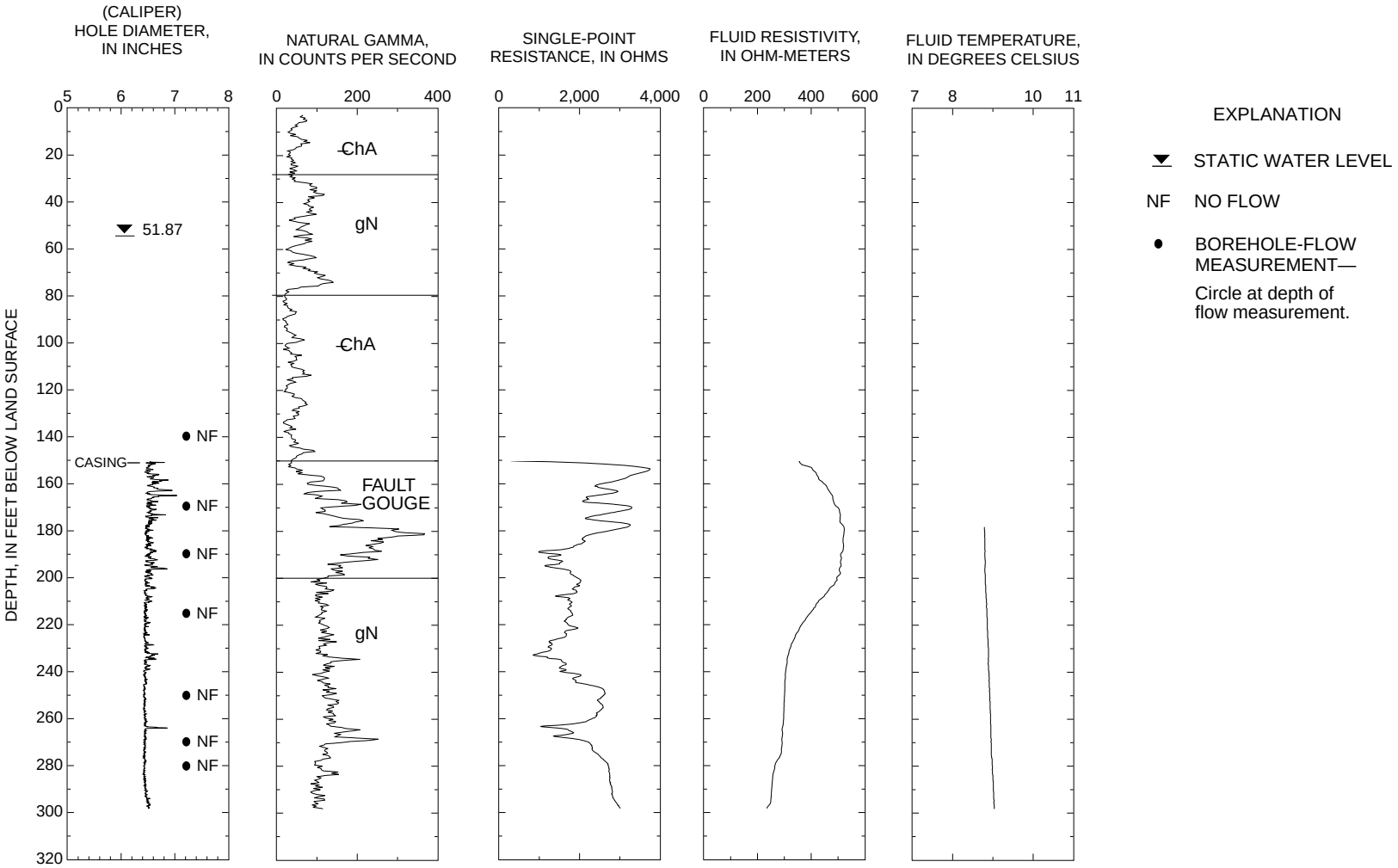

Figure 11. Borehole geophysical logs for borehole BE-1641 (HN-15-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

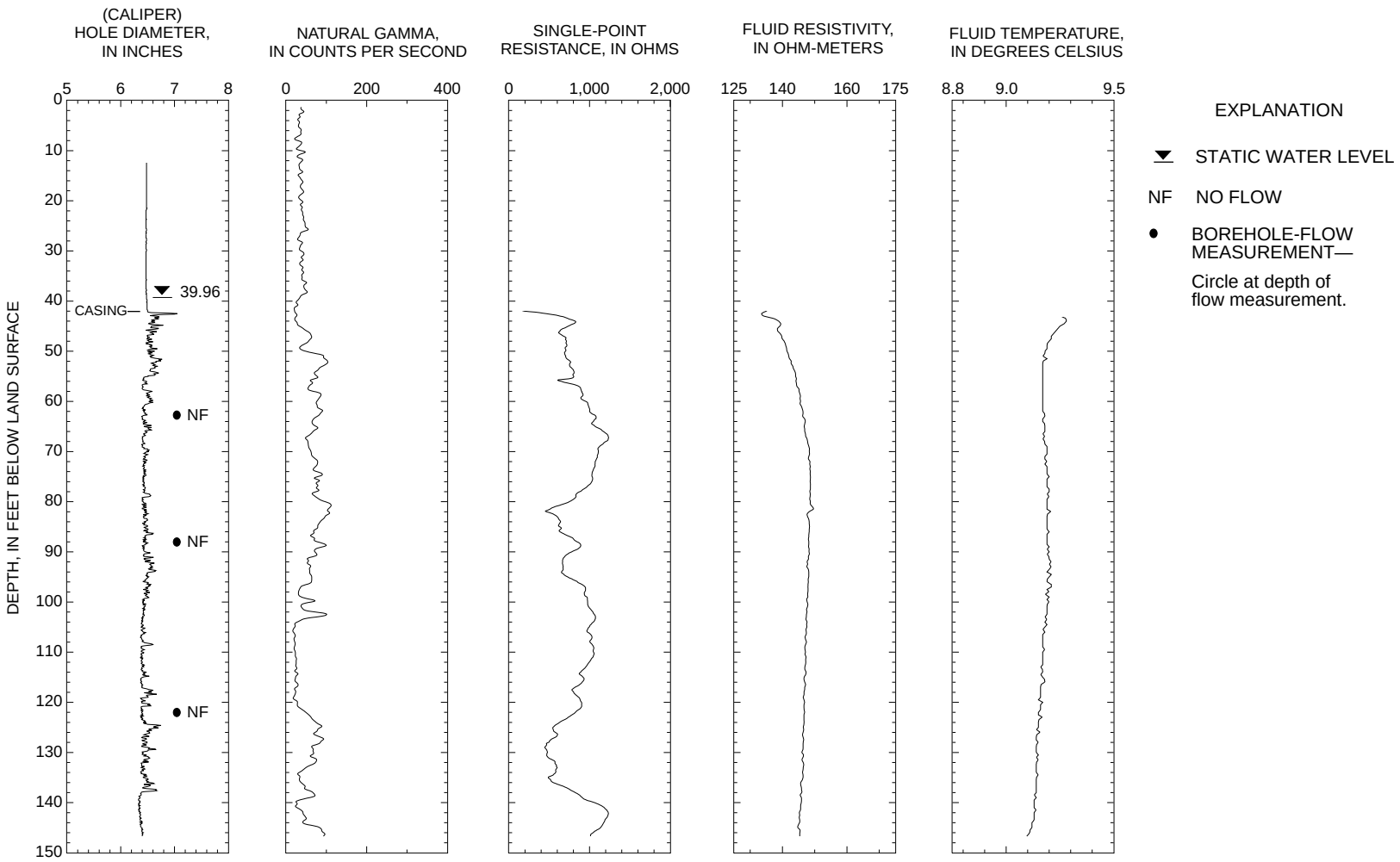

Figure 12. Borehole geophysical logs for borehole BE-1642 (HN-9-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1643 (HN-9-S)

Well BE-1643 was drilled in the Precambrian granite gneiss. The caliper log shows the total depth of the borehole is 100 ft and it is cased with 6.5-in.-diameter casing to approximately 34 ft bls (fig. 13). The static water level at the time of logging was 40.37 ft bls. The caliper log shows major fractures at 34 and 37 ft bls and minor fractures throughout the open-hole interval. The fluid-temperature log shows a minor change in slope at 57 ft bls that correlates to a fracture zone shown on the caliper log. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 44, 64, and 92 ft bls. The single-point-resistance log shows a low resistance zone at 40-60 ft bls that correlates to fractures shown on the caliper log and may indicate water-producing zones. The driller reported drill cuttings were damp at 62-63.5 ft bls, which is probably produced from just above 60 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999). A screen was placed at 45-60 ft bls with a sand pack at 42-64 ft bls to include the probable water-producing fractures at 62-63.5 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

BE-1644 (HN-01-D)

Well BE-1644 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 262 ft, and it is cased with 6.5-in.-diameter casing to approximately 163.5 ft bls (fig. 14). The static water level at the time of logging was 33.35 ft bls. The caliper log shows minor fractures throughout the open-hole interval. The fluid-temperature log shows almost no temperature gradient below 180 ft bls, which indicates vertical borehole flow. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 190, 200, and 215 ft bls and no flow at 160 and 170 ft bls (table 4). The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through the fractures at 180 ft bls, moves downward, and exits the borehole through fractures at 208, 222, and 240 ft bls. A submersible pump was placed at 50 ft bls, and the borehole was pumped at less than 0.5 gal/min. The water level in the borehole declined 6.12 ft after 81 minutes. Under pumping conditions, the geophysical logs and the heatpulse-flowmeter measurements indicate the largest quantity of water enters the borehole through fractures at about 182 ft bls. A multi-port packer system was placed in the borehole open to 174-187, 202-214, and 239-265 ft bls to isolate the water-producing fracture at 180 and 195 ft bls and the water-receiving fractures at 208 and 252-254 ft bls (Seth Pelepko, Tetra Tech NUS, Inc., written commun., 1999).

Table 4. *Summary of heatpulse-flowmeter measurements for borehole BE-1644 (HN-01-D) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
160	no flow		0.5	up
170	no flow		.5	up
190	0.02	down	no flow	
200	.05	down	.02	down
215	.02	down	.01	down
230	not consistent	not determined	not consistent	not determined
250	not consistant	not determined	not consistent	not determined

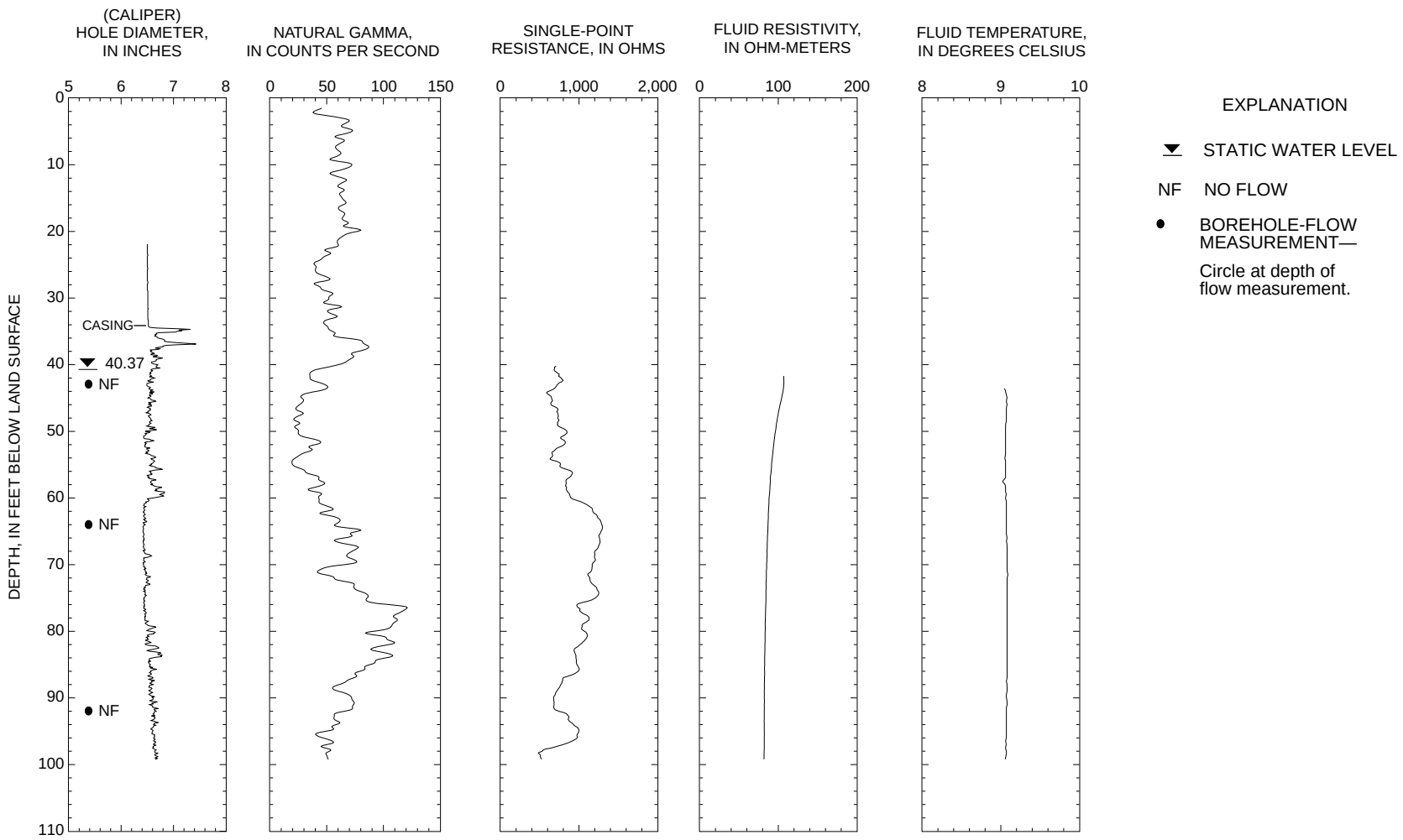

Figure 13. Borehole geophysical logs for borehole BE-1643 (HN-9-S), Crossley Farms Superfund Site, Berks County, Pennsylvania.

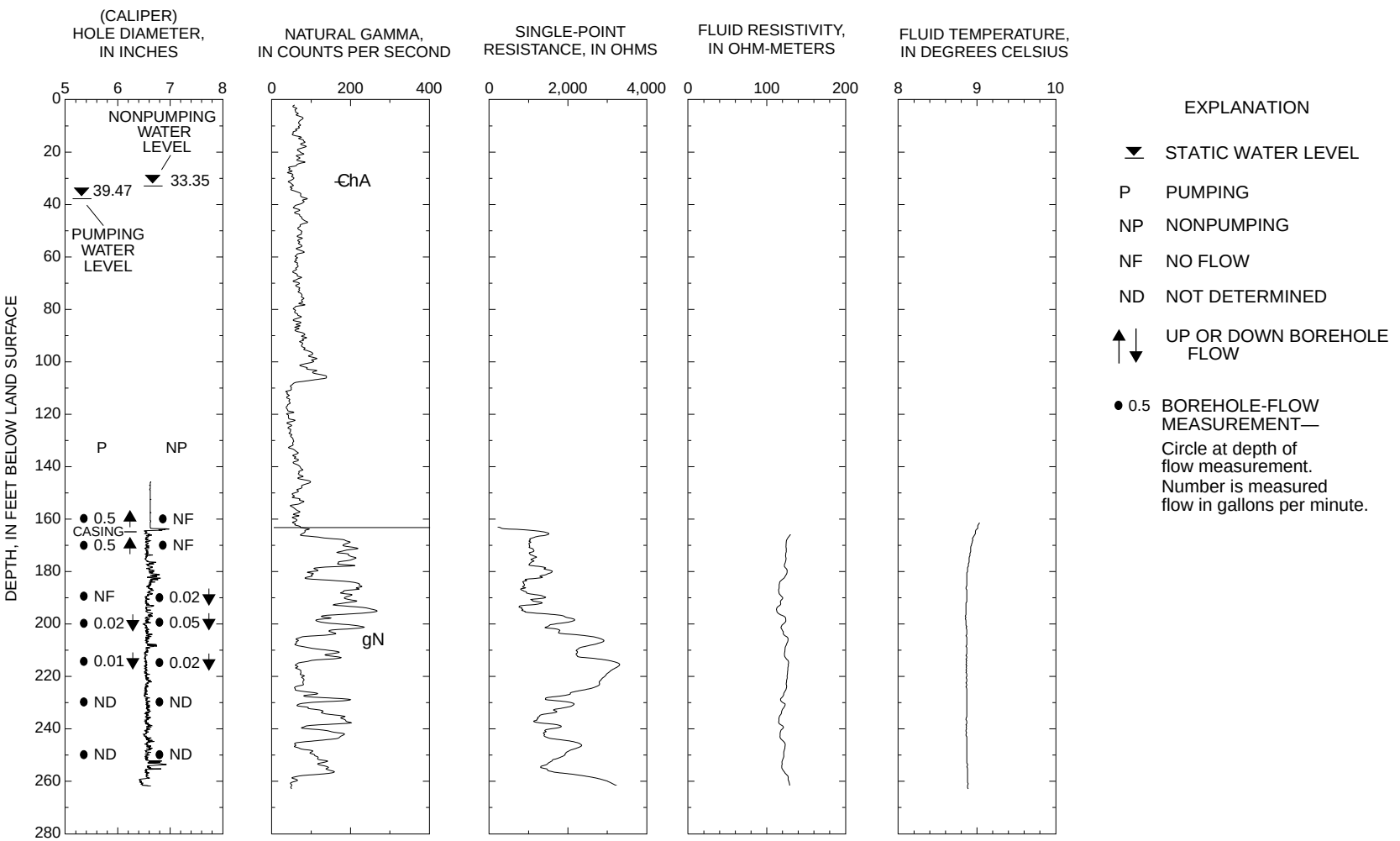

Figure 14. Borehole geophysical logs for borehole BE-1644 (HN-01-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1645 (HN-12-I)

Well BE-1645 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 148 ft, and it is cased with 6.5-in.-diameter casing to 78 ft bls (fig. 15). The static water level at the time of logging was 47.70 ft bls. The caliper log shows a major fracture at 104-105 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 90, 112, 128, and 140 ft bls. The fluid-resistivity log show changes in slope at 105, 119-123, and 132-135 ft bls that correlate to fractures shown on the caliper log and low resistance on the single-point-resistance log, which suggests water-producing zones. A screen was placed at 118-138 ft bls to include the fractures at 119-123 and 132-135 ft bls. The sand pack was placed 110-145 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

BE-1646 (HN-12-D)

Well BE-1646 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 304 ft, and it is cased with 6.5-in.-diameter casing to 151 ft bls (fig. 16). The static water level at the time of logging was 101.20 ft bls. The caliper log shows prominent fractures at 151.5, 156-158, 278-279, and 294-296 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 170, 202, 230, 260, and 292 and no flow at 140, 154, and 298 ft bls (table 5). The borehole video shows numerous thin vertical fractures throughout the open borehole. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 156-158 ft bls, moves downward, and exits the borehole through fractures at 278-279 and 294-296 ft bls. A screen was placed at 275-304 ft bls to include the water-receiving fractures at 278-279 and 294-296 ft bls. The sand pack was placed from 260.5 to 304 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 5. *Summary of heatpulse-flowmeter measurements for borehole BE-1646 (HN-12-D) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
140	no flow	--
154	no flow	--
170	0.02	down
202	.02	down
230	.02	down
260	.02	down
292	.01	down
298	no flow	--

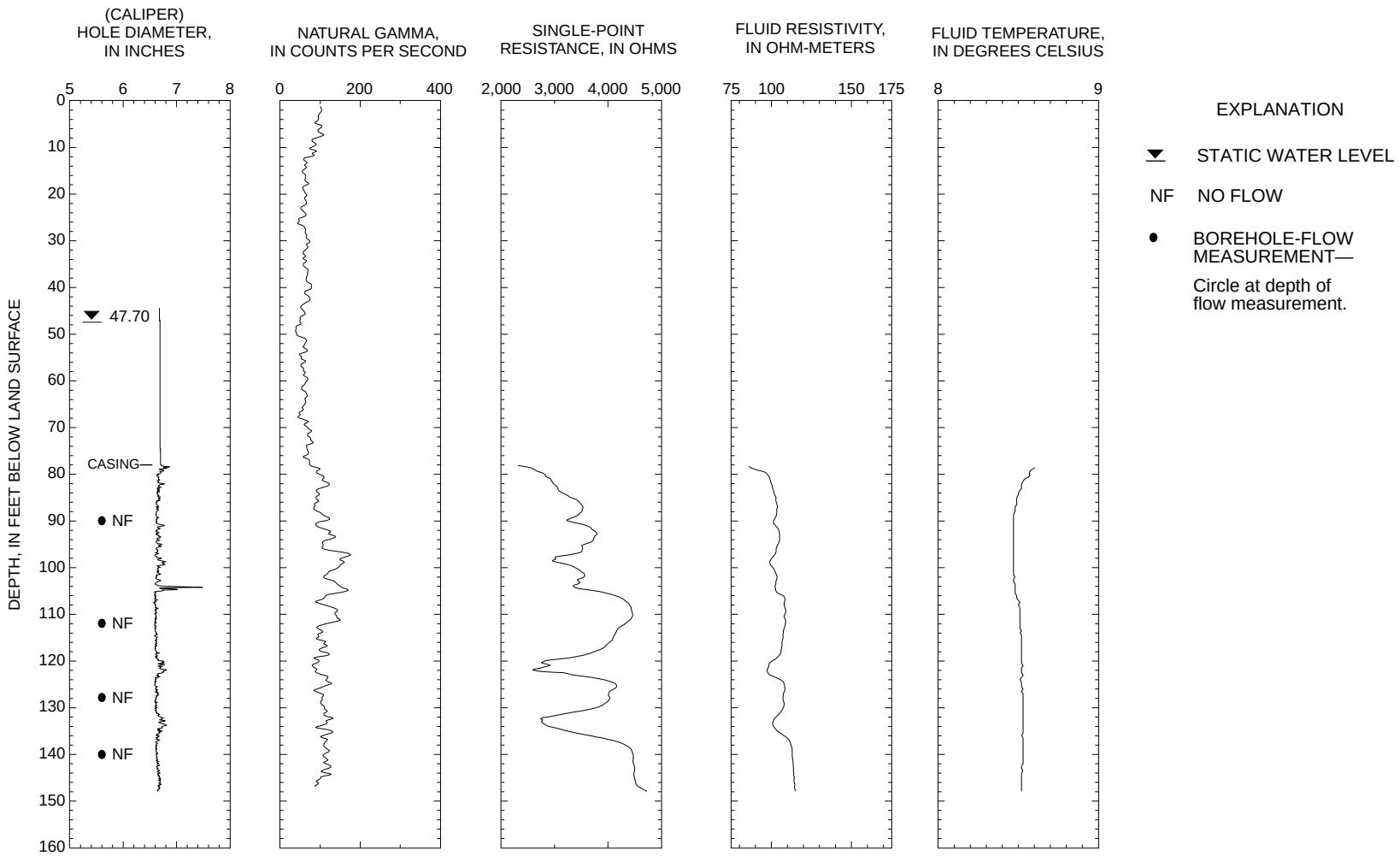

Figure 15. Borehole geophysical logs for borehole BE-1645 (HN-12-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

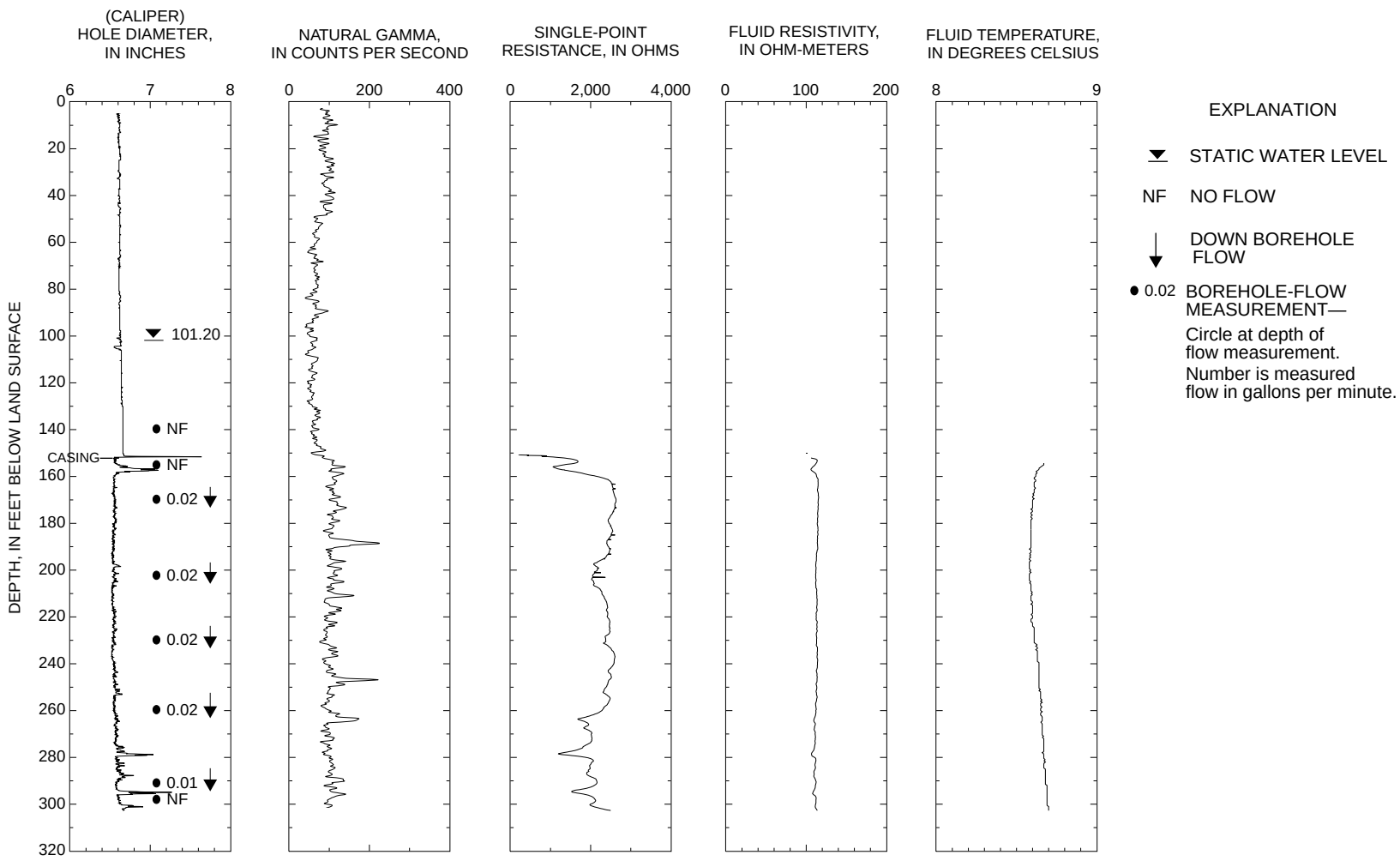

Figure 16. Borehole geophysical logs for borehole BE-1646 (HN-12-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1647 (HN-15-I)

Well BE-1647 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 204 ft, and it is cased with 6.5-in.-diameter casing to 92 ft bls (fig. 17). The static water level at the time of logging was 41.88 ft bls. The caliper log shows numerous fractures throughout the open-hole interval. The gamma log suggests a thrust fault contact between the overlying Hardyston Formation and the basal Precambrian granite gneiss is at 193 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 105, 125, and 148 ft bls and no flow at 162 and 182 ft bls (table 6). The borehole video shows numerous vertical fractures throughout the borehole. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 98-102 ft bls, moves downward, and exits the borehole through fractures at 110-119, 128-132, and 161 ft bls. On the basis of the driller's log, a screen was placed at 184-204 ft bls to include the fractures at 192-201 ft bls. The sand pack extended from 174.5 to 204 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 6. *Summary of heatpulse-flowmeter measurements for borehole BE-1647 (HN-15-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
105	0.3	down
125	.2	down
148	.1	down
162	no flow	--
182	no flow	--

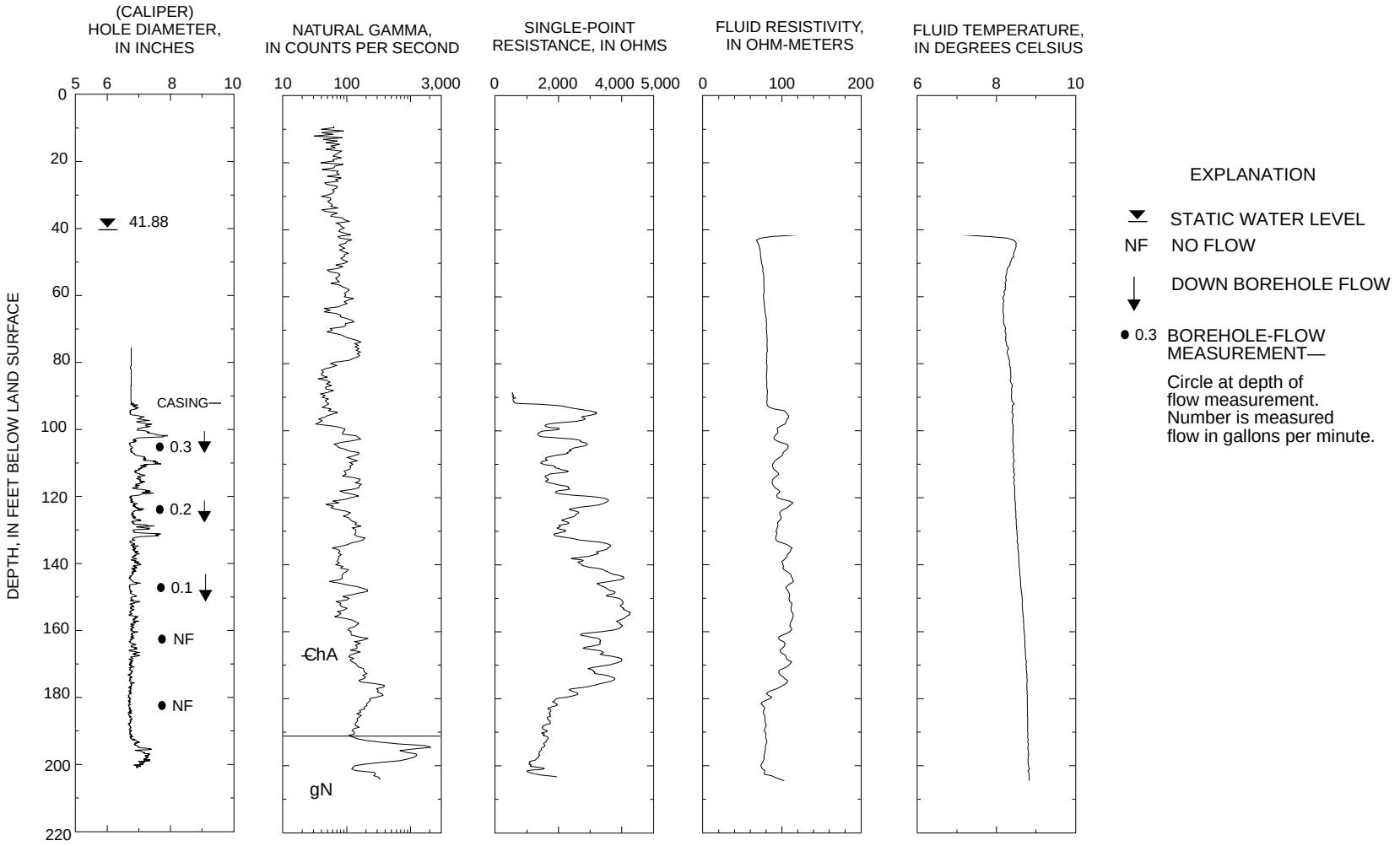

Figure 17. Borehole geophysical logs for borehole BE-1647 (HN-15-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1648 (HN-11-I)

Well BE-1648 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 150.5 ft, and it is cased with 6.5-in.-diameter casing to 84 ft bls (fig. 18). The static water level at the time of logging was 46.21 ft bls. The caliper log shows numerous fractures throughout the open-hole interval. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 107 and 112 ft bls (table 7). The borehole video shows the borehole is very rough and out of plumb; there is poor visibility below 140 ft bls because of suspended sediment. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 115-117 ft bls, moves upward, and exits the borehole through fractures at 108-110 and 103-105 ft bls. A screen was placed at 114-119 ft bls to include the water-producing fractures at 115-117 ft bls. The sand-pack interval extends from 109-123.5 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 7. *Summary of heatpulse-flowmeter measurements for borehole BE-1648 (HN-11-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
90	no flow	--
100	no flow	--
107	0.06	up
112	.10	up
120	no flow	--
130	no flow	--
136	no flow	--
145	no flow	--

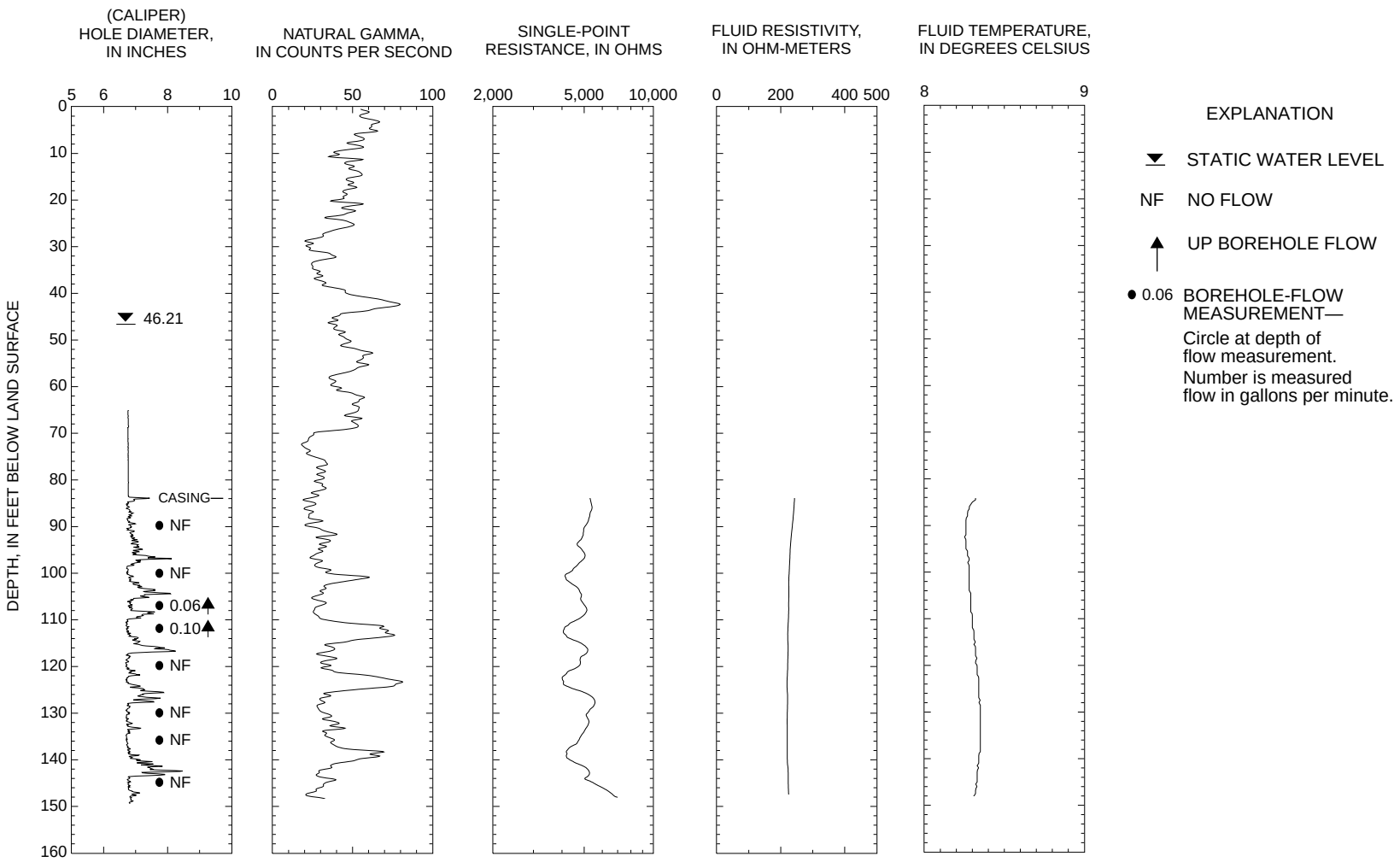

Figure 18. Borehole geophysical logs for borehole BE-1648 (HN-11-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1649 (HN-11-D)

Well BE-1649 was drilled in the Hardyston Formation. The caliper log shows the total depth of the borehole is 299 ft, and it is cased with 6.5-in.-diameter casing to 140 ft bls (fig. 19). The static water level at the time of logging was 45.82 ft bls. The caliper log shows major fractures at 142, 170, 180, 200, and 260 ft bls. The caliper log shows the borehole was reamed for casing to 150 ft bls. The deviation log shows the borehole deviates from vertical approximately 25 ft to the northwest from 140 to 299 ft bls (fig. 20). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows that most fracture planes trend northeast-southwest (fig. 21). The greatest concentration of poles of fracture planes are in the right side of figure 21, indicating high angle fracture planes that dip to the northwest. The average orientation of all fracture planes is N. 15° E., dipping 62° NW. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 154, 175, 193, 218, 234, 248, and 270 ft bls. The fluid-resistivity and fluid-temperature logs show a sudden change at 258 ft bls that correlates to a fracture shown on the caliper log indicating a water-producing zone. The fluid-resistivity log shows sudden and unusual changes at 222-225, 240-242, 255-257 ft bls that indicates the borehole water is very low in dissolved solids. A multi-port packer system open to 139-152, 164-176, 185-205, 214-231, 234-247, and 250-264 ft bls was installed to isolate individual fractures and fluid-resistivity anomalies that are probably water-producing zones as indicated by the driller's log (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

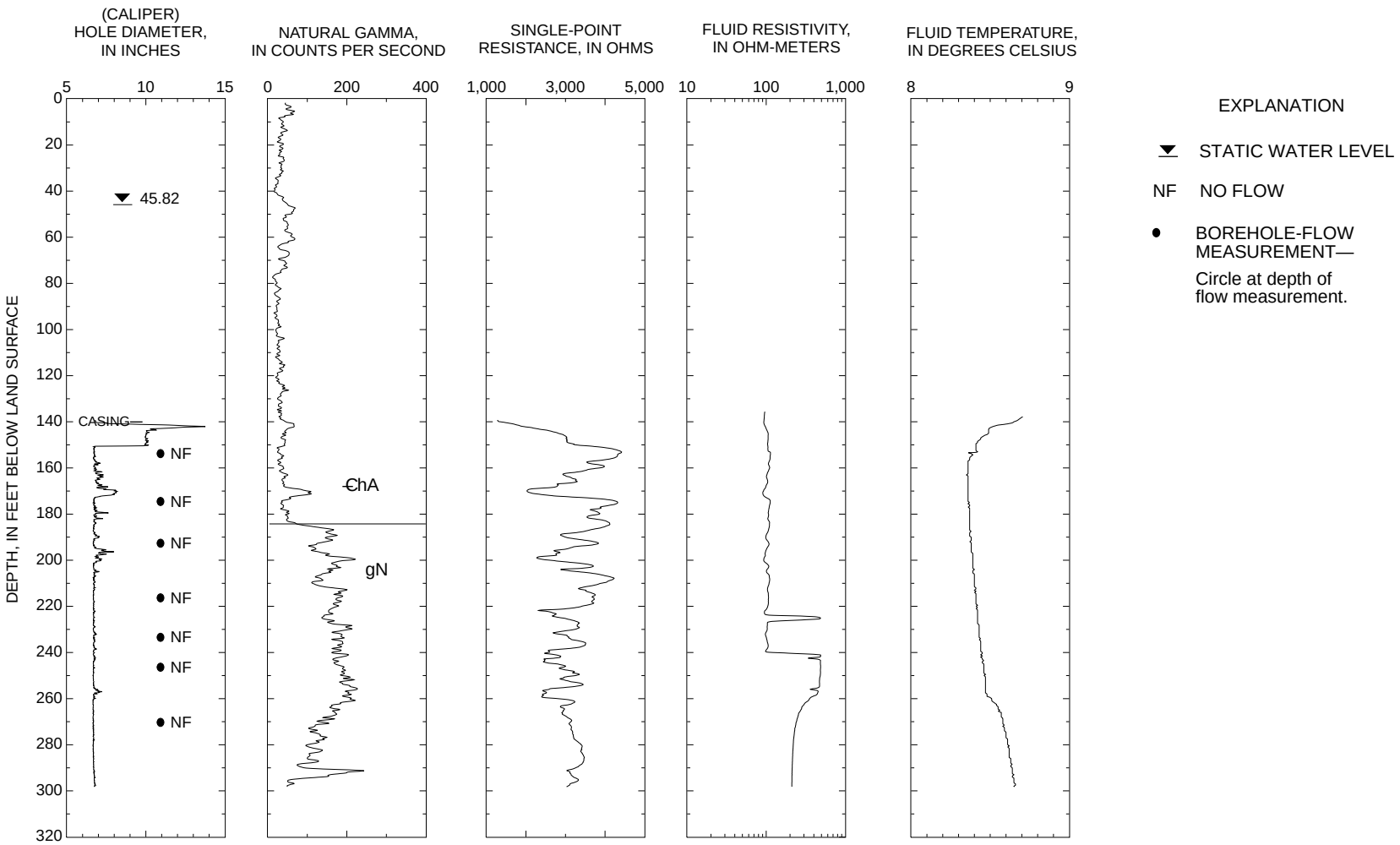

Figure 19. Borehole geophysical logs for borehole BE-1649 (HN-11-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

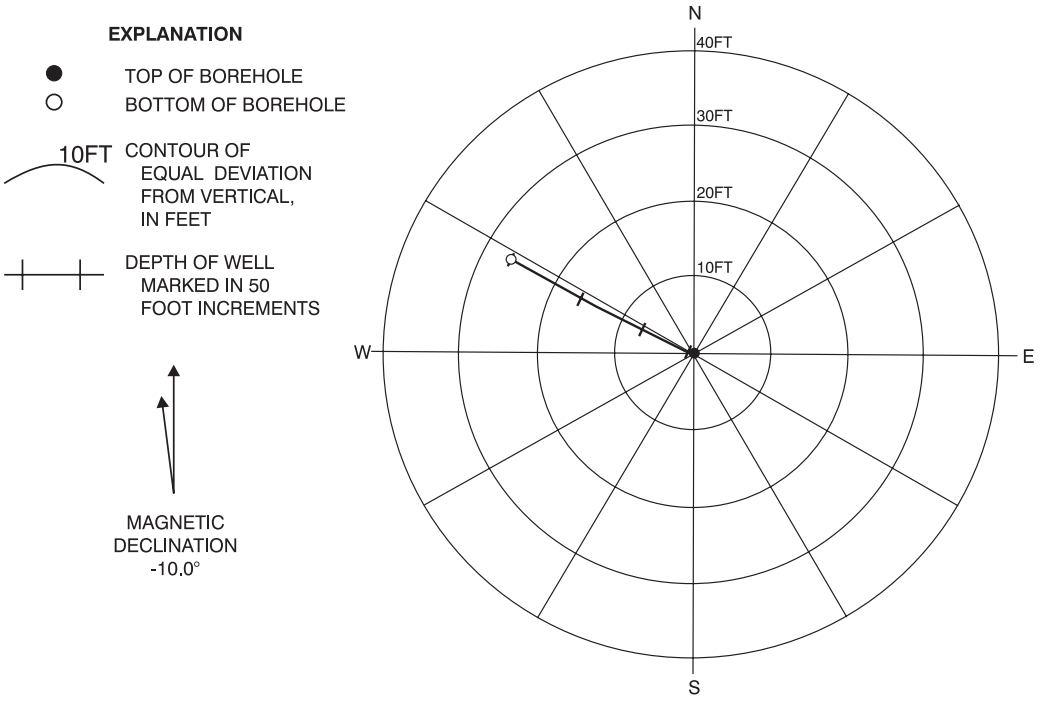

Figure 20. Magnitude and direction of deviation from vertical of borehole BE-1649 (HN-11-D).

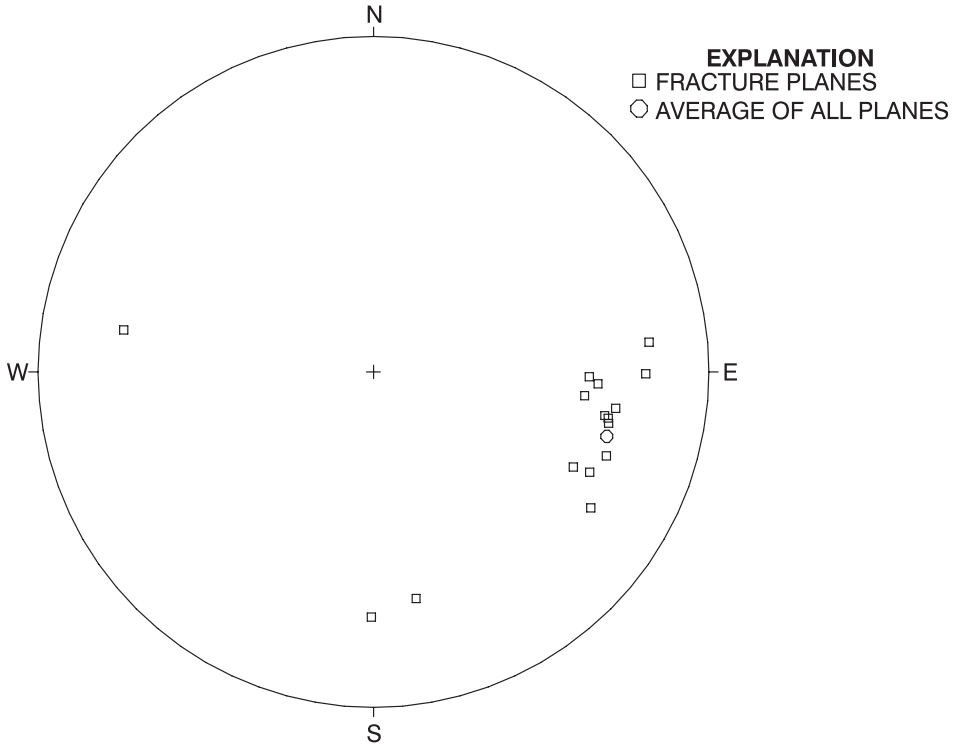

Figure 21. Equal-area lower-hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole BE-1649 (HN-11-D).

BE-1650 (HN-10-D)

Well BE-1650 was drilled in the Precambrian hornblende gneiss. The caliper log shows the total depth of the borehole is 300 ft, and it is cased with 6.5-in.-diameter casing to 152 ft bls (fig. 22). The static water level at the time of logging was 7.08 ft bls. The caliper log shows a major fracture at 153 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 153, 174, 190, 218, 244, 265, and 279 ft bls. The fluid-resistivity log shows changes in slope at 170 and 253 ft bls that indicate water-producing fractures. Screens were placed at 247-257 ft bls to isolate the water-producing zones about 253 ft bls. A sand pack was placed from 235-262 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

BE-1651 (HN-18-D)

Well BE-1651 was drilled in the granitic gneiss. The caliper log shows the total depth of the borehole is 500 ft, and it is cased with 4.5-in.-diameter casing to 151 ft bls (fig. 23). The static water level at the time of logging was 87.91 ft bls. The caliper log shows only minor fractures throughout the open-hole interval and a constriction at 491-493 ft bls. The natural-gamma log shows a zone at 324-329 ft bls with elevated gamma counts that probably are due to higher concentrations of potassium feldspar. The single-point-resistance log shows lower resistance peaks at 180, 250, 278, and 345 ft bls that correlate to fractures identified on the caliper log. The single-point-resistance log shows a lower resistance peak at 427 ft bls that correlates to a change in fluid resistivity. These deflections suggest water-producing zones. The deviation log shows the borehole deviates from vertical approximately 0.5 ft to the northwest from 151 to 279 ft bls (fig. 24); the total borehole could not be logged because of equipment problems. An equal-area stereonet, with poles plotted at right angles to the fracture planes, shows most fracture planes trend almost east-west (fig. 25). The average orientation of all fracture planes is N. 87° W., dipping 67° S. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 166, 212, 264, 314, 410, and 454 ft bls. Multi-port packers open to 172-188, 238-255, and 400-433 ft bls were placed in the borehole to include water-producing zones indicated by the geophysical logs (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

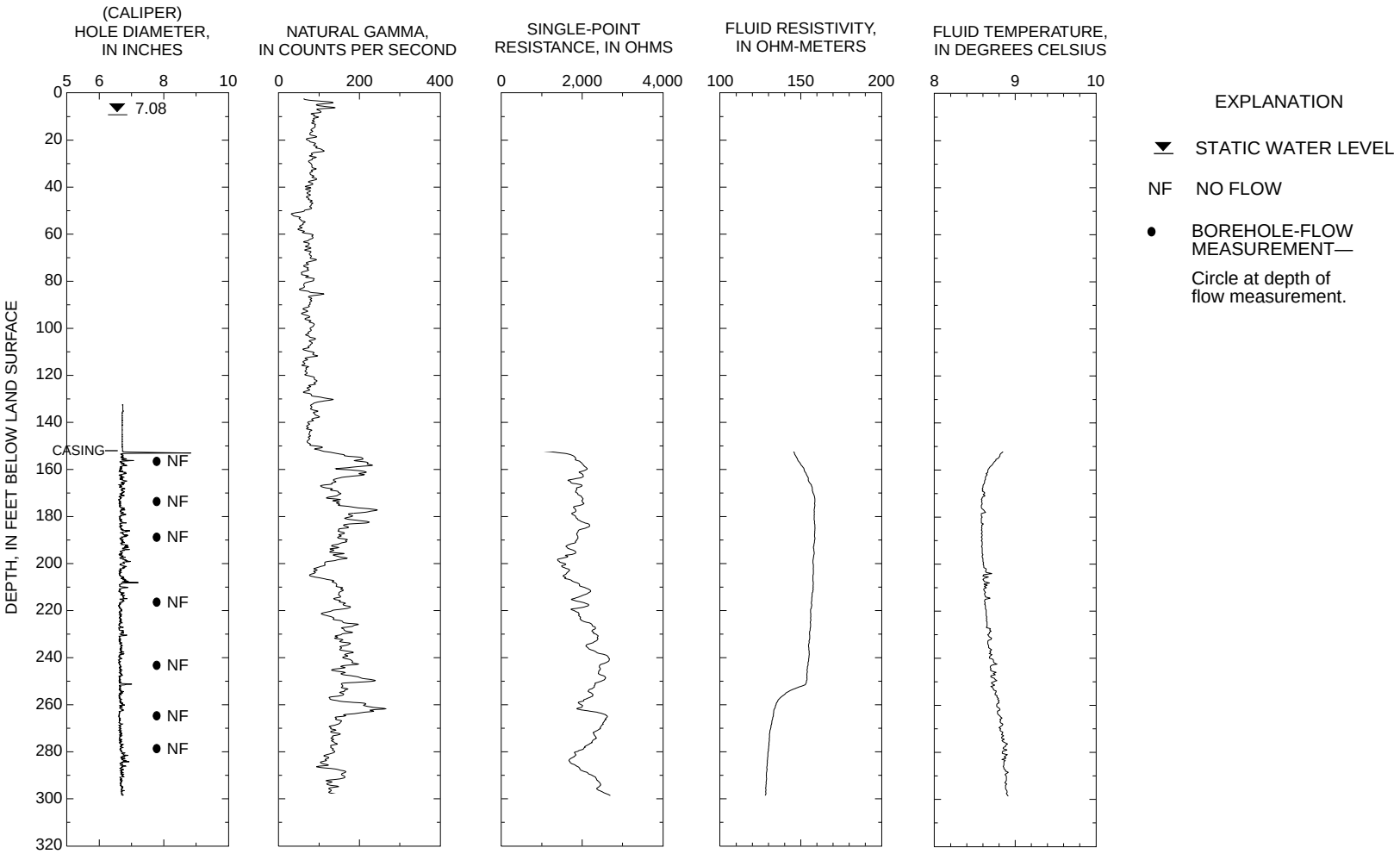

Figure 22. Borehole geophysical logs for borehole BE-1650 (HN-10-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

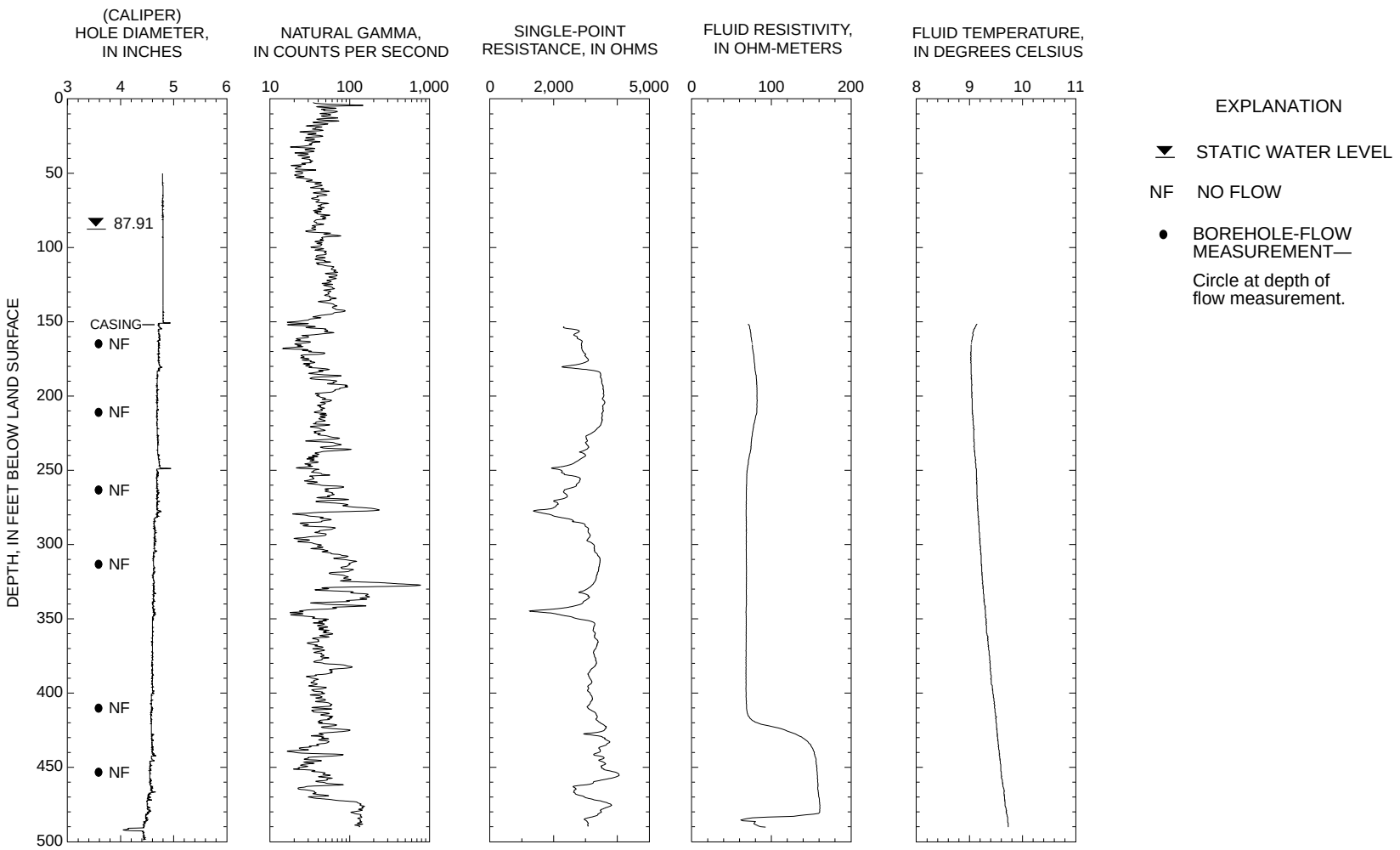

Figure 23. Borehole geophysical logs for borehole BE-1651 (HN-18-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

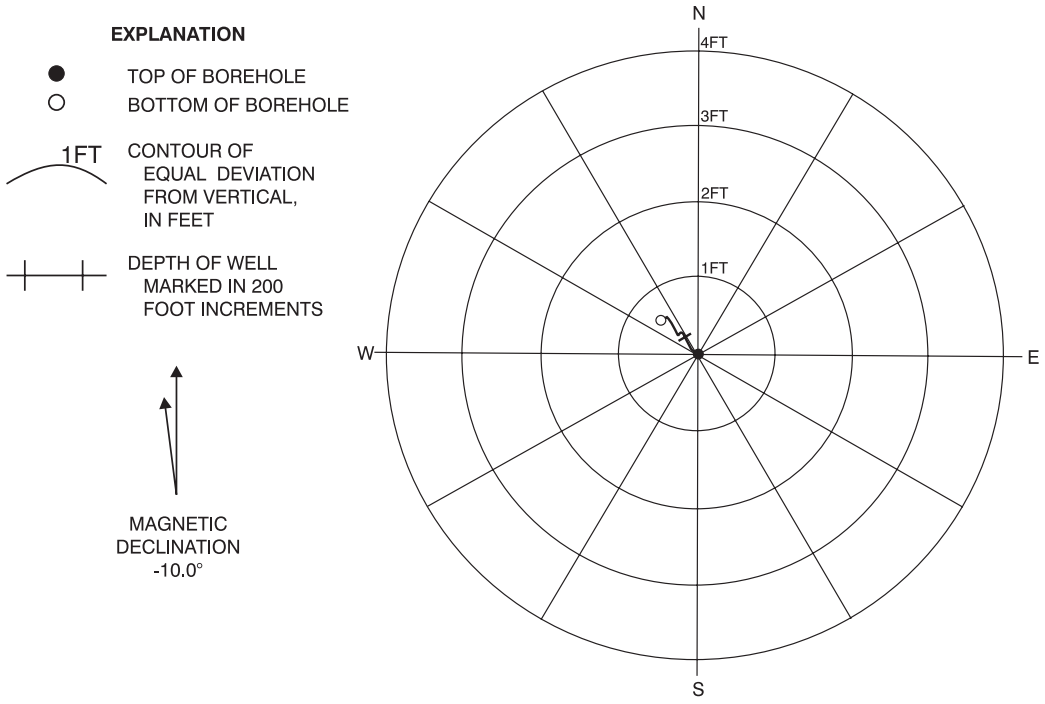

Figure 24. Magnitude and direction of deviation from vertical of borehole BE-1651 (HN-18-D).

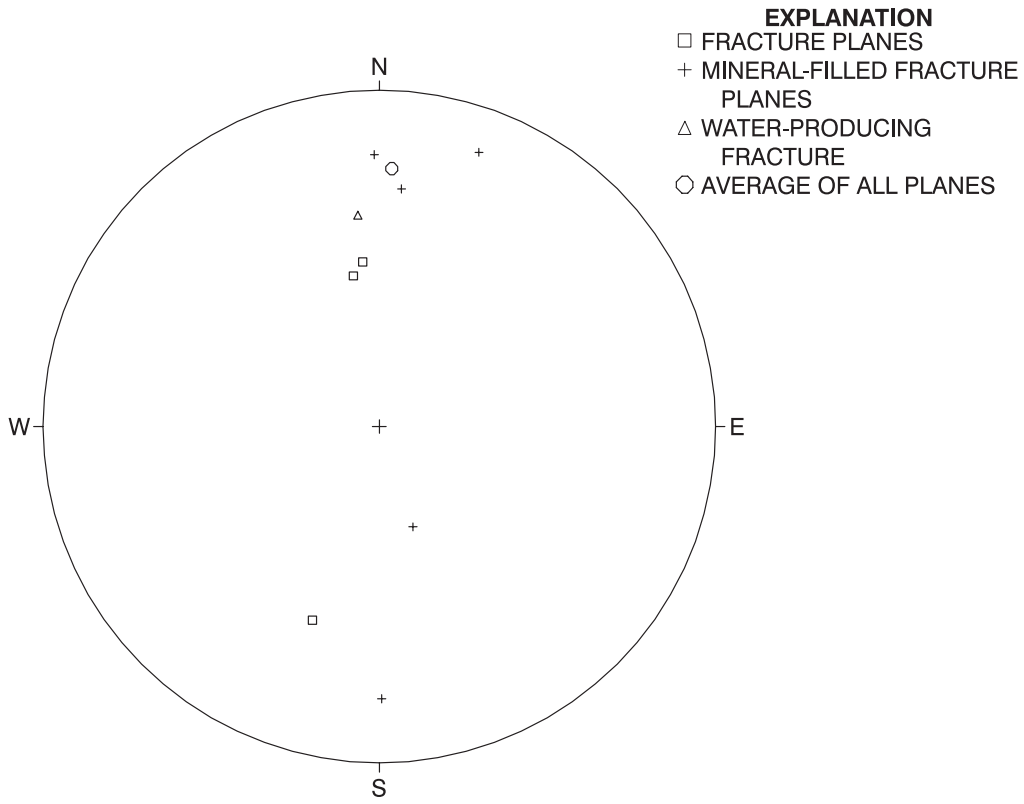

Figure 25. Equal-area lower-hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole BE-1651 (HN-18-D).

BE-1652 (HN-18-I)

Well BE-1652 was drilled in the Precambrian granitic gneiss. The caliper log shows the total depth of the borehole is 150 ft, and it is cased with 6.5-in.-diameter casing to 35 ft bls (fig. 26). The static water level at the time of logging was 84.35 ft bls. The caliper log shows a major fracture at 35.5 ft bls and minor fractures at 46-48, 59-61, and 119 ft bls. The single-point-resistance log shows a lower resistance peak at 118 ft bls that correlates to minor fractures shown on the caliper log. These minor fractures suggest a water-producing zone. The borehole video confirms the borehole is out of plumb to the south-southwest. The deviation log shows the borehole deviates from vertical approximately 3.2 ft to the south-southwest (fig. 27). An equal-area stereonet, with poles plotted at right angles to the fracture planes, shows most fracture planes trend northwest-southeast (fig. 28). The average orientation of all fracture planes is N. 51° W., dipping 67° SW. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 105 and 130 ft bls. The driller's log reports no water discharge from the borehole upon completion of drilling; therefore, the borehole remains an open-hole monitor well (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

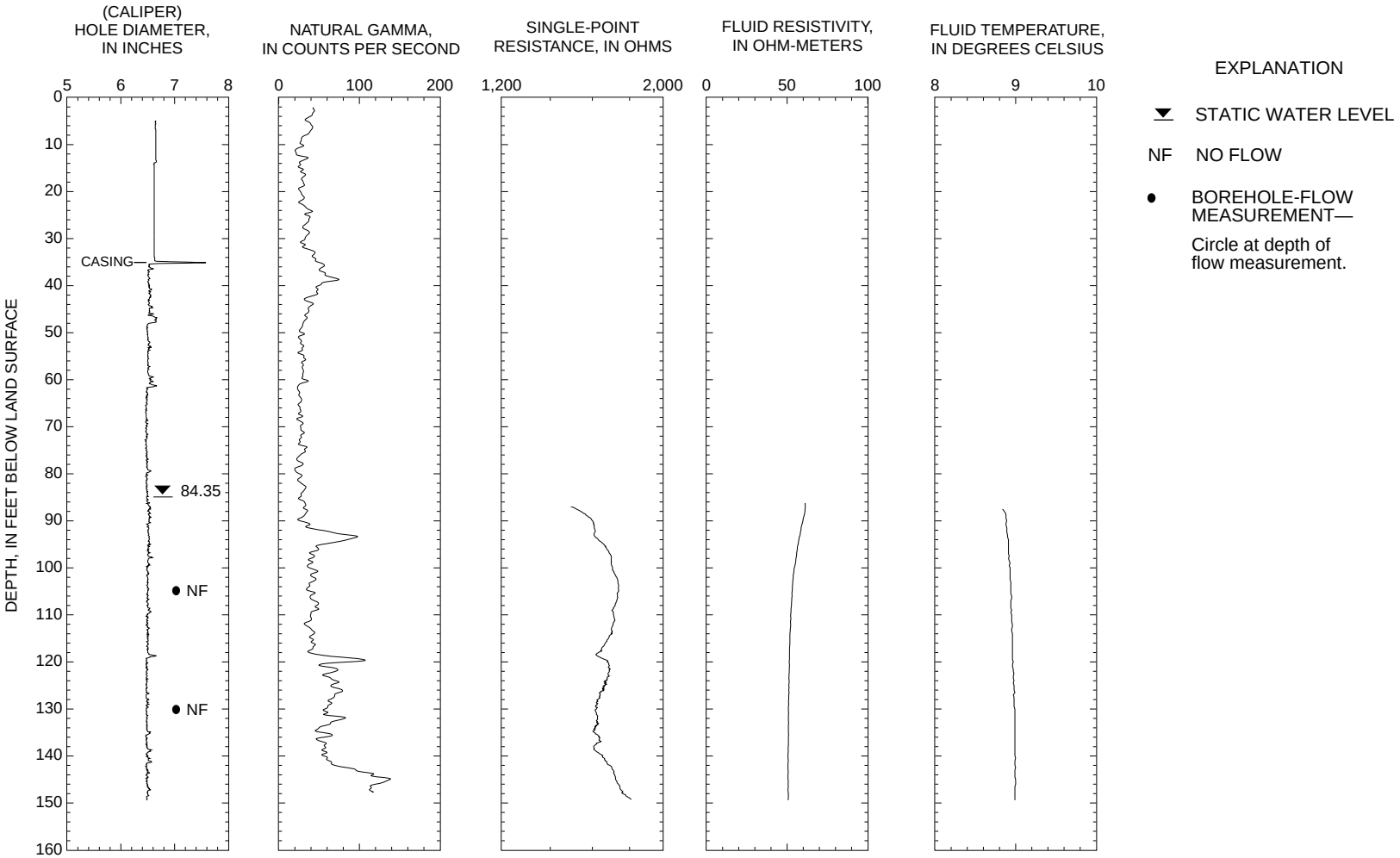

Figure 26. Borehole geophysical logs for borehole BE-1652 (HN-18-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

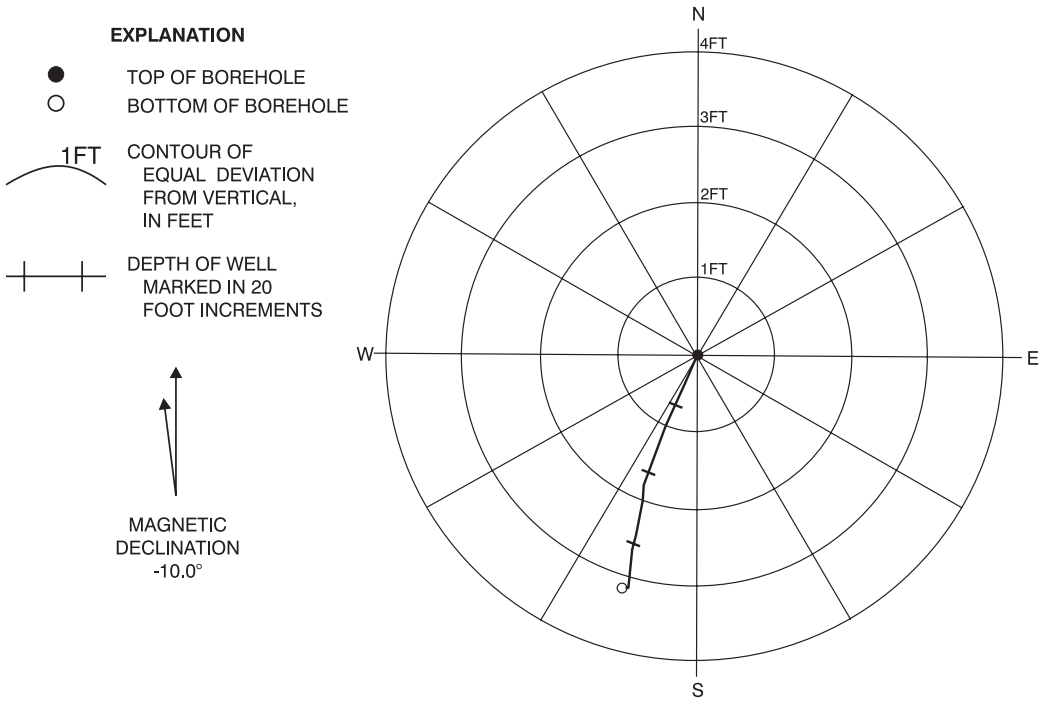

Figure 27. Magnitude and direction of deviation from vertical of borehole BE-1652 (HN-18-I).

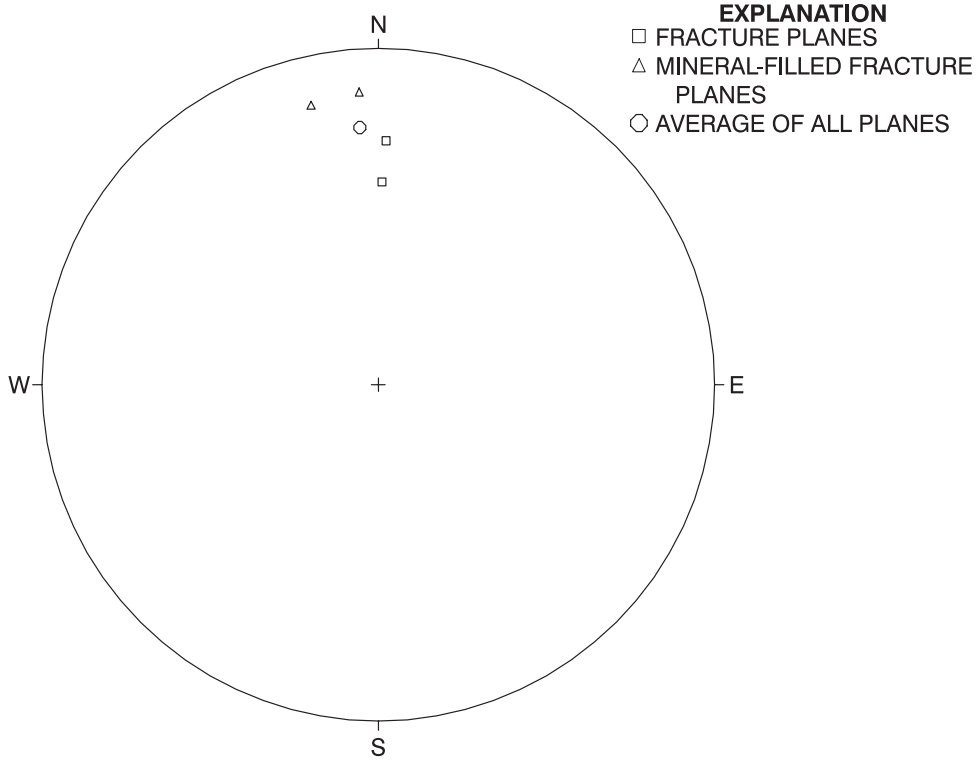

Figure 28. Equal-area lower-hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole BE-1652 (HN-18-I).

BE-1653 (HN-17-D)

Well BE-1653 was drilled in the Precambrian granitic gneiss. The caliper log shows the total depth of the borehole is 463 ft, and it is cased with 4.5-in.-diameter casing to 150 ft bls (fig. 29). At the time of logging, water was flowing from the wellhead at 0.22 gal/min. The caliper log shows only minor fractures throughout the open-hole interval. The natural-gamma log shows elevated gamma counts at numerous locations and the formation probably recorded higher concentrations of potassium feldspar within the granite gneiss. The single-point-resistance log shows low resistance peaks at 180, 220, 265, 280, 290, 300, 380, and 400 ft bls that correlates to minor deflections on the fluid-resistivity log, which are probably water-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 139, 216, 270, 394, and 430 ft bls and minor but inconsistent upward flow at 320 and 360 ft bls (table 8). The borehole video shows poor visibility throughout the open-hole section. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 380 ft bls, moves upward, and exits the borehole through fractures at 286-290 ft bls. Water also enter through a break in casing above 139 ft bls and flows upward. Multi-port packers open to 215-232, 285-302, and 391-410 ft bls were placed in the borehole (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 8. *Summary of heatpulse-flowmeter measurements for borehole BE-1653 (HN-17-D) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow direction under nonpumping conditions	Flow rate under nonpumping conditions (gal/min)
-0.90	0.22	up
139	--	no flow
216	--	no flow
270	--	no flow
320	.09	up
360	.07	up
394	--	no flow
430	--	no flow

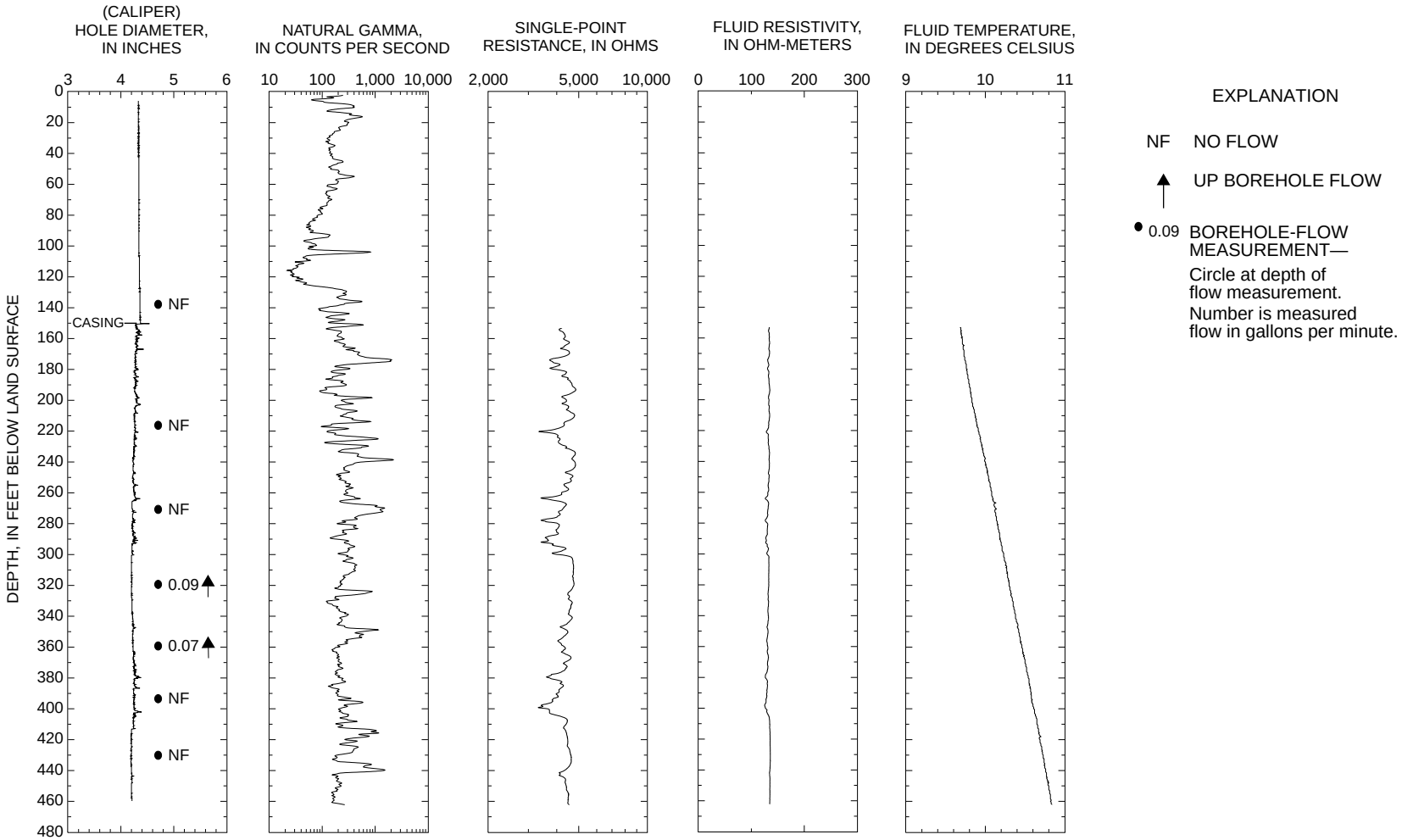

Figure 29. Borehole geophysical logs for borehole BE-1653 (HN-17-D), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1654 (HN-10-I)

Well BE-1654 was drilled in the Precambrian hornblende gneiss. The caliper log shows the total depth of the borehole is 145 ft, and it is cased with 6.5-in.-diameter casing to 69 ft bls (fig. 30). The static water level at the time of logging was 15.36 ft bls. The caliper log shows major fractures at 69.5, 73, 74-75, 78-79, and 116-118 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow inside casing at 40 ft bls and in the open borehole at 100 ft bls and no flow at 130 ft bls (table 9). The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 116-118 ft bls, moves upward, and exits the borehole through fractures at 70-82 ft bls. A minor quantity of water continues to flow upward and exists the borehole through a break in casing above 40 ft bls, probably between 20-30 ft bls. A screen was placed at 71-81 and 112-122 ft bls to include the water-producing fractures at 73-75, 78-79, and 116-118 ft bls. The sand-pack interval extends from 65-86 and 105-132 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 9. *Summary of heatpulse-flowmeter measurements for borehole BE-1654 (HN-10-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
40	0.04	up
100	.6	up
130	no flow	--

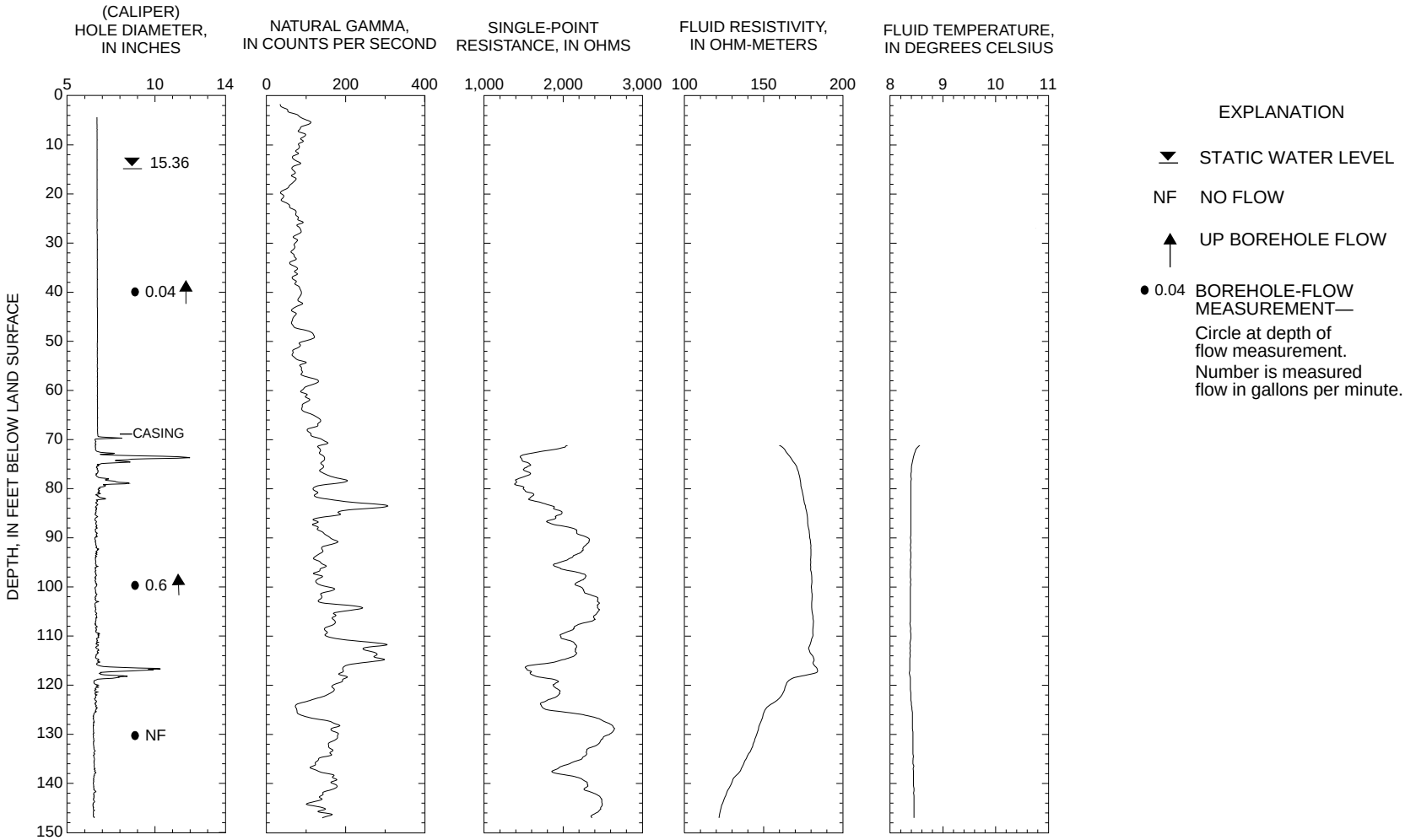

Figure 30. Borehole geophysical logs for borehole BE-1654 (HN-10-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1655 (HN-19-I)

Well BE-1655 was drilled in the granitic gneiss. The caliper log shows the total depth of the borehole is 168 ft, and it is cased with 6-in.-diameter casing to 60 ft bls (fig. 31). The static water level at the time of logging was 20.63 ft bls. The caliper log shows major fractures at 70-72, 77-79, 89-93, 97-99, and 108-110 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 85 and 95 ft bls and no flow at 65 ft bls (table 10). After collecting geophysical data the borehole bridged or collapsed at 99 ft bls. Because the borehole collapsed at 99 ft, flowmeter measurements could not be made below that depth. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures below 99 ft bls, moves upward, and exits the borehole through fractures at 70-72 or 77-79 ft bls. The driller reported a yield of 8-10 gal/min from a depth of 97-99 ft bls. The borehole was cleaned out, and a screen was placed at 90-100 ft bls to include the water-producing fractures at 97-99 ft bls. The sand pack was placed from 84-105 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 10. *Summary of heatpulse-flowmeter measurements for borehole BE-1655 (HN-19-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
65	no flow	
85	0.2	up
95	.2	up

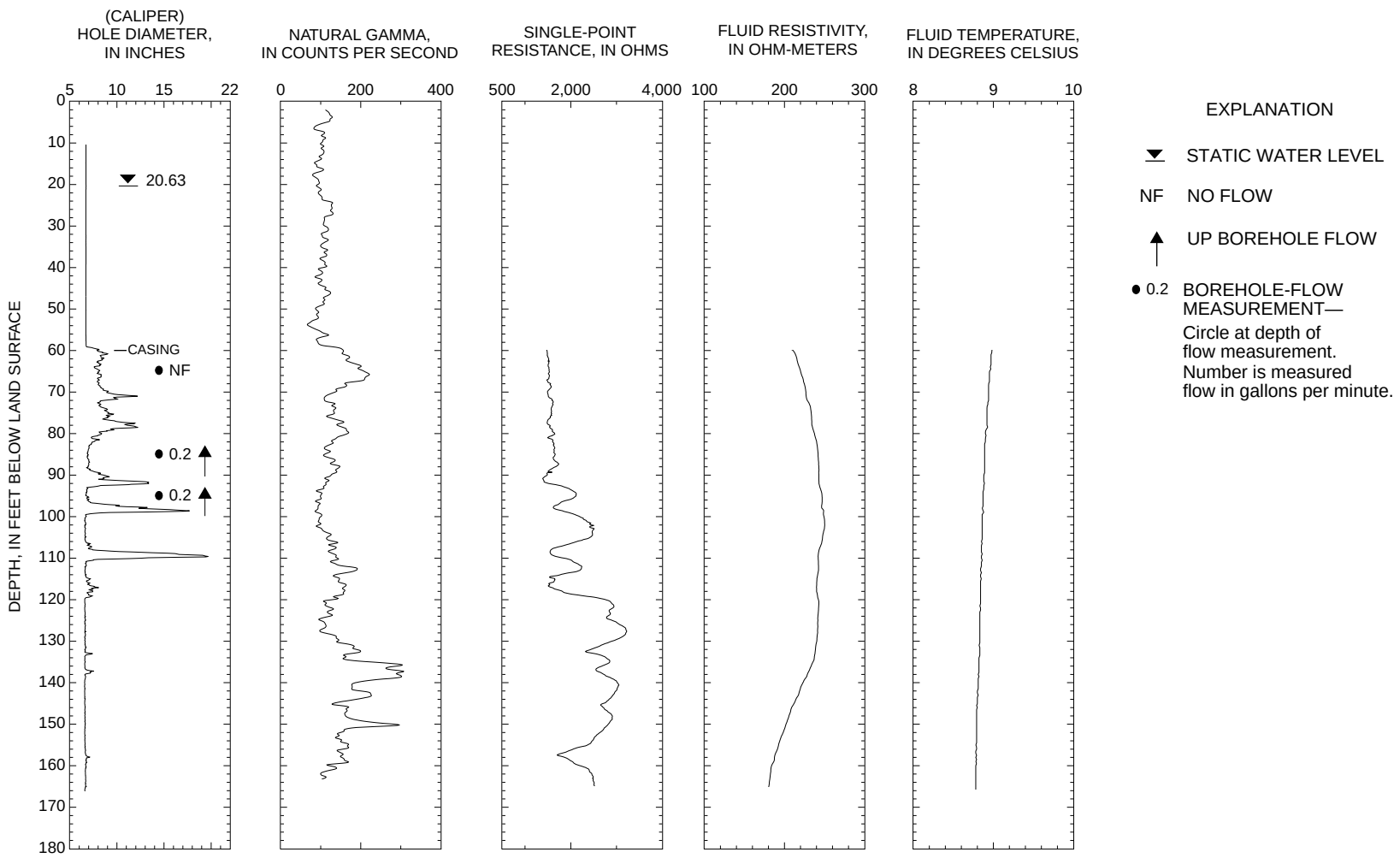

Figure 31. Borehole geophysical logs for borehole BE-1655 (HN-19-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1656 (HN-20-I)

Well BE-1656 was drilled in the fault between Hardyston Formation and the Granitic Gneiss. The caliper log shows the total depth of the borehole is 194 ft, and it is cased with 6.5-in.-diameter casing to 60 ft bls (fig. 32). The static water level at the time of logging was 26.50 ft bls. The caliper log shows a major fracture at 70 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 77, 92, 108, and 138 ft bls and no flow at 146 and 165 ft bls (table 11). The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 70, 72, and about 115 ft bls, moves downward, and exits the borehole through a fracture at 144 ft bls. A screen was placed at 110-120 ft bls to include the water-producing fracture at 115 ft bls. The sand pack was placed at 107-126.5 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 11. *Summary of heatpulse-flowmeter measurements for borehole BE-1656 (HN-20-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
77	0.08	down
92	.10	down
108	.09	down
138	.25	down
146	no flow	--
165	no flow	--

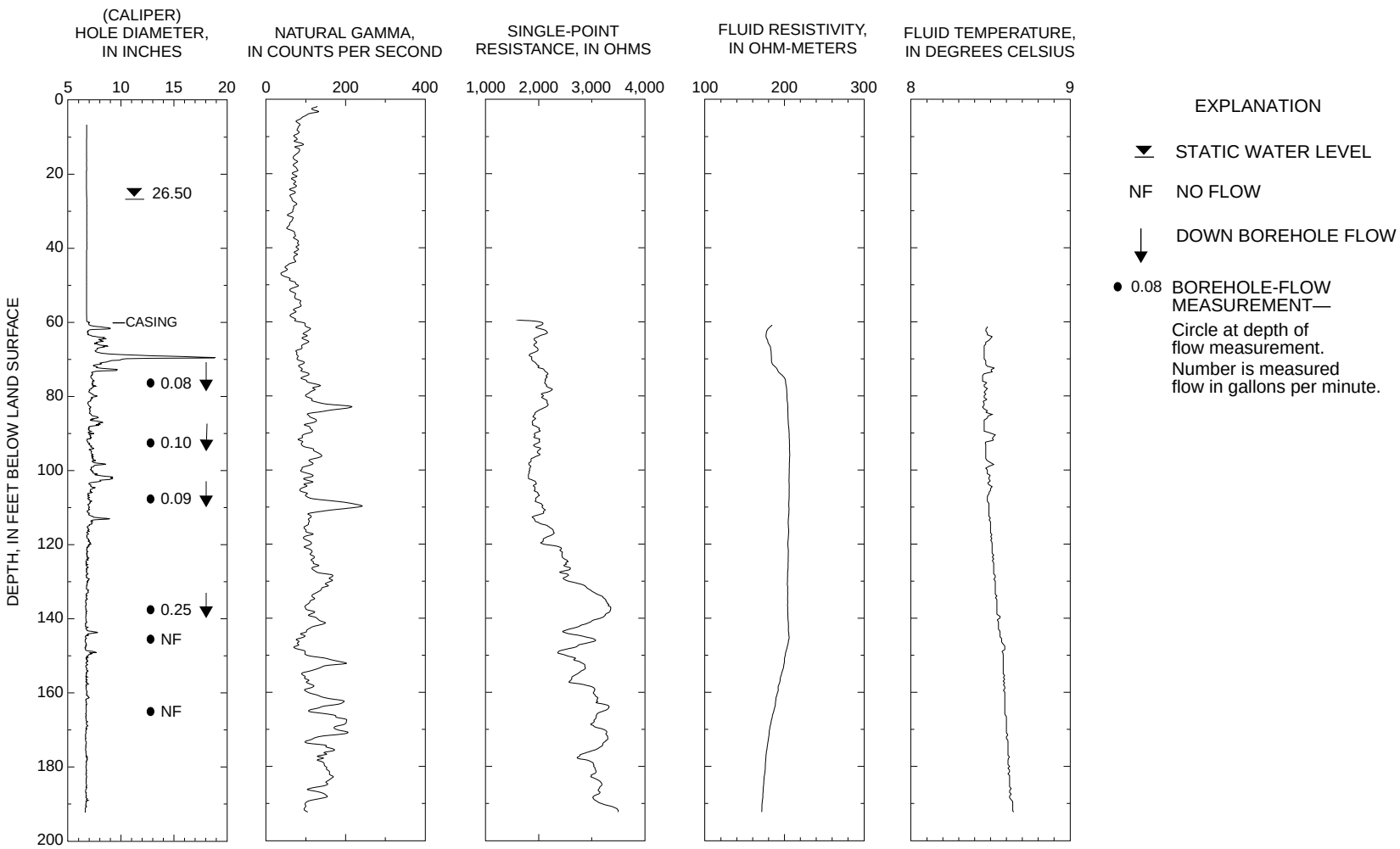

Figure 32. Borehole geophysical logs for borehole BE-1656 (HN-20-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1657 (HN-21-I)

Well BE-1657 was drilled in the granitic gneiss. The caliper log shows the total depth of the borehole is 193 ft. No casing was installed at the time of logging (fig. 33). The borehole was drilled with an 8.5-in.-diameter drill bit to 78 ft bls, then drilled from 79 ft bls to 193 ft bls with a 6.5-in.-diameter bit. The static water level at the time of logging was approximately 23 ft bls. The caliper log shows numerous fractures down to 115 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 82, 92, and 106 ft bls and no flow at 120 and 170 ft bls (table 12). The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through a fracture at 115 ft bls, moves upward, and exits the borehole through fractures at 97, 87, and 77-81 ft bls. A screen was placed from 110-120 ft bls to include the water-producing fracture at 115 ft bls. The sand pack was placed from 108-122 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 12. *Summary of heatpulse-flowmeter measurements for borehole BE-1657 (HN-21-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; --, not determined]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
82	0.3	up
92	.5	up
106	>1.2	up
120	no flow	--
170	no flow	--

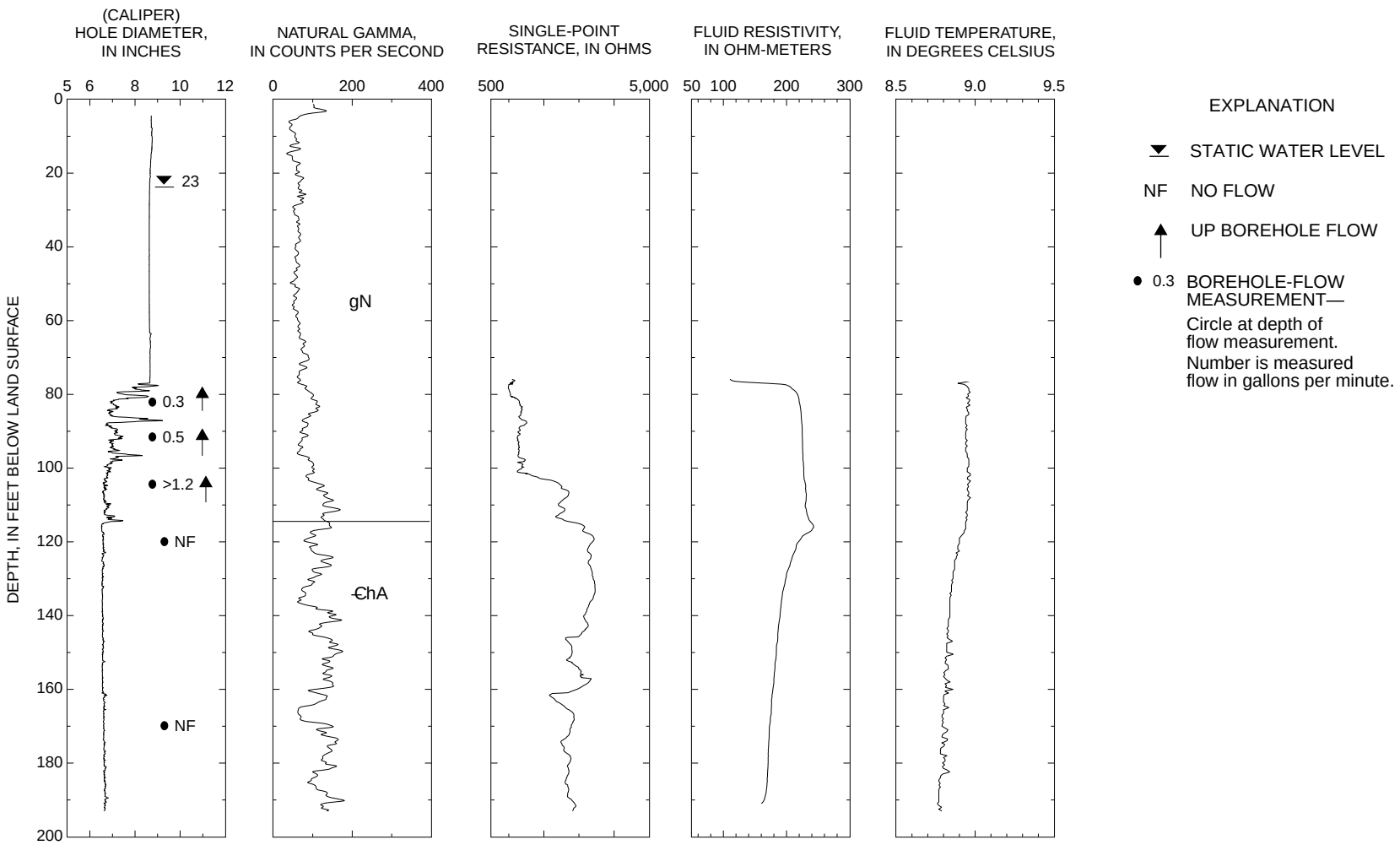

Figure 33. Borehole geophysical logs for borehole BE-1657 (HN-21-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1658 (HN-22-I)

Well BE-1658 was drilled in the granitic gneiss. The caliper log shows the total depth of the borehole is 151 ft, and it is cased with 6.5-in.-diameter casing to 57 ft bls (fig. 34). The static water level at the time of logging was 26.07 ft bls. The caliper log shows major fractures at 73, 84, 95, and 149 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 70, 80, 90, 102, 116, 130, and 140 ft bls (table 13). The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 63, 66, 73, and 126 ft bls, moves downward, and exits the borehole through fractures at 92, 95, 104, 138, and 149 ft bls. A screen was placed at 68-78 and 132-142 ft bls to include the water-producing fracture at 73 ft and water-receiving fracture at 138 ft bls. The sand pack was placed from 64.5-92 and 127-146 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

Table 13. *Summary of heatpulse-flowmeter measurements for borehole BE-1658 (HN-22-I) at Crossley Farms Superfund Site, Berks County, Pennsylvania*

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

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
70	0.2	down
80	.9	down
90	.9	down
102	.5	down
116	.4	down
130	.6	down
140	.1	down

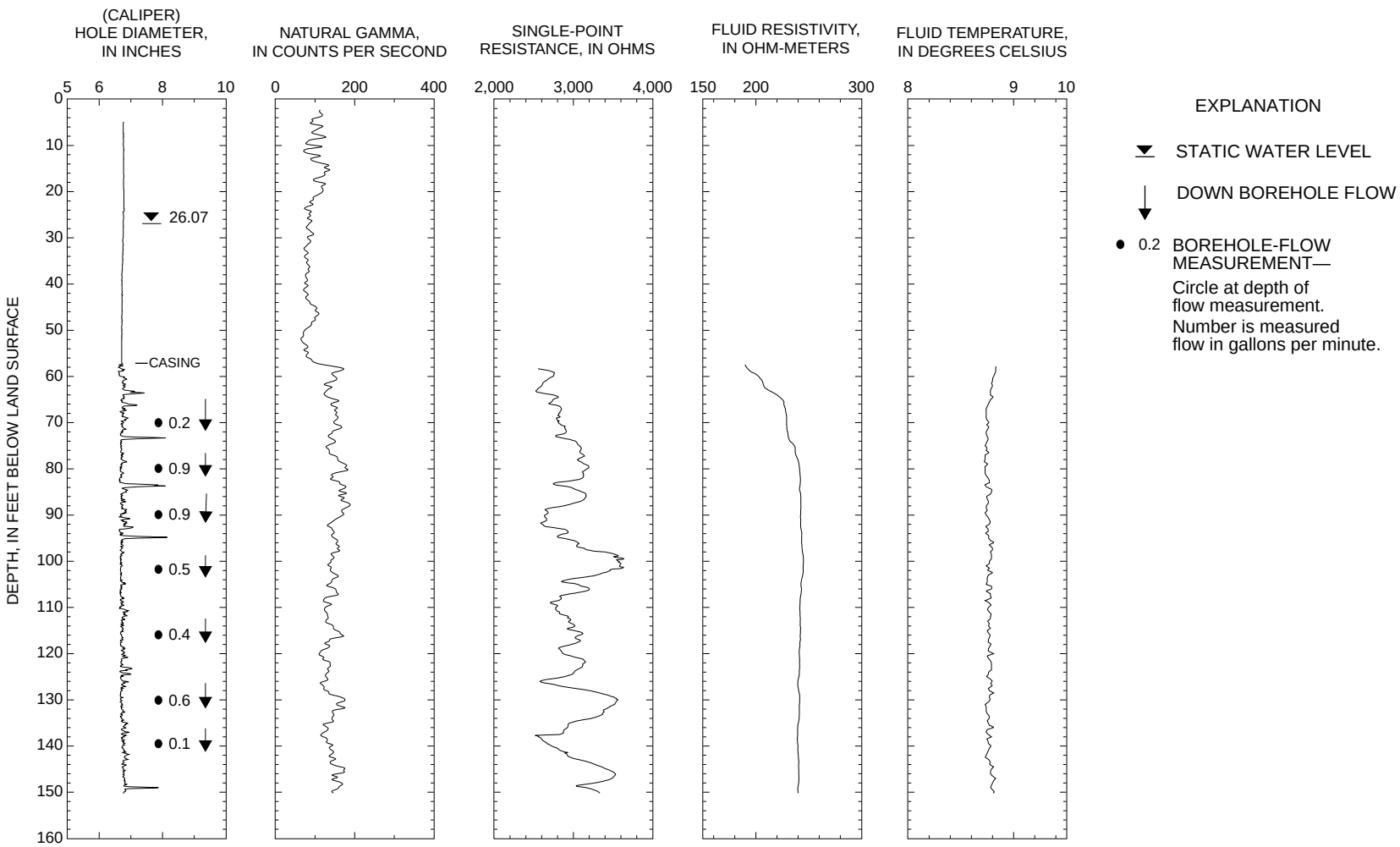

Figure 34. Borehole geophysical logs for borehole BE-1658 (HN-22-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

BE-1659 (HN-23-I)

Well BE-1659 was drilled in the granitic gneiss. The caliper log shows the total depth of the borehole is 130 ft, and it is cased with 6.5-in.-diameter casing to 74 ft bls (fig. 35). The static water level at the time of logging was 6.11 ft bls. The caliper log shows a major fracture at 120.5-123 ft bls. The single-point-resistance and fluid-resistivity logs show deflections at 87-88, 98-100, and 120.5-123 ft bls that correspond to fractures on the caliper log, which suggest water-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 81, 95, 103, and 117 ft bls. The driller reported the greatest water production below 102 ft bls (Robert Good, Tetra Tech NUS, written commun., 1999). A screen was placed at 100-125 ft bls to include the reported water-producing fracture below 102 ft bls. The sand pack was placed from 95-132 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

BE-1660 (HN-9-D)

The acoustic televiewer log shows the total depth of the borehole is approximately 360 ft, and it is cased to 150 ft bls. The static water level at the time of logging was 59.30 ft bls. The deviation log shows the borehole deviates from vertical approximately 10 ft to the northeast from 150 to 360 ft bls (fig. 36). An equal-area stereonet, with poles plotted at right angles to the fracture planes, shows most fracture planes trend northeast-southwest (fig. 37). The greatest concentration of poles to possible fracture planes are in the upper left of figure 37, indicating high-angle fracture planes. The average orientation of all fracture planes are N. 50° E., dipping 65° SE. The driller reported no noticeable water production during drilling (Robert Good, Tetra Tech NUS, Inc., written commun., 1999). This borehole yields little water and will remain an open-borehole monitor well (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 1999).

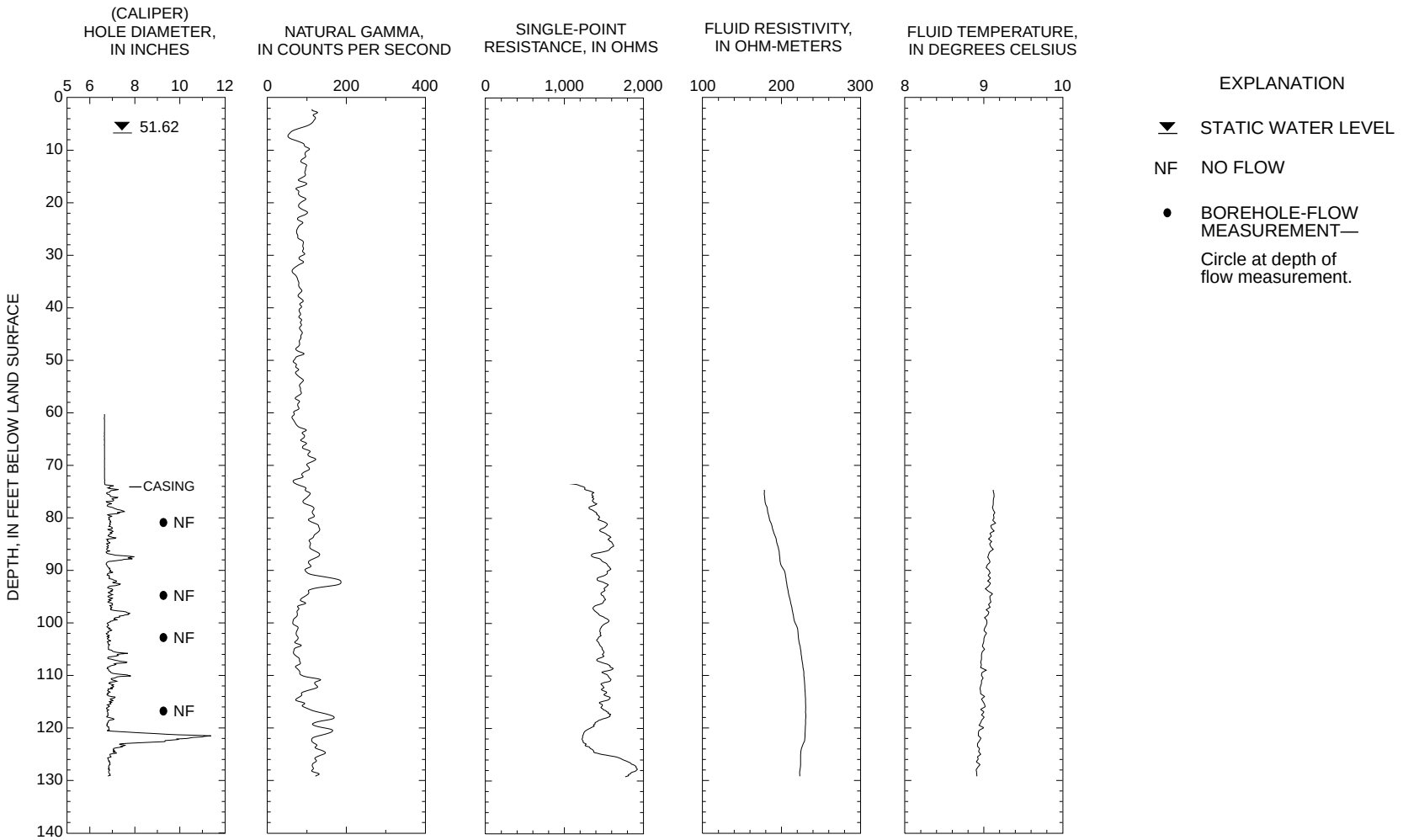

Figure 35. Borehole geophysical logs for borehole BE-1659 (HN-23-I), Crossley Farms Superfund Site, Berks County, Pennsylvania.

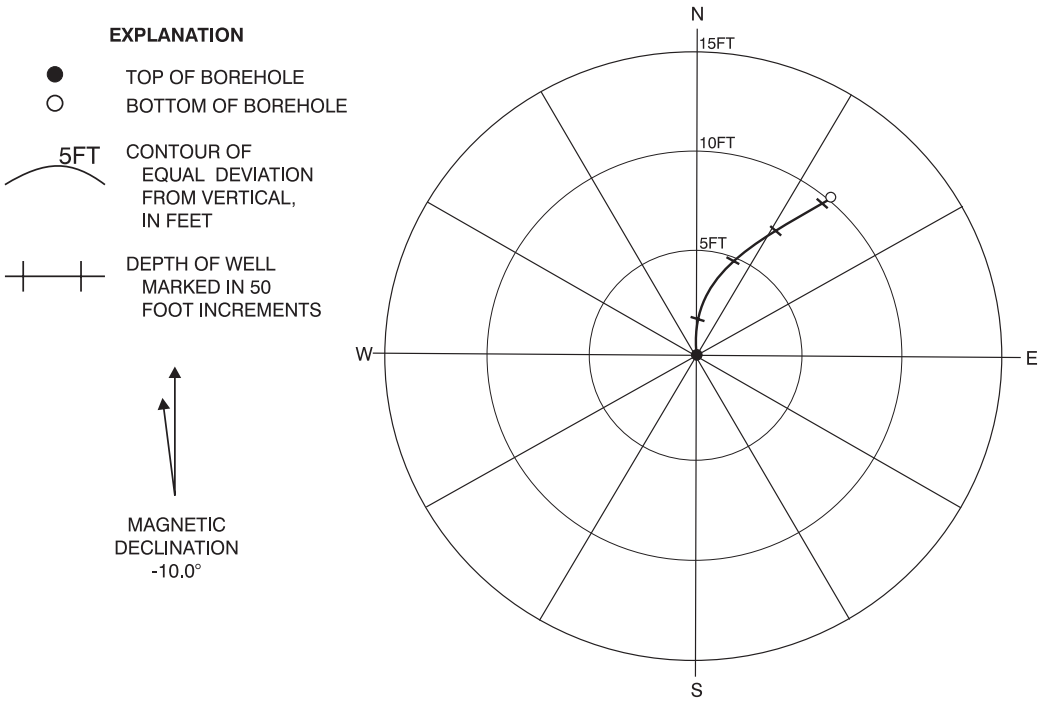

Figure 36. Magnitude and direction of deviation from vertical of borehole BE-1660 (HN-9-D).

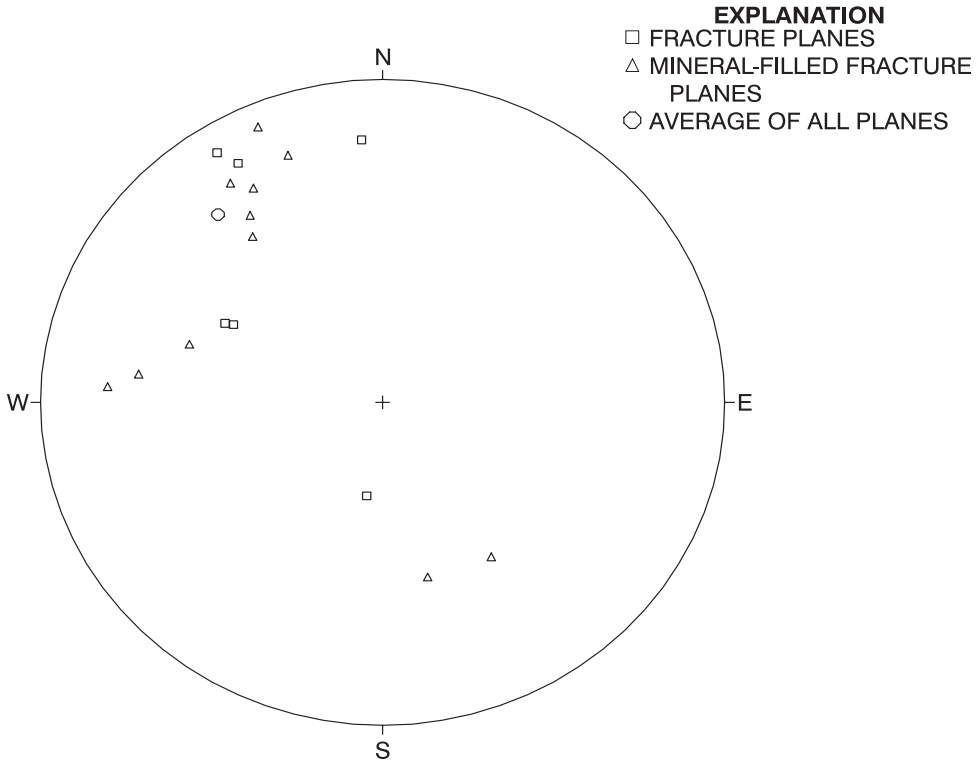

Figure 37. Equal-area lower-hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole BE-1660 (HN-9-D).

SUMMARY

Water-producing zones, water-receiving zones, and intervals of vertical flow in boreholes at the Crossley Farms Superfund Site in Berks County, Pa., were identified by the use of geophysical logs, heatpulse-flowmeter measurements, and video and acoustic-televiewer logs. These data, collected from November 1998 to May 1999, were used to help place well screens and packers in monitor wells. Screens and packers are used to monitor horizontal and vertical distribution of ground water from selected horizons within individual boreholes.

Geophysical logging was conducted in 29 boreholes completed in either the Precambrian granite gneiss, Hardyston Quartzite, and Leithsville Formation. Of the 29 boreholes, 20 located on top of Blackhead Hill range in depth from 110 to 500 ft bls, 10 showed no borehole flow under nonpumping conditions, 5 boreholes showed upward borehole flow ranging from 0.06 to greater than 1.2 gal/min over a depth range of approximately 80 to 320 ft bls, and 5 boreholes showed downward flow from 0.01 to 0.9 gal/min over a depth range of about 140-300 ft bls. Generally, downward flow occurred mostly in wells on top of Blackhead Hill (Crossley Farm property) that penetrate the Hardyston Quartzite. Borehole flow and yield of water from the granite-gneiss, granite-hornblende-gneiss depend upon chance penetration of interconnected water-producing zones. Boreholes BE-1644, BE-1655, BE-1656, BE-1657, and BE-1659 of the wells onsite, which are in close proximity to a thrust fault and lithologic contact, produce the site's greatest yields (3 to 20 gal/min). These boreholes are downgradient from a drum burial site and are the most contaminated boreholes onsite.

Nine of the boreholes logged are off the Crossley Farm property to the south and are down gradient from the Crossley Farm. Of these nine, seven boreholes are near Blackhead Hill in the Leithsville Formation. Generally, rocks penetrated in these boreholes are intensely fractured, the boreholes collapse easily, the boreholes yield very high large quantities of water, and little or no hydraulic-head difference exists within the boreholes down to depths of 380 ft bls.

In general, water production and nonpumping-flow direction are formation and elevation dependant. Heatpulse-flowmeter data indicate most boreholes penetrate several water-bearing zones depending on well depth; the deeper wells penetrate more fractures. The boreholes with the highest yields are in the Leithsville Formation.

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