Evaluation of Geophysical Logs and Aquifer-Isolation Tests, Phase III, August 2002 to March 2004, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania

By Randall W. Conger and Dennis J. Low

In cooperation with the
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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

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

$$°F = (1.8 \times °C) + 32$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Altitude, as used in this report, refers to distance above the vertical datum.

Evaluation of Geophysical Logs and Aquifer-Isolation Tests, Phase III, August 2002 to March 2004, at Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania

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Abstract

Between August 2002 and March 2004, geophysical logging was conducted in 23 boreholes at the Crossley Farm Superfund Site, Hereford Township, Berks County, Pa., to determine the water-producing zones, water-receiving zones, zones of vertical-borehole flow, and fracture orientation where applicable. The boreholes ranged in depth from 71 to 503 ft (feet) below land surface. 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 the horizontal and vertical distribution of contaminated ground water migrating from known sources could be determined. Geophysical logging included collection of caliper (22 boreholes), fluid-temperature (17 boreholes), single-point-resistance (17 boreholes), natural-gamma (17 boreholes), fluid-flow (18 boreholes), and acoustic-televiewer (13 boreholes) logs. Caliper and acoustic-televiewer logs were used to locate fractures, joints, and weathered zones. Inflections on fluid-temperature and single-point-resistance logs indicated possible water-bearing zones, and flowmeter measurements verified these locations. Single-point-resistance, natural-gamma, and geologist logs provided information on stratigraphy; the geologist log also provided information on the location of possible water-producing zones.

Borehole geophysical logging and heatpulse flowmetering indicated active flow in 10 boreholes. Seven of the boreholes are in ground-water discharge areas and three boreholes are in ground-water recharge areas. Heatpulse flowmetering, in conjunction with the geologist logs, indicates lithologic contacts (changes in lithology from a gneiss dominated by quartz-plagioclase-feldspar mineralogy to a gneiss dominated by hornblende mineralogy) are typically fractured, permeable, and effective transmitters of water.

Single-well, aquifer-isolation (packer) tests were performed on two boreholes. Packers were set at depths ranging from 210 to 465 ft below land surface to isolate water-bearing zones at discrete intervals. Placement and inflation of the packers provided information on hydraulic heads, specific capacities, the hydraulic connection between intervals, and depth-specific water-quality samples.

Upon completion of borehole geophysical logging and interpretation of geophysical logs, geologist logs, drillers notes, and packer work, 13 boreholes were reconstructed such that water levels could be monitored and water samples could be collected from discrete shallow, intermediate, and deep water-bearing fractures in each borehole. Boreholes BE-1672, BE-1674, BE-1676, and BE-1677 remained open-hole for sampling purposes. Boreholes RI-2, RI-3, and RI-4 remained open-hole for injection purposes. Boreholes P-1, P-2, and P-3 remained open and were converted to pumping wells.

Introduction

The Crossley Farm Superfund Site (Crossley Site) is in the community of Huffs Church in Hereford Township, Berks County, Pa. The site is about 20 mi northeast of Reading and is on the U.S. Geological Survey (USGS) Manatawny and East Greenville, Pa., 7.5-minute topographic quadrangle maps (fig. 1). The Crossley Site boundaries are not delineated but are assumed to be the extent of the ground-water contamination plume (Halliburton NUS, 1995).

Commercial hazardous wastes were reportedly disposed of during the mid-1960s to the mid-1970s on or near Blackhead Hill (Halliburton NUS, 1995). In the early 1980s, nearby residents 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 lesser concentrations of tetrachloroethene (PCE). Additional sampling identified TCE as the principal contaminant at concentrations as great as 22,857 µg/L (micrograms per liter) in residential well water.

In 1987–88, a hydrogeologic assessment was conducted at the Crossley Site by Roy F. Weston, Inc., and IT Corporation (R.F. Weston/IT, 1988). They conducted soil-gas surveys and drilled 21 monitor wells in proximity to the site and concluded the source of TCE was probably the abandoned quarry and borrow-pit area near the top of Blackhead Hill (Halliburton NUS, 1995). To delineate the extent of ground-water contamination, to better characterize the nature and extent of hazardous con-

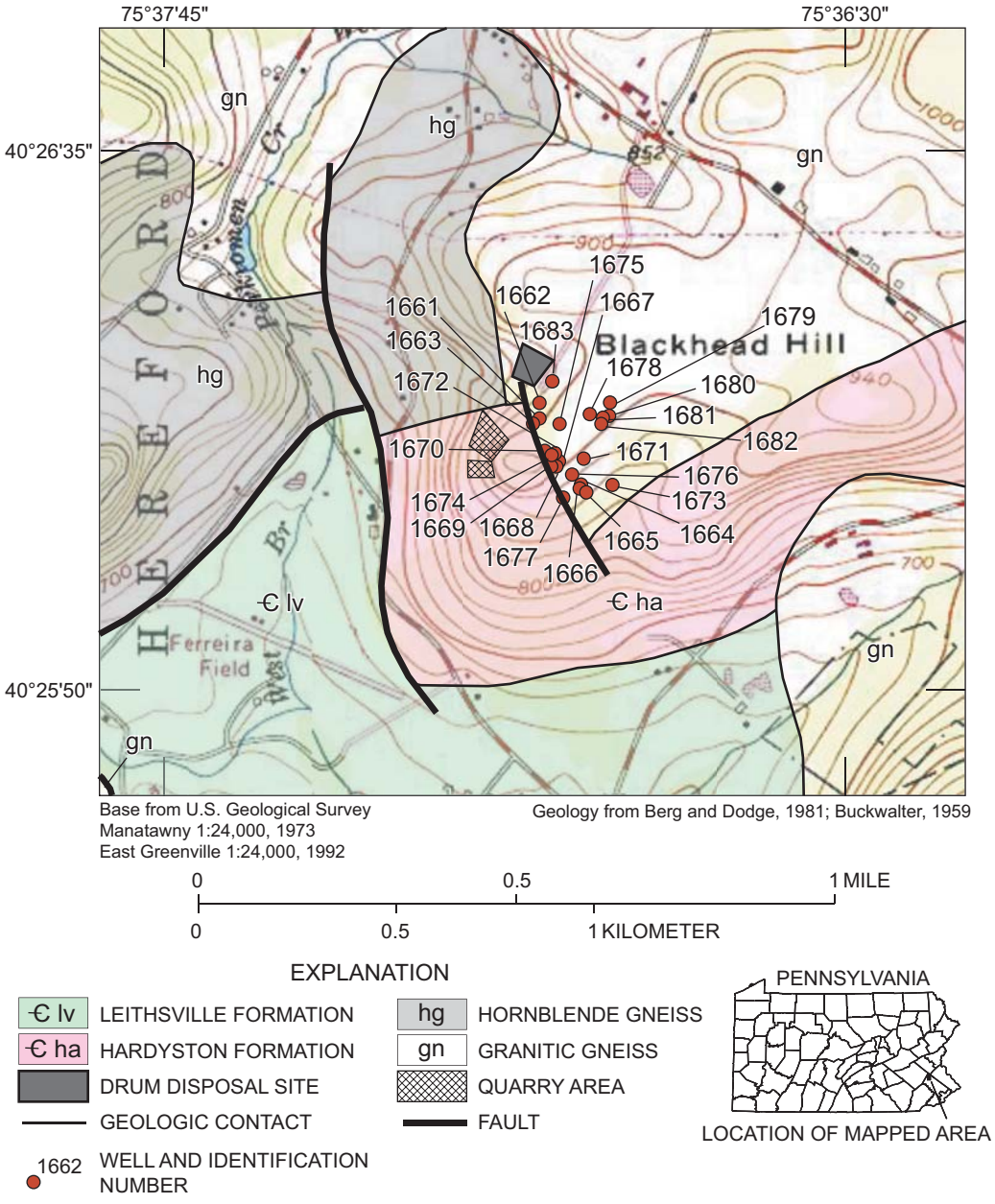


Figure 1. Location of boreholes logged at Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

tamination, and to evaluate remedial options for the contaminated residential wells, a Focused Feasibility Study (FFS) and Remedial Investigation/Feasibility Study (RI/FS) were conducted by Tetra Tech NUS Inc. (TTNUS). Currently (2005), about 2,000 of the affected residential wells are equipped with carbon filters at the point of use.

Purpose and Scope

This report presents the results of a study the USGS did in cooperation with the U.S. Environmental Protection Agency (USEPA) from August 2002 to March 2004. The purpose of this report is to present an evaluation of borehole-geophysical logging, and aquifer-isolation (packer-test) data collected by the USGS in 23 boreholes at the Crossley Site (table 1 and fig. 1). Water-producing or water-receiving zones and bedrock fractures are identified in boreholes on the basis of geophysical logs, geologist logs, and driller notes. As part of this study, geologist logs were collected in 17 boreholes by TTNUS (Tetra Tech NUS Inc., written commun., 2003), a contractor working for USEPA. Caliper, natural-gamma, single-point-resistance, fluid-temperature, or borehole-flow (heatpulse-flowmeter) logs were collected in 23 boreholes. Acoustic-televiewer logs were collected in 13 boreholes. Aquifer-isolation tests were performed in two boreholes. Samples for water-quality analyses for volatile organic compounds (VOCs) were collected from discrete zones in two boreholes for the USEPA to use to determine the distribution of contamination in the two boreholes.

Hydrogeologic Setting

The Crossley Site is in the Reading Prong Section of the New England Physiographic Province (Fenneman, 1938). The upland area of Blackhill is underlain by Precambrian granitic-gneiss (gn) that is light colored, with a medium-grained texture, containing mostly quartz and feldspar that was derived from an igneous origin. Adjacent to the site, to the north and west, the granitic-gneiss (hg) becomes darker, nearly black, with a fine to medium-grained texture composed of mostly the dark minerals hornblende and andesine (Epstein and Lytle, 1987). To the east and south, the granitic-gneiss contacts a Cambrian quartzite of the Hardyston Formation (fig. 1; Berg and Dodge, 1981, p. 183 and 355; Buckwalter, 1959). There are three prominent faults near Blackhead Hill, two offsite and one onsite. The onsite fault is directly adjacent to the wellfield and typically transmits larger quantities of water from any borehole in close proximity. The adjacent valley to the south and west is underlain mainly by Cambro-Ordovician dolomite of the Leithsville Formation (fig. 1). Bedrock is overlain by 30 to 120 ft of unconsolidated regolith (R.F. Weston/IT, 1988).

Ground water is present within and moves through secondary openings in the regolith, fractures, joints, and cleavage planes in the bedrock. Within the Leithsville Formation, the fractures have been enlarged because of dissolution and weathering of the dolomite. The shallow part of the regolith is saturated at many locations. Maps of the water table in the regolith indicate shallow ground water probably flows from the summit of Blackhead Hill to the south and west (R.F. Weston/IT, 1988). Maps of the potentiometric surface in the fractured bedrock indicate a potential for ground water to flow southward and eastward from Blackhead Hill and the quarry area toward the valley of West Branch Perkiomen Creek. Hydraulic gradients within the Leithsville Formation are much less steep than in the crystalline bedrock. Specific flow paths of ground water are difficult to characterize because they can be affected greatly by the anisotropy of the fractured bedrock and heterogeneity of water-producing and water-receiving zones.

Table 1. Borehole geophysical and geologist logs and applicable subsurface information.

[A, acoustic televiewer; C, caliper; D, deviation; R, single-point resistance; T, fluid temperature; V, heatpulse flowmeter; N, natural gamma; DG, geologist log]

Borehole geophysical log	Subsurface information
A, C	Location and orientation of fractures and water-producing zones
A, D	Deviation of borehole from vertical
R, T	Location of water-producing and water-receiving zones
T, V	Intervals of vertical borehole flow
V	Quantification of borehole flow
N, R	Lithologic correlation
C, N	Casing length
C	Borehole diameter
DG	Depth to bedrock, depth of water-bearing zones, lithologies of rocks penetrated, competence of rock

Methods of Investigation

Geophysical logs, geologist logs, and driller notes were used in the investigation to identify water-producing or water-receiving zones and bedrock fractures at the Crossley Site. Interpretive results from geophysical and geologist logs were used to select borehole intervals to perform aquifer-isolation tests. Aquifer-isolation tests were done to determine hydraulic properties of discrete fractures in boreholes.

Borehole Geophysical and Geologist Logs

Borehole geophysical logs, geologist logs, and driller notes provide information on well construction, location and orientation of fractures, water-producing and water-receiving zones, intervals of vertical borehole flow, quantification of borehole flow, and lithologic correlation. The types of subsurface information determined by the use of geologist logs and the borehole geophysical methods are summarized in table 2. Typically, all boreholes were logged within a week of being drilled.

The acoustic televiewer is a sonic imaging tool that scans the borehole wall with an acoustic beam. The reflected acoustic waves are recorded digitally on a portable computer, and images of transit time and amplitude of the waves are produced. The logs are corrected for magnetic orientation, magnetic declination (from true north), and borehole deviation from vertical by the logging software. Fractures are detected by longer transit times and decreased signal amplitudes. Because the returned data is oriented to true north and corrected for borehole deviation from vertical, strike and dip for each fracture or bedding

Table 2. Boreholes logged, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[A, acoustic televiewer; B, borehole video; C, caliper; D, deviation; G, natural-gamma; R, single-point-resistance; T, fluid-temperature; V, borehole-flow measurement]

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 well logged and water level measured	Geophysical logs collected
BE-1661	TT27-I	130	75-85 (S)	37.46	8/19/2002	A,B,C,D,G,R,T,V
BE-1662	TT27-D1	303	285-300 (S)	36.20	8/19/2002	A,B,C,D,G,R,T,V
BE-1663	TT27-D2	503	492-502 (S)	38.09	9/06/2002	A,B,C,D,G,R,T,V
BE-1664	TT-26-I	159	140-160(S)	24.75	9/09/2002	A,B,C,D,G,R,T,V
BE-1665	TT26-D1	302	246-256 (S)	22.33	9/10/2002	A,B,C,D,G,R,T,V
BE-1666	TT26-D2	476	185-205 (S)	21.05	9/11/2002	A,B,C,D,G,R,T,V
BE-1667	TT25-I	72	67-72 (S)	29.59	9/20/2002	A,B,C,D,G,R,T,V
BE-1668	TT25-D1	303	264-274 (S)	27.98	9/20/2002	A,B,C,D,G,R,T,V
BE-1669	TT25-D2	503	95-105 (S)	28.88	9/24/2002	A,B,C,D,G,R,T,V
BE-1670	TT25-S	71	56-66 (S)	28.48	9/25/2002	A,B,C,D,G,R,T,V
BE-1671	TT24-I	152	132-152 (S)	15.35	9/26/2002	A,B,C,D,G,R,T,V
BE-1672	TT28-I	150	30-150 (O)	16.48	12/16/2002	A,B,C,G,R,T,V
BE-1673	TT29-I	151	75-150 (S)	8.38	12/16/2002	C,G,R,T,V
BE-1674	TT28-D	338	158-338 (O)	19.51	12/17/2002	B,C,G,R,T,V
BE-1675	TT31-I	152	85-150 (S)	23.50	1/21/2003	C,G,R,T,V
BE-1676	TT29-D	357	170-338 (O)	23.50	1/21/2003	B,C,G,R,T,V
BE-1677	TT30-D	419	158-418 (O)	25.63	1/27/2003	C,G,R,T,V
BE-1678	RI-2	137	62-137 (O)	14.03	2/05/2004	C
BE-1679	RI-3	168	90-160 (O)	7.36	2/12/2004	C
BE-1680	RI-4	157	78-153 (O)	7.30	2/12/2004	C
BE-1681	P-1	160	105-155 (O)	9.54	2/24/2004	C
BE-1682	P-2	136	58-136 (O)	9.00	2/26/2004	C
BE-1683	P-3	162	39-162 (O)	24.14	3/02/2004	A,V

plane can be determined. The acoustic televiewer can be used underwater in 6- to 8-in.-diameter boreholes. Because of magnetic interference, the acoustic televiewer cannot determine fracture orientation within 6 ft of the bottom of steel casing.

Caliper logs provide a continuous record of average borehole diameter, which may be related to fractures, lithology, or drilling methods. Caliper logs can be used to identify fractures and possible water-producing or water-receiving zones and to correct other geophysical logs for changes in borehole diameter. They also can be correlated with fluid-temperature logs and heatpulse flowmetering to identify additional fractures and water-producing and water-receiving zones.

Borehole deviation 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, fracture traces, mineralization, or bedding obtained from acoustic-televiewer logs.

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. The gamma log can be collected in or out of water or casing. However, casing reduces the gamma response. The gamma log is used to correlate geologic units between wells (Keys, 1988).

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-producing fractures, and increasing concentration of dissolved solids of borehole water. The single-point-resistance log is used to correlate geologic units between wells and may help identify water-producing zones (Keys, 1988).

A fluid-temperature log provides a continuous record of the vertical temperature variation in the water in a borehole. Fluid-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 sheet of water between two sensitive thermistors (heat sensors) located the same distance from the heat source. The time it takes for the heated water to move upward or downward past one of the thermistors is recorded. Because the thermistors are in a channel of fixed diameter, the flow rate can be determined from the time it takes for the peak of the heatpulse to pass one of the thermistors. A flexible diverter is used to block the annular space around the tool to channel all the flow through the measurement channel. The range of flow measurement is about 0.01–1.5 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 (occurs only if the well is pumped while being logged). 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 used primarily as a relative indicator to identify water-producing and (or) water-receiving zones.

The geologist logs (Tetra Tech NUS, Inc., written commun., 2003) consist of a series of notes and visual observations that include descriptions of material penetrated, rate of penetration, and presence or increase of water blown from the borehole. Regolith (overburden, saprolite, and strongly weathered rock) was penetrated by a 10-in.-diameter air hammer; consolidated bedrock was penetrated by a 10-in. and (or) 6-in.-diameter air hammer. As drilling advanced, the geologist collected small samples of rock cuttings at known depths. The geologist recorded his observations and provided comments or interpretations regarding the texture, color, competence, and predominant rock or mineral. More detailed descriptions may be available if the borehole is cored. These descriptions also may include information on foliation and fractures. Changes in drilling speed indicated possible voids, fractures, and changes in lithology and rock competence. Approximately every 20 ft, the driller added another length of drill rod. In conjunction, the driller typically cleaned out the accumulated water, mud, rock, and other debris by “blowing” the borehole with air pressure. The geologist was then able to estimate the volume of water entering the borehole and noted the increase of flow into the borehole over the previous 20 ft.

Aquifer-Isolation Tests

Single-well, aquifer-interval-isolation tests (packer) tests were conducted in boreholes BE-1665 and BE-1666. Because ground water moves through discrete fractures or fracture zones, the hydraulic properties and water quality of individual fractures or fracture zones can differ. The properties of individual fractures and zones can be obtained by isolating them with a straddle-packer assembly. The straddle-packer assembly consists of two inflatable bladders (packers) separated by a length of perforated pipe in which a pump is set (fig. 2). Both packers were inflated to isolate three intervals, and a single packer was used to isolate two intervals in the open borehole. The perforated pipe length was adjusted to cover the vertical length of the fracture or fracture zone to be tested. Transducers allowed the water level below the bottom packer and above the upper packer to be recorded concurrently with the water level in the isolated zone.

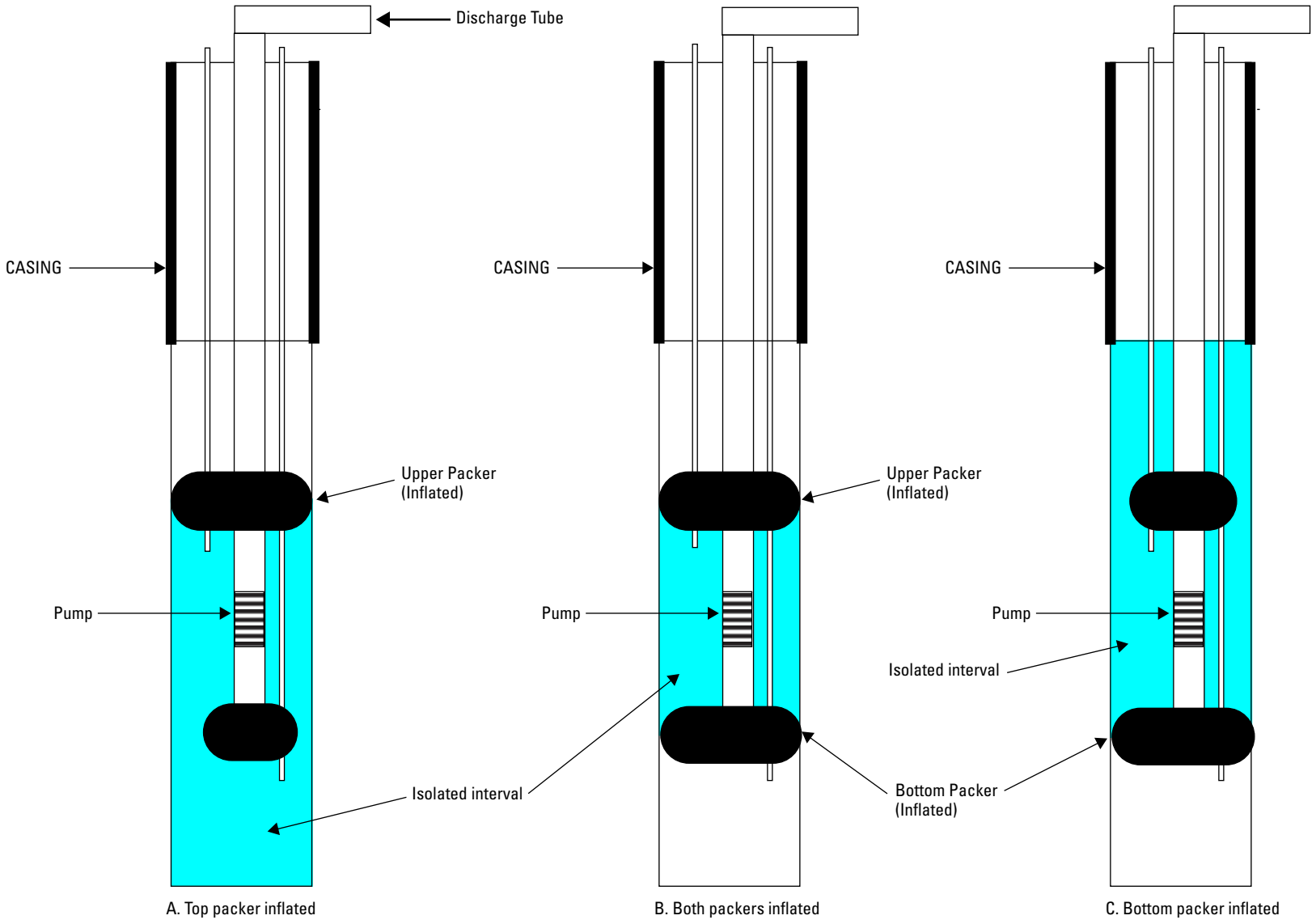


Figure 2. Generalized sketch of straddle-packer assembly and pump used in aquifer-isolation tests.

Water-Quality Samples

Water-quality samples were collected from the isolated intervals after the collection of water-level drawdown data. To insure a representative water sample from the aquifer, either a standard three borehole volume was purged from the borehole or water-quality measurements of specific conductance, pH, and temperature were consistent after several measurements.

Well-Numbering System

The USGS well-numbering system consists of a two letter county abbreviation followed by a sequential number. A borehole in Berks County is denoted by a prefix BE. Tetra Tech NUS numbering system consists of the prefix letters TT followed by a sequential site-specific borehole number, with a suffix letter indicating approximate borehole depth, such as S (shallow), I (intermediate), D (deep). A cross-reference of USGS and TTNUS borehole numbers used at the Crossley Site are listed in table 2.

Description of Borehole-Geophysical and Geologist Logs

The locations of boreholes logged are shown on figure 1. The reference measuring point for all geophysical logs is land surface. Depth of boreholes, casing lengths, and water levels at the time of logging are given in feet below land surface (ft bls).

BE-1661 (TT27-I)

Borehole BE-1661 was drilled in Precambrian gneiss (table 3). The geologist log notes the regolith is about 21 ft thick, consisting of a boulder and sandy silt. Bedrock is made up of a sequence of hornblende-poor and hornblende-rich gneiss. The geologist log also notes a number of possible fractures, soft zones, and bottom of casing (table 3). The static water level at the time of logging was 37.46 ft bls. The caliper log shows the total depth of the borehole is 130 ft, and it is cased with 6-in.-diameter casing to 44 ft bls (fig. 3). The caliper log shows major fractures at 44.5, 45–49, 59–60, 71, 73–74, and 78–81 ft bls and smaller fractures at 86–88, 92–94.5, 101, and 113 ft bls. Changes in lithology at 75, 87, 93, 95, and 113 ft bls correlate to fractures identified on the caliper log. The single-point-resistance log shows changes in slope at 45–49, 59–60, 73, 86–88, 92, 101, and 113 ft bls that correlate closely to fractures shown on the caliper log. The fluid-temperature log shows minor changes in slope at 52, 60, 75, 80, 87, 100, and 112 ft bls that correlate closely to fractures shown on the caliper log. The acoustic-televiewer log shows 25 fractures (table 4). An equal-area stereonet produced from acoustic-televiewer data, with poles plotted at right angles to the fracture planes, was used to compute that the average orientation of all fracture planes and fracture traces (mineral-filled fractures) is a strike of N. 36° E. and a dip of 81° NW. (fig. 4). The average orientation of all water-producing fractures within the borehole is a strike of N. 45° W. and a dip of 73° SW. The borehole deviation log (fig. 5) shows the borehole deviates from vertical approximately 1.4 ft to the southwest.

Table 3. Geologist log for borehole BE-1661 (TT27-I), collected on Aug. 8, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–5	**BOULDER,** quartzite and crushed stone; hard; dusty
6–21	**SAPROLITE**, abundant sandy silt; soft; moist
22–64	**GNEISS**, quartz, plagioclase, and feldspar; harder, but weathered; dusty
	Soft at 34 ft bls
	Soft and wet at 40 ft bls,
	Bottom of casing set at 44 ft bls
	Producing about 3 gal/min at 52 ft bls
	Producing about 2 gal/min at 60 ft bls
65–75	**GNEISS**, hornblende
	Possible fracture at 75 ft bls
	Producing 5 gal/min by 75 ft bls
76–113	**GNEISS**, quartz, plagioclase, feldspar alternating with hornblende
	Possible fracture at 80 ft bls producing about 2 gal/min
	Producing 5 to 7 gal/min by 82 ft bls
	Producing 5 to 10 gal/min by 86 ft bls
	Possible fracture at 87 ft bls
	Possible producing zone at 100 ft, borehole producing 10 gal/min by 100 ft bls
	Producing 10 to 15 gal/min by 107 ft bls
114–130	**GNEISS**, hornblende
	Producing 15 gal/min by 115 ft bls
	Producing some water at a possible fracture at 127 ft bls
	Producing 20 gal/min by 130 ft bls

Table 4. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1661 (TT27-I), Aug. 19, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
48	N58W	76NE	74	N45W	35SW
49	N20E	31NW	80	N64W	70NE
52	N71W	63NE	88	N63W	69NE
52	N78W	43NE	88	N66W	54NE
54	N75E	64SE	92	N65W	73NE
58	N19W	56SW	93	N72W	60NE
58	N27W	61SW	94	N34E	47NW
60	N74E	18NW	100	N32E	17NW
62	N54W	61NE	101	N11W	54SW
66	N74W	66NE	109	N53E	72SE
67	N52W	25SW	112	N69E	53SE
69	N73W	59NE	118	N51W	56NE
71	N33W	16SW			

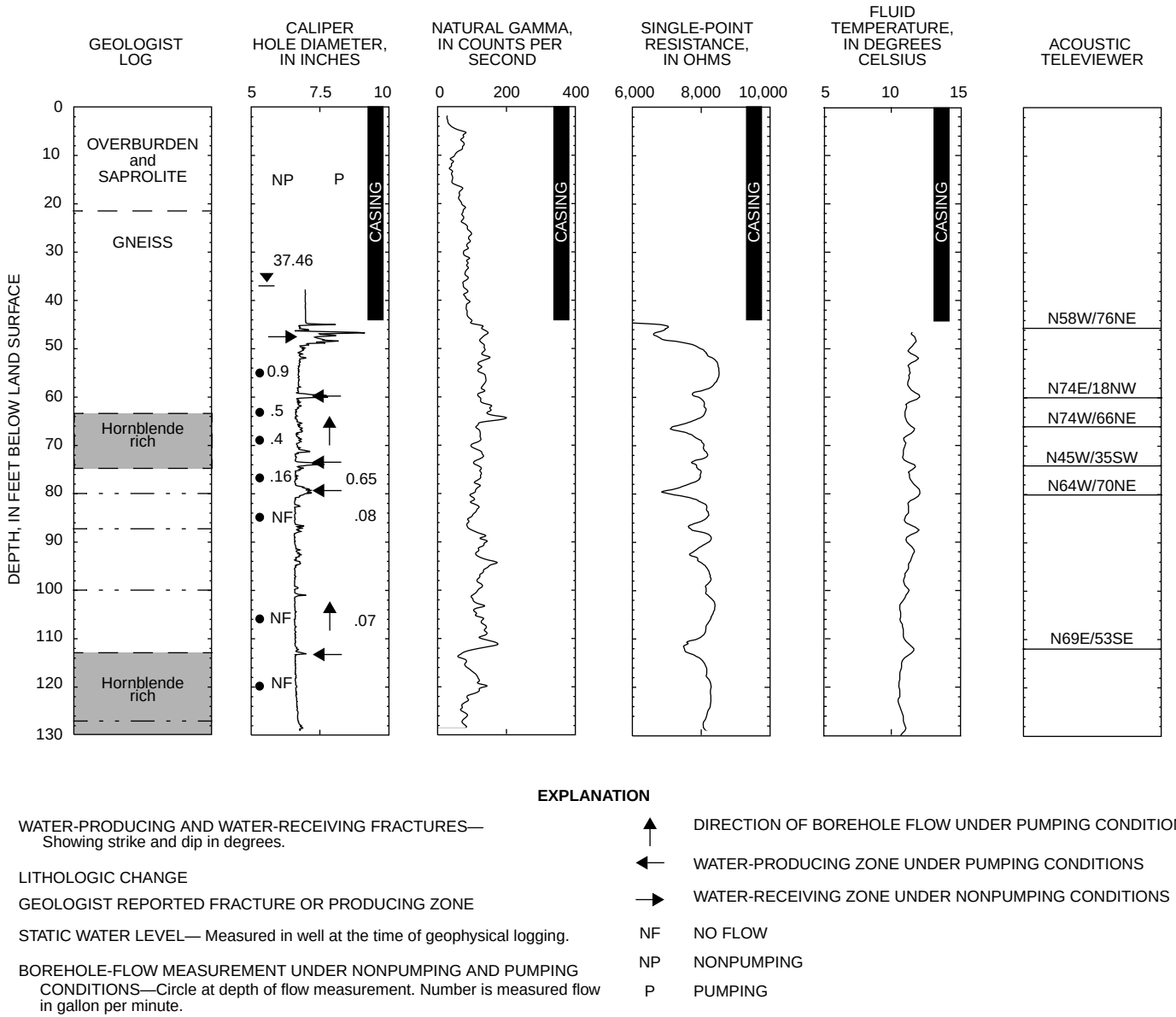


Figure 3. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1661 (TT27-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 8 through August 9, 2002. Borehole geophysical logs collected on August 19, 2002.)

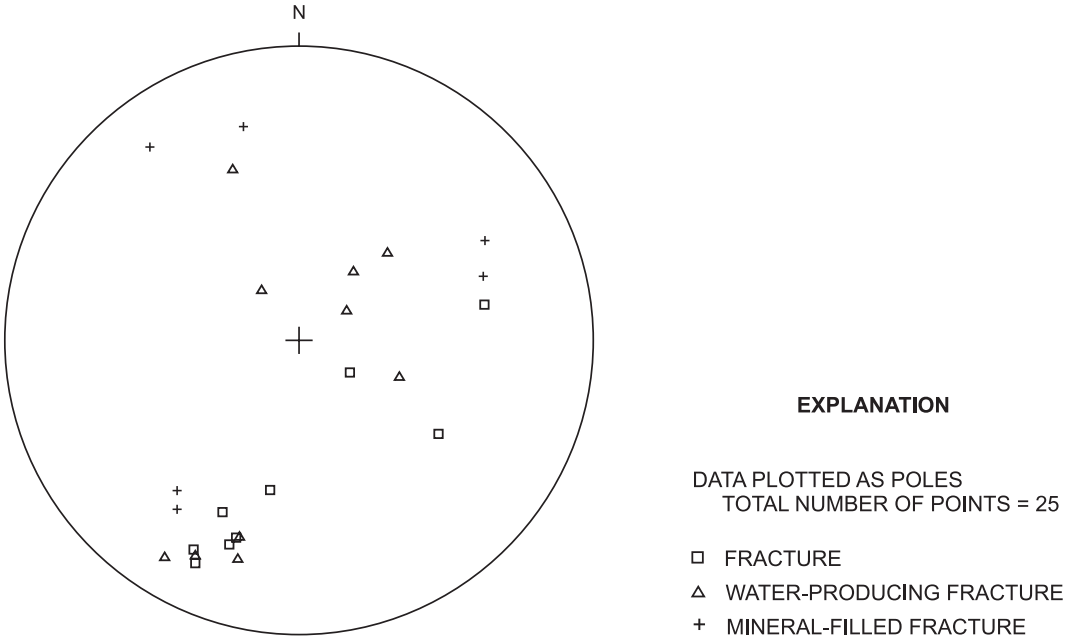


Figure 4. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1661 (TT27-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

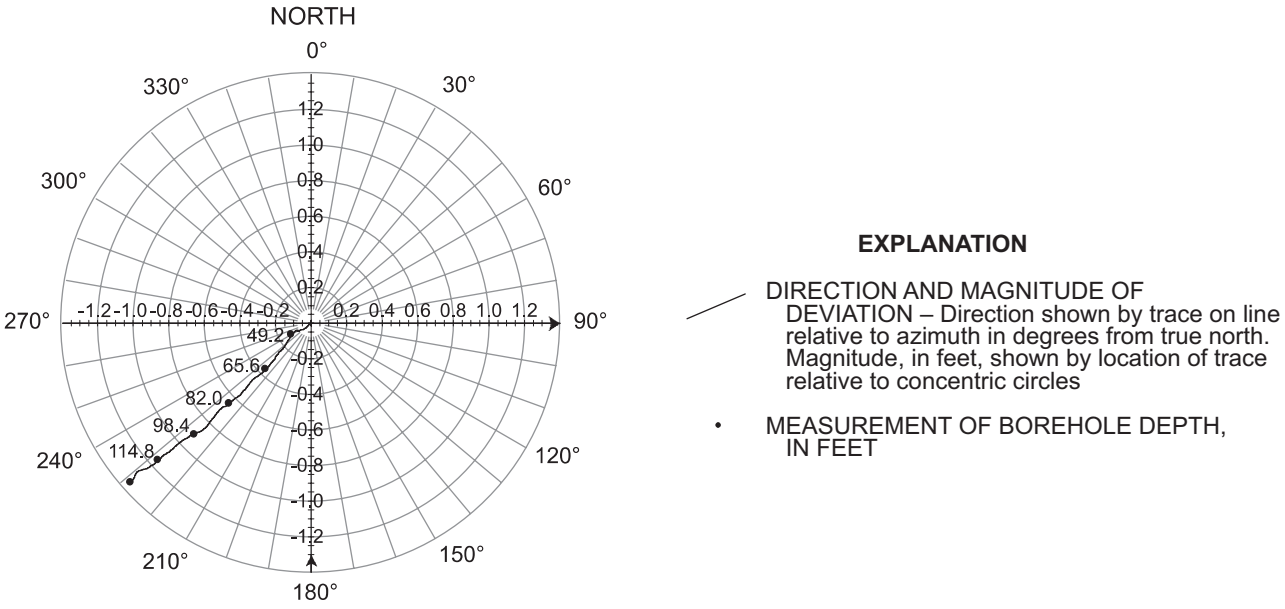


Figure 5. Magnitude and direction of deviation from vertical of borehole BE-1661 (TT27-I), Aug. 19, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 55, 63, 69, and 77 ft bls and no flow at 85, 106, and 120 ft bls (table 5 and fig. 3). The largest producing zone was at depth of approximately 60 ft bls (fig. 3). This water-producing zone is at a lithologic change on the geologist log (table 3) and is shown as a large fracture on the acoustic-televiewer log (table 4). Water exited the borehole just below casing through a major fracture at 45–49 ft bls.

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole. The pump was turned on, and the discharge rate set at approximately 1.5 gal/min. At 106 ft bls, flow increased from zero to an upward flow of 0.07 gal/min (table 5 and fig. 3). The fracture at 78–81 ft bls exhibited increased flow of approximately 0.5 gal/min. After pumping for 38 minutes and removing 64.7 gal, the pump was turned off. The borehole was completed as a monitor well by placing a pvc plastic screen at 75 to 85 ft bls, to include the water-producing fracture at 78–81 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 5. Summary of heatpulse-flowmeter measurements for borehole BE-1661 (TT27-I), Aug. 19, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

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

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
55	0.9	up	—	—
63	.5	up	—	—
69	.4	up	—	—
77	.16	up	0.65	up
85	no flow	not determined	.08	up
106	no flow	not determined	.07	up
120	no flow	not determined	—	—

BE-1662 (TT27-D1)

Borehole BE-1662 was drilled into Precambrian gneiss (table 6). The geologist log notes about 40 ft of regolith and a sequence of hornblende-poor and hornblende-rich gneiss. The geologist log also notes a number of possible fractures, soft zones, and estimates of yield as well as the bottom of casing (table 6). The static water level at the time of logging was 36.20 ft bls. The caliper log shows the total depth of the borehole is 303 ft, and it is cased with 6-in.-diameter casing to approximately 117.5 ft bls (fig. 6). The caliper log shows major fractures at 118, 266–270, and 285–287 ft bls plus additional smaller fractures throughout the open-hole interval. Changes in lithology at 123, 186, and 196 ft bls correlate to fractures identified on the caliper log. The natural-gamma log shows a marked increase in counts beginning at a depth of 170 ft bls and continuing to the bottom of the borehole; there is a noticeable spike at 118 to 120 ft bls. The increase in natural-gamma counts is probably because of changes in lithology as described in the geologist log (table 6), specifically higher concentrations of potassium feldspar within the granite gneiss. The single-point-resistance log shows changes in slope at 128, 142, 182, 188–191, 205, 208, 212, 231, 247, 266–270, 286, and 292 ft bls that correlate closely to fractures shown on the caliper log. The fluid-temperature log shows changes in slope at 124, 188, and 220 ft bls that approximately correlate to fractures shown on the caliper log and (or) changes in lithology as shown in the gamma log. The acoustic-televiewer log shows 28 fractures (table 7). An equal-area stereonet produced from acoustic-televiewer data, with poles plotted at right angles to the fracture planes, shows all fracture planes and mineral-filled fractures generally strike N. 33° E. and dip 84° SE. (fig. 7). The average orientation of all water-producing fractures is a strike of N. 70° E. and a dip of 61° NW. The borehole deviation log (fig. 8) shows the borehole deviates from vertical 4.5 ft to the northeast.

Table 6. Geologist log for borehole BE-1662 (TT27-D1), Aug. 5-8, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–5	**BOULDER,** quartzite and crushed stone; hard; dusty
6–40	**SAPROLITE**,
	Harder at 14 ft bls
	Soft at 16 ft bls
	Moist at 18 ft bls
	Harder at 28 ft bls
	Wet and harder at 40 ft bls
41–66	**GNEISS**, quartz, plagioclase, and feldspar; harder, but weathered
	Fracture at 50–52 ft bls
	Producing 5–10 gal/min by 52 ft bls
	Producing 10–15 gal/min by 55 ft bls
	Fracture at 61–63 ft bls
67–76	**GNEISS**, quartz, plagioclase, feldspar, and hornblende
	Soft at 66–68 ft bls
	Fracture at 70–72 ft bls
	Fracture at 74 ft bls
77–97	**GNEISS**, hornblende
	Fracture at 77–78 ft bls
	Fracture at 86 ft bls
	Producing 20 gal/min by 86 ft bls
	Fracture at 91 ft bls
	Producing 20–25 gal/min by 91 ft bls
98–123	**GNEISS**, quartz, plagioclase, and feldspar
	Producing 25 gal/min by 100 ft bls
	Bottom of casing set at 117.5 ft bls
124–174	**GNEISS**, hornblende
	Producing about 3 gal/min by 123 ft bls
	Producing 3–5 gal/min by 130 ft bls
	Producing 5–7 gal/min by 152 ft bls
175–186	**GNEISS**, quartz, plagioclase, feldspar, alternating with hornblende
	Possible fracture at 183 ft bls
187–196	**GNEISS**, hornblende
197–266	**GNEISS**, quartz, plagioclase, and feldspar
267–276	**GNEISS**, hornblende
277–302	**GNEISS**, quartz, plagioclase, and feldspar
	Fracture at 286 ft bls
	Possible fracture at 293 ft bls
303–303	**GNEISS**, hornblende
	Producing 7–10 gal/min by 303 ft bls

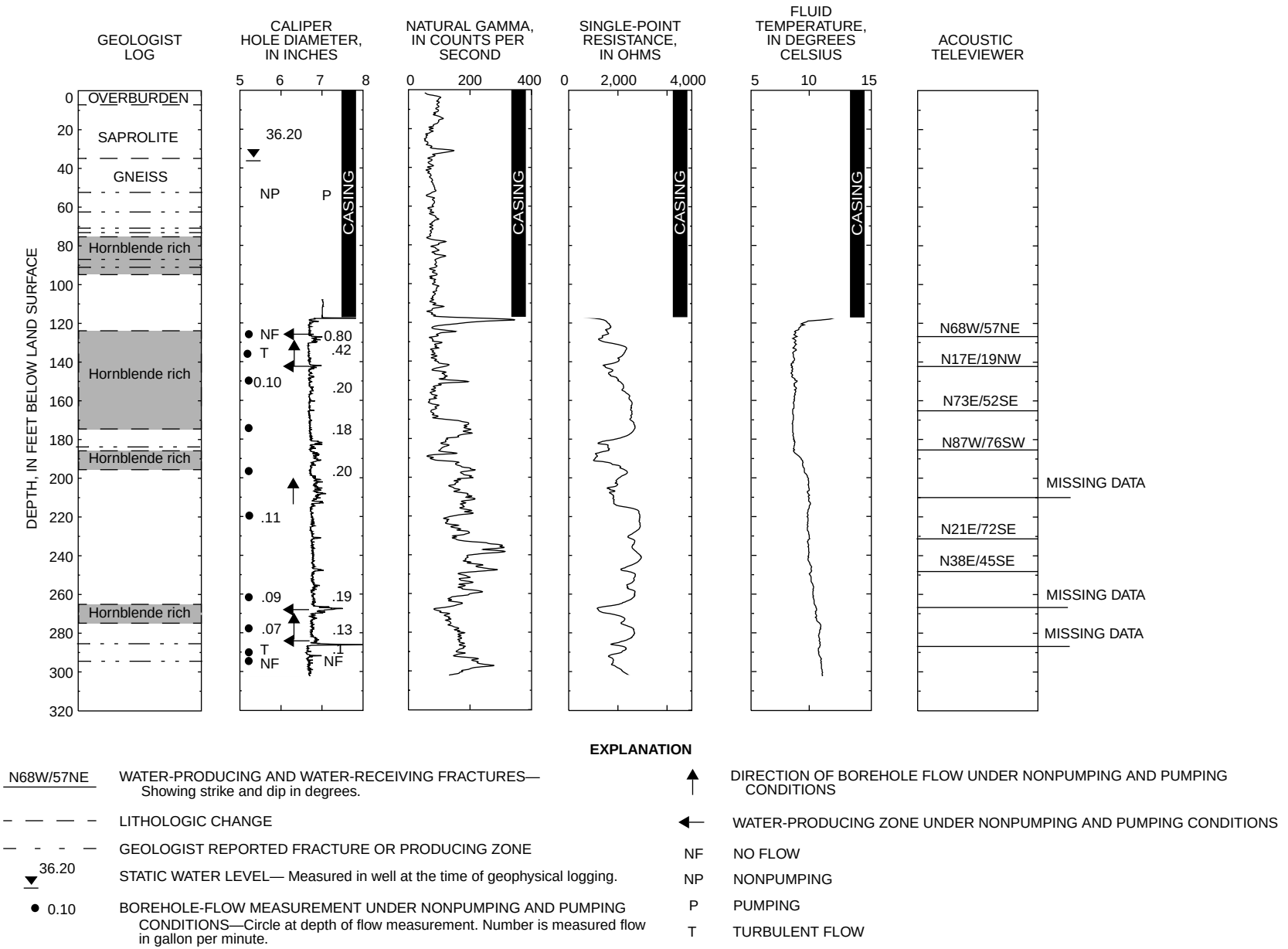


Figure 6. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1662 (TT27-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 5 through August 8, 2002. Borehole geophysical logs collected on August 20, 2002.)

Table 7. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1662 (TT27-D1), Aug. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
119	N1E	66SE	162	N12W	76NE
120	N85W	59NE	163	N64E	84SE
121	N51E	78SE	165	N73E	52SE
127	N88W	61NE	170	N50E	72SE
128	N68W	57NE	183	N49W	69SW
129	N68W	72NW	185	N68W	24NE
139	N87W	43SW	185	N74W	66SW
140	N8E	64SE	185	N87W	76SW
142	N17E	32NW	224	N76W	68SW
143	N81W	19SW	232	N81E	64SE
144	N57W	30NE	233	N21E	72SE
146	N87W	47NE	247	N39W	60NE
148	N17E	32NW	249	N38E	45SE
149	N87E	54SE	249	N77E	53SE

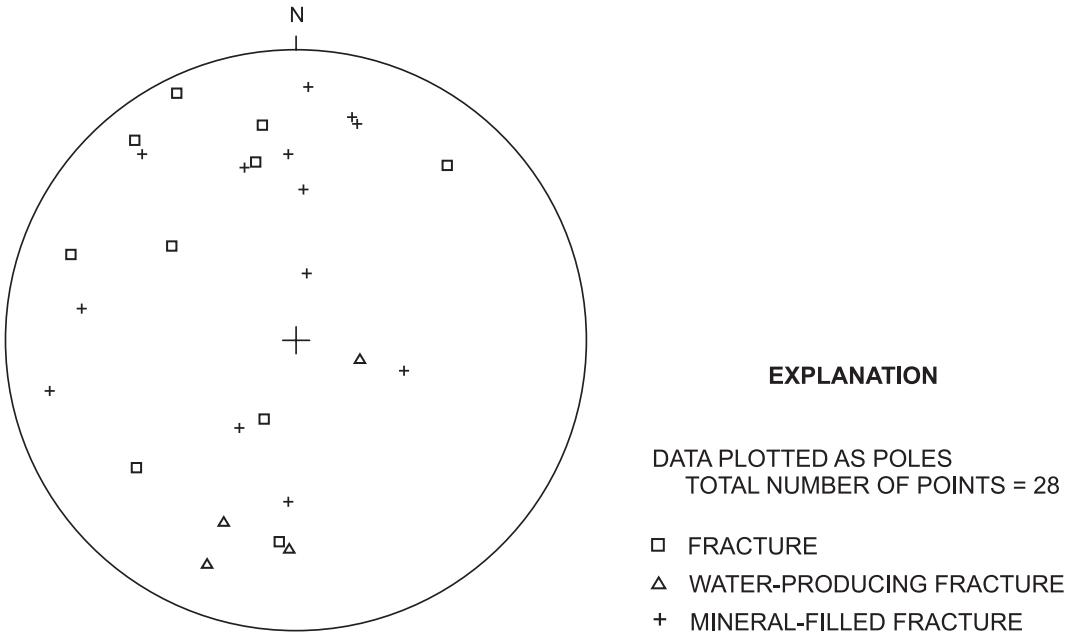


Figure 7. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1662 (TT27-D1), Aug. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

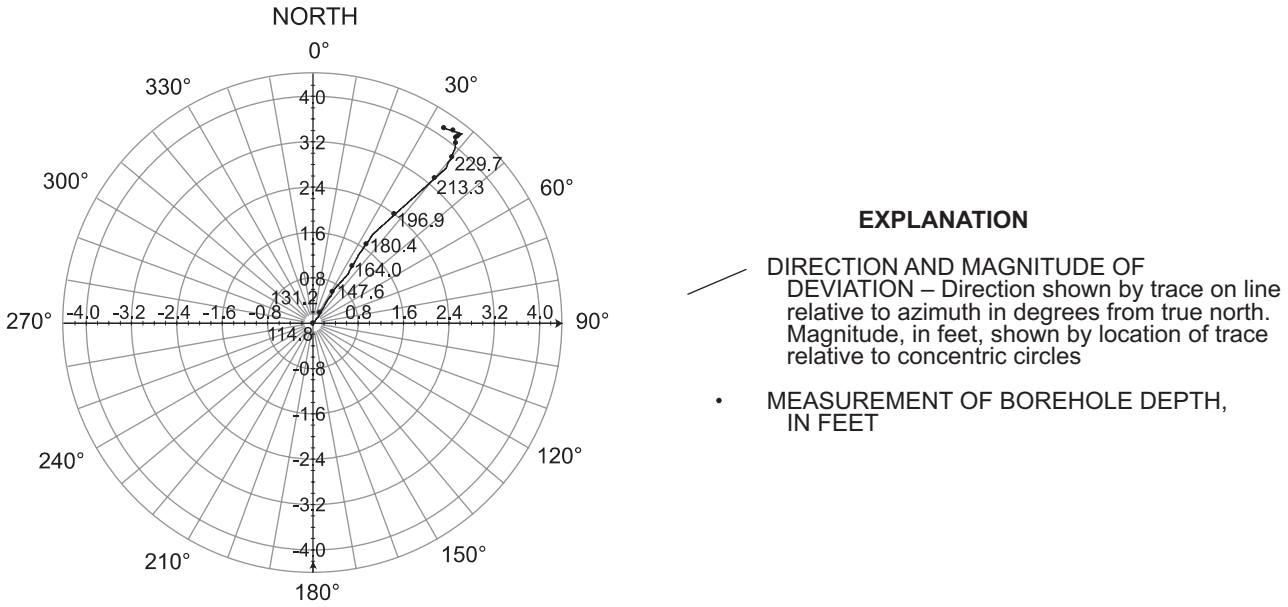


Figure 8. Magnitude and direction of deviation from vertical of borehole BE-1662 (TT27-D1), Aug. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 150, 220, 262, and 278 ft bls and no flow at 124 and 295 ft bls (table 8 and fig. 6). Turbulent flow was noted at 136 and 290 ft bls, which prevented a determination of the flow rate and direction of borehole flow. The largest producing zone was at depth of approximately 286 ft bls and is identified as a fracture on the geologist log (fig. 6). Water flowed upward and exited the borehole through a fracture zone from 127 to 130 ft bls.

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole. The pump was turned on and the discharge rate varied from 1.1 to 1.3 gal/min; the water level decreased from 36.64 to 39.05 ft bls over 78 minutes of pumping. Under pumping conditions, flow at 124 ft bls increased from zero to 0.8 gal/min (table 8 and fig. 6). At 136 ft bls, turbulent flow became upward flow; the measured vertical flow rate was 0.42 gal/min. Flow at 262 ft bls increased 0.10 gal/min. Flow at 278 ft bls almost doubled to 0.13 gal/min. Turbulent flow at 290 ft bls became 0.10 gal/min of upward flow. The borehole was completed as a monitor well by placing a pvc plastic screen at 285–300 ft bls, to include the water-producing fractures at 286 and 292 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 8. Summary of heatpulse-flowmeter measurements for borehole BE-1662 (TT27-D1), Aug. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

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

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
124	no flow	not determined	0.80	up
136	turbulent	not determined	.42	up
150	0.10	up	.20	up
173	—	—	.18	up
197	—	—	.20	up
220	.11	up	—	—
262	.09	up	.19	up
278	.07	up	.13	up
290	turbulent	not determined	.10	up
295	no flow	not determined	no flow	not determined

BE-1663 (TT27-D2)

Borehole BE-1663 was drilled into Precambrian gneiss (table 9). The geologist log notes the regolith is about 38 ft thick and consists of silt, sand, and very weathered rock fragments. The bedrock is a sequence of hornblende-poor and hornblende-rich gneiss. The geologist log also notes a number of possible fractures, soft zones, and estimates of yield as well as the bottom of casing (table 9). The static water level at the time of logging was 38.09 ft bls. The caliper log shows the total depth of the borehole is 503 ft, and it is cased with 6-in.-diameter casing to 117 ft bls (fig. 9). The caliper log shows major fractures at 118 and 302 ft bls plus numerous smaller fractures throughout the open-hole interval. Changes in lithology at 118, 180–202, and 302 ft bls correlate closely to fractures identified on the caliper log. The natural-gamma log shows some variation in lithology with relatively large spikes at 245–250 and 480–482 ft bls. The single-point-resistance log shows changes in slope at 118,

Table 9. Geologist log for borehole BE-1663 (TT27-D2), July 26-31, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–18	**OVERBURDEN,** silt, sand, rock fragments; moist
19–38	**SAPROLITE,** quartz, plagioclase; harder at 20 ft bls, but very weathered; dusty
39–79	**GNEISS**, quartz, plagioclase; harder
	Producing less than 1 gal/min at 40 ft bls
	Fracture, producing 15–20 gal/min at 52–54 ft bls
	Producing about 2 gal/min by 68 ft bls
80–118	**GNEISS**, hornblende
	Producing 5 gal/min by 79 ft bls
	Producing about 10 gal/min by 107 ft bls
	Bottom of casing set at 117 ft bls
119–123	**GNEISS**, quartz, plagioclase, feldspar
	Producing about 2 gal/min by 120 ft bls
124–142	**GNEISS**, hornblende
	Producing 2–3 gal/min by 138 ft bls
143–180	**GNEISS,** quartz, plagioclase, feldspar
	Producing 2 gal/min by 163 ft bls
181–186	**GNEISS**, hornblende
187–190	**GNEISS,** quartz, plagioclase, feldspar
191–202	**GNEISS**, hornblende
	Producing 1–2 gal/min by 192 ft bls
	Producing 2–3 gal/min by 202 ft bls
203–302	**GNEISS,** quartz, plagioclase, feldspar
	Producing 3–5 gal/min by 244 ft bls
	Producing about 3 gal/min by 252 ft bls
303–305	**GNEISS**, hornblende
306–340	**GNEISS,** quartz, plagioclase, feldspar
341–354	**GNEISS**, hornblende
355–426	**GNEISS,** quartz, plagioclase, feldspar
	Producing about 3–5 gal/min by 392 ft bls
427–432	**GNEISS**, hornblende
433–490	**GNEISS,** quartz, plagioclase, feldspar
491–503	**GNEISS**, hornblende

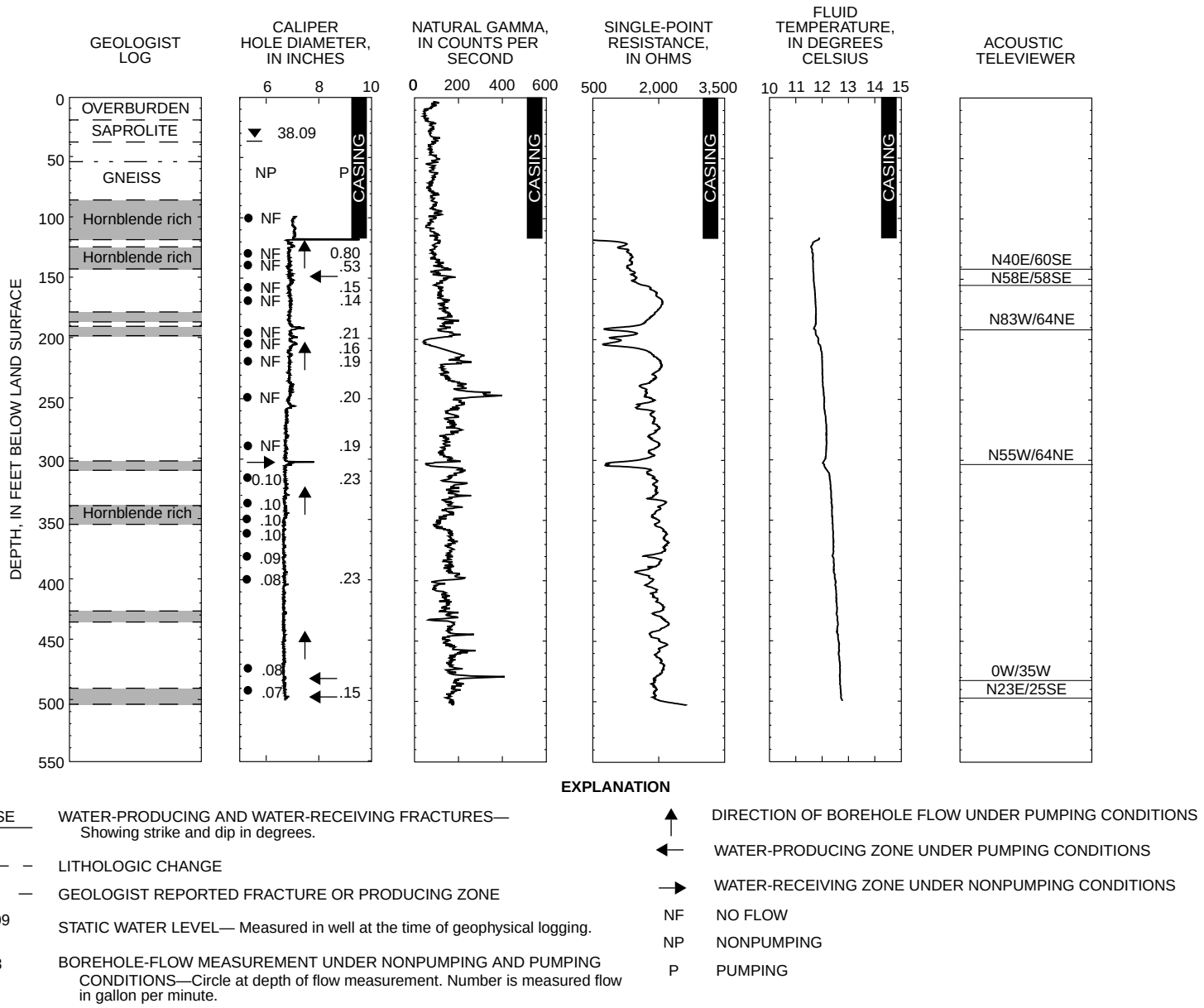


Figure 9. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1663 (TT27-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from July 26 through July 31, 2002. Borehole geophysical logs collected on September 6, 2002.)

191–192, 199, 203–205, and 302 ft bls that correlate closely to fractures shown on the caliper log. The fluid-temperature log shows changes in slope at 118, 191, and 302 ft bls that correlate to fractures shown on the caliper log and changes in slope on the single-point-resistance log. The acoustic-televiewer log shows 36 fractures (table 10). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of all fracture planes and mineral-filled fractures. From that figure, an average strike of N. 1° E. and dip of 81° SE. was computed. The average orientation of all water-producing fractures is a strike of N. 14° E. and a dip of 72° SE. (fig. 10). The borehole deviation log (fig. 11) shows the borehole deviates from vertical approximately 3.5 ft to the northwest, approximately on strike with the fracture planes.

Table 10. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1663 (TT27-D2), Sept. 6, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
124	N76W	71SW	199	N42W	66NE
125	N82W	68SW	230	N84E	64SE
129	N17W	81SW	249	N47E	79NW
140	N60E	68SE	254	N18E	53SE
141	N40E	60SE	257	N87E	79NW
143	N75W	37SW	295	N28E	75NW
144	N90E	29SE	303	N55W	64NE
147	N46E	47SE	304	N78W	57NE
148	N16E	47SE	305	N69W	58NE
150	N41E	38SE	332	N58W	51NE
152	N58E	58SE	339	N21W	27NE
154	N19E	72NW	380	N52E	66NW
154	N32E	68SE	393	N77W	80NE
154	N18E	70NW	404	N48W	39NE
180	N71E	74NW	482	0W	35W
191	N83W	64NE	482	N32E	84NW
193	N76W	70NE	486	N68W	10NE
193	N85E	62SE	497	N23E	25SE

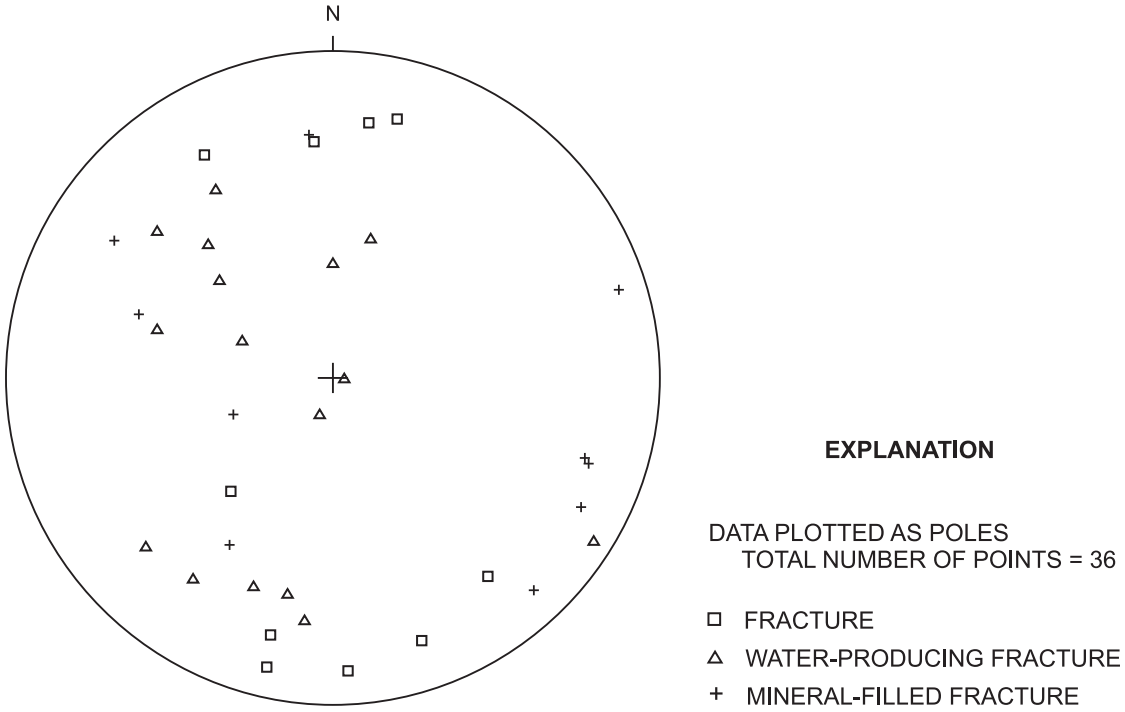


Figure 10. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1663 (TT27-D2), Sept. 6, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

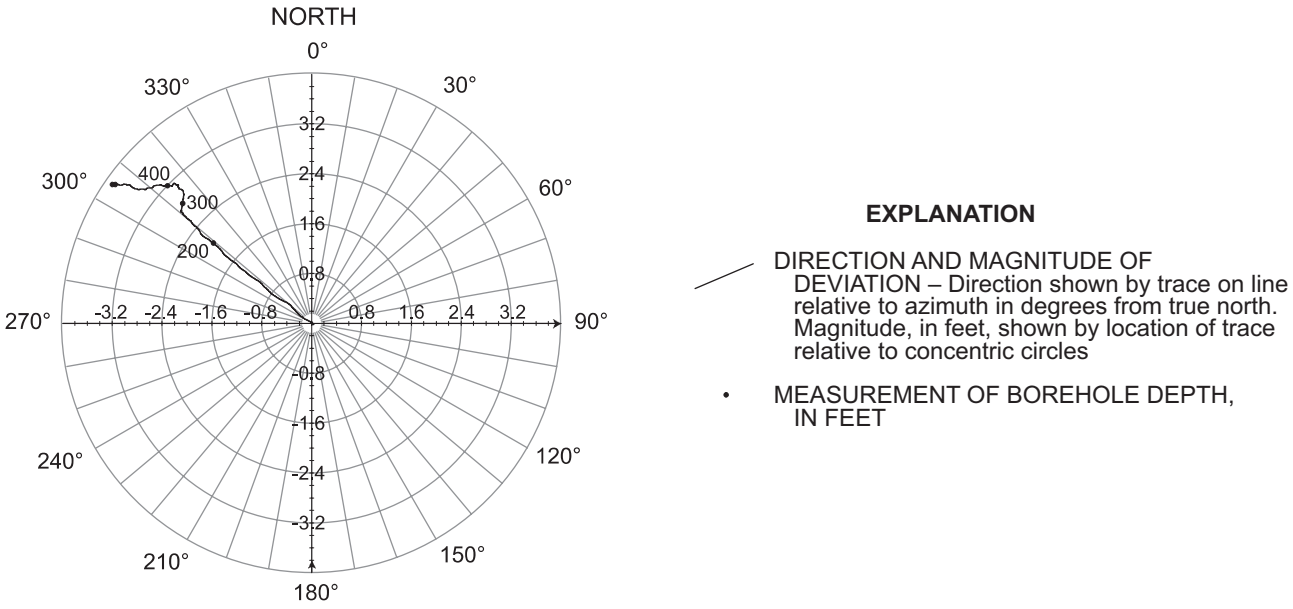


Figure 11. Magnitude and direction of deviation from vertical of borehole BE-1663 (TT27-D2), Sept. 6, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 315, 336, 350, 362, 383, 400, 475, and 493 ft bls and no flow at 100, 130, 140, 158, 170, 196, 201, 220, 250, and 290 ft bls (table 11). The largest producing zone was at depth of approximately 495–497 ft bls (fig. 9). Water exited the borehole through major fractures at 118 and 302 ft bls. The water-producing and water-receiving zones were at or near changes in lithology as described in the geologist log.

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole. The pump was turned on, and the discharge rate varied from 0.8 to 1.2 gal/min; the water level decreased from 38.0 to 42.86 ft bls over 135 minutes of pumping. Under pumping conditions, upward flow was measured throughout the depth of the borehole including areas previously identified as having no vertical flow (table 11). Flow from the fractures at 497–498 ft bls increased from 0.07 to 0.15 gal/min, and there was a minimal increase in flow from minor fractures at 480–482 ft bls. Although the fracture at 302 ft bls was still a receiving zone, the amount of water leaving the borehole through this fracture declined from 0.1 to approximately 0.04 gal/min. The greatest quantity of water entered the borehole through a series of fractures at a depth of 139–152 ft bls (table 11 and fig. 9), a depth that exhibits rapid changes in lithology (table 9). The borehole was completed as a monitor well by placing a pvc plastic screen at 492–502 ft bls, to include the deepest water-producing fractures at 497–498 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 11. Summary of heatpulse-flowmeter measurements for borehole BE-1663 (TT27-D2), Sept. 6, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

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

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
100	no flow	not determined	—	—
130	no flow	not determined	0.80	up
140	no flow	not determined	.53	up
158	no flow	not determined	.15	up
170	no flow	not determined	.14	up
196	no flow	not determined	.21	up
201	no flow	not determined	.16	up
220	no flow	not determined	.19	up
250	no flow	not determined	.20	up
290	no flow	not determined	.19	up
315	0.10	up	.23	up
336	.10	up	—	—
350	.10	up	—	—
362	.10	up	—	—
383	.09	up	—	—
400	.08	up	.23	up
475	.08	up	—	—
493	.07	up	.15	up

BE-1664 (TT26-I)

Borehole BE-1664 was drilled into Precambrian gneiss (table 12). The geologist log noted the regolith was about 67 ft thick, had an estimated yield of 1–5 gal/min, and consisted of clay, silt, sand, and weathered rock fragments of gneiss and some phyllite. The geologist log also noted a possible fracture at 128 to 130 ft bls and estimates of yield as well as the bottom of casing (table 12). The static water level at the time of logging was 24.75 ft bls. The caliper log (fig. 12) shows the total depth of the borehole is 159 ft, and it is cased with 6-in.-diameter casing to 99.5 ft bls. The caliper log shows major fractures at 100, 110, 111.5, 136–138, 140–144, and 151–159 ft bls plus numerous smaller fractures throughout the open-hole interval. The gamma log shows very little change in lithology. The single-point-resistance log shows changes in slope at 111, 122, 138, 140–142, 144–146, and 156–158 ft bls that correlated closely to fractures on the caliper log. The fluid-temperature log shows changes in slope at 100 and 133 ft bls that correlate to fractures on the caliper log. The acoustic-televiewer log shows 11 fractures (table 13). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the orientation of all fracture planes and mineral-filled fractures generally strike N. 16° E. and dip 83° NW. The average orientation of all water-producing fractures is a strike of N. 54° E. and a dip of 74° NW. (fig. 13). The borehole deviation log (fig. 14) shows the borehole deviates from vertical approximately 0.6 ft to the west-southwest.

Table 12. Geologist log for borehole BE-1664 (TT26-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–59	**OVERBURDEN,** sand, silt, clay, some rock fragments; moist
	Producing 1–3 gal/min by 52 ft bls
	Producing 3–5 gal/min by 59 ft bls
60–67	**SAPROLITE**, sand and weathered rock fragments and phyllite
	Producing 1–3 gal/min by 65 ft bls
68–140	**GNEISS**, quartz, plagioclase, and feldspar; harder, but weathered
	Producing 5–10 gal/min by 77 ft bls
	Harder at 90 ft bls
	Bottom of casing set at 99.5 ft bls
	Total yield 1–2 gal/min at 100 ft bls
	Possible fracture at 128–130 ft bls
141–150	**GNEISS and PHYLLITE**, weathered
	Producing 5–7 gal/min by 142 ft bls
151–160	**GNEISS**, weathered
	Total yield 5–10 gal/min at 160 ft bls

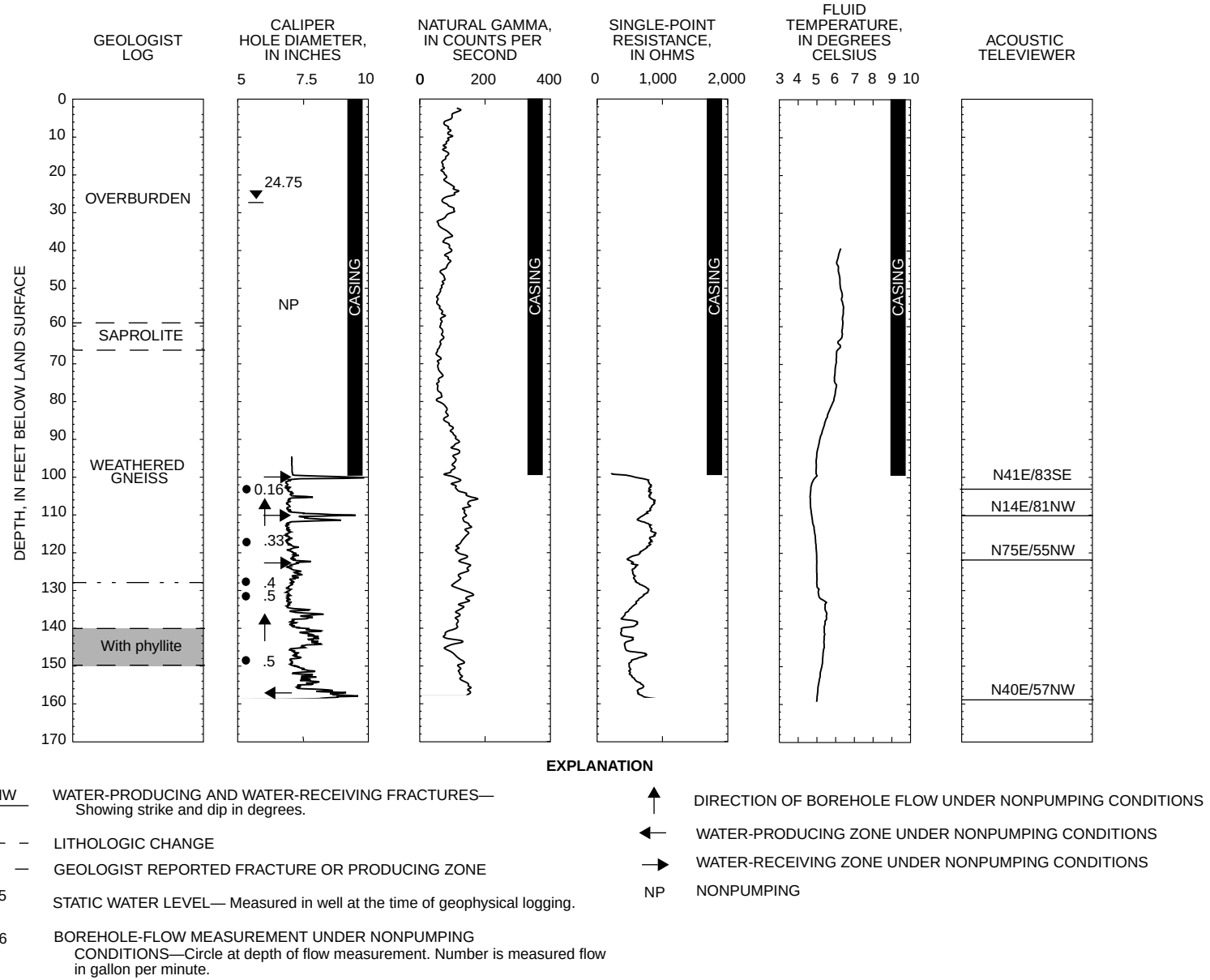


Figure 12. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1664 (TT26-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 26 through August 29, 2002. Borehole geophysical logs collected on September 9, 2002.)

Table 13. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1664 (TT26-I), Aug. 29, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
104	N41E	83SE	137	N72W	73SW
110	N14E	81NW	137	N82W	71SW
114	N89E	76SE	141	N75W	61NE
117	N39W	85NE	154	N8E	67NW
122	N75E	55NW	159	N40E	57NW
136	N37W	66SW			

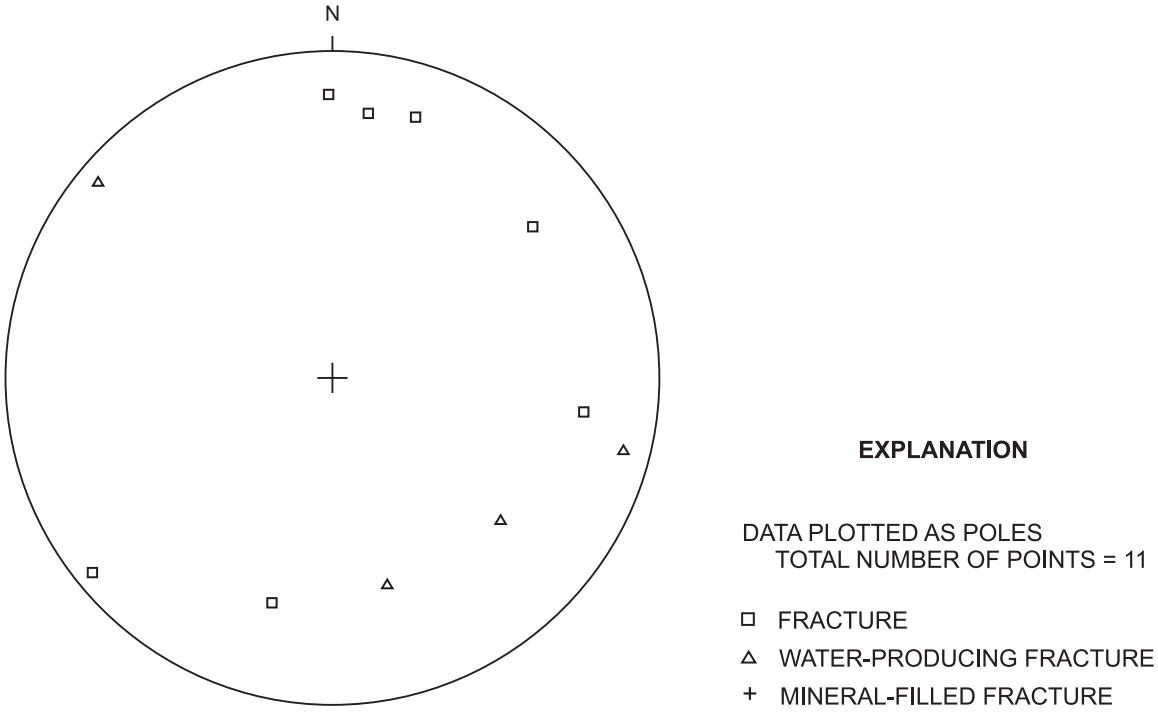


Figure 13. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1664 (TT26-I), Sept. 9, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

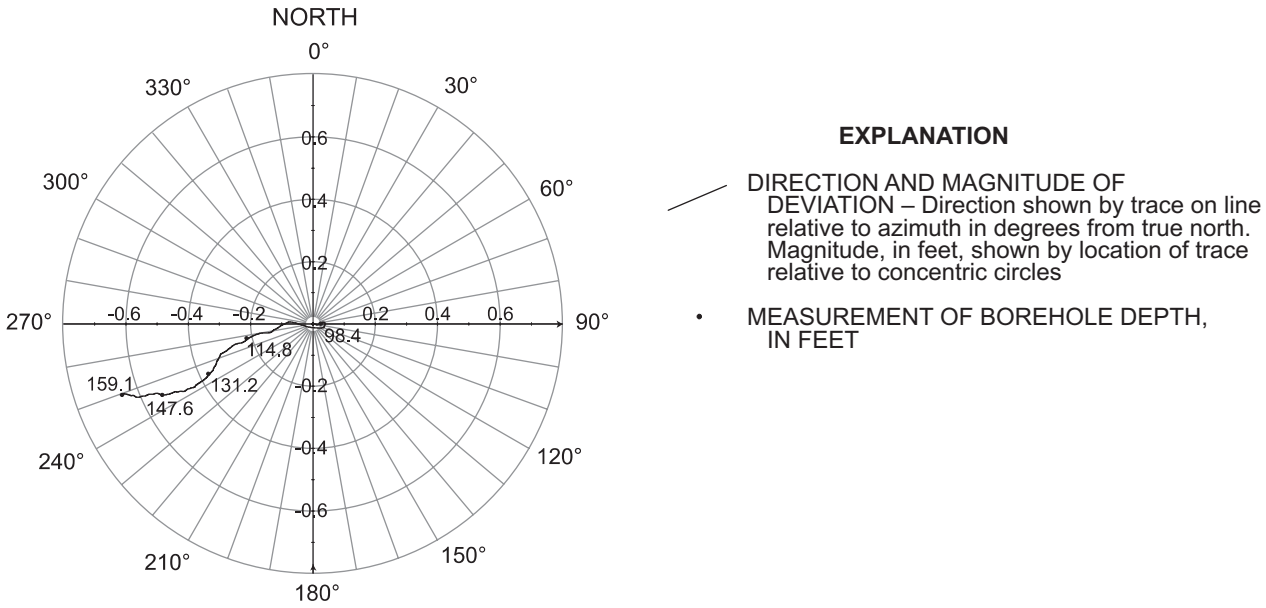


Figure 14. Magnitude and direction of deviation from vertical of borehole BE-1664 (TT26-I), Sept. 9, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 103, 117, 128, 131, and 149 ft bls (table 14). The largest producing zone was at approximately 152–159 ft bls (fig. 12). Water flowed upward and exited the borehole through fractures at 100, 109–112, and 122 ft bls. The borehole was completed as a monitor well by placing a pvc plastic screen at 140–159 ft bls, to include the water-producing fractures at 152–159 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 14. Summary of heatpulse-flowmeter measurements for borehole BE-1664 (TT26-I), Sept. 9, 2002, Crossley Farm Superfund Site, Hereford Township, 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
103	0.16	up
117	.33	up
128	.4	up
131	.5	up
149	.5	up

BE-1665 (TT26-D1)

Borehole BE-1665 was drilled into Precambrian gneiss (table 15). The geologist log notes the regolith is about 82 ft thick, produces 20–30 gal/min, and consists of clay, silt, sand, and weathered rock fragments of gneiss and phyllite. Bedrock is a sequence of hornblende-poor and hornblende-rich gneiss and phyllite. The geologist log also notes a number of fractures especially from about 82 to 177 ft bls, soft zones, and bottom of casing (table 15). The static water level at the time of logging was 22.33 ft bls. The caliper log (fig. 15) shows the total depth of the borehole is 302 ft, and it is cased with 6-in.-diameter casing to 158 ft bls. The caliper log shows major fractures at 158, 166, 228, and 250 ft bls plus numerous smaller fractures throughout the open-hole interval. The large change in borehole diameter at 298–302 ft bls is not a fracture, rather it is a product of developing the well using air pressure. The natural-gamma log reflects changes in lithology with a decrease in counts from 180 to 190 ft bls (quartz rich) and a spike in counts at a depth of 200 ft bls. The changes in natural-gamma counts are probably because of differences in the concentration of potassium feldspar within the gneiss. The single-point-resistance log shows changes in slope at 166, 179, 184–188, 199, 213, 251, and 278 ft bls that correlate closely to fractures shown on the caliper log or are described in the geologist log as fractures, water-producing zones, or changes in lithology. The fluid-temperature log shows sudden changes in temperature at 204–217 and 278 ft bls indicating water-producing zones. The acoustic-televiewer log shows 25 fractures (table 16). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of all fracture planes and mineral-filled fractures strike N. 60° E. and dip 70° NW. The average orientation of all water-producing fractures is a strike of N. 86° E. and a dip of 54° NW. (fig. 16). The borehole deviation log (fig. 17) shows the borehole deviates from vertical approximately 4 ft to the northwest.

Table 15. Geologist log for borehole BE-1665 (TT26-D1), Aug. 20-23, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–60	**OVERBURDEN,** sand, silt, clay, some rock fragments; moist
	Producing about 3 gal/min by 46 ft bls
61–82	**SAPROLITE**, sand, weathered rock fragments, and phyllite
	Harder at 60 ft bls
	Softer at 64 ft bls
	Harder at 66 ft bls
	Producing 20–30 gal/min at 80 ft bls
83–147	**GNEISS**, quartz, plagioclase, feldspar, hornblende; weathered
	Soft 86–90 ft bls, yield disappears
	Mostly mafic at 95 ft bls; hard
	Producing about 3 gal/min by 98 ft bls
	Soft at 99 ft bls; 50/50 hornblende and plagioclase
	Fracture at 101 ft bls, producing 5–7 gal/min
	Fracture at 109 ft bls
	Fracture at 112 ft bls, producing 10–15 gal/min
	Producing about 15 gal/min by 117 ft bls
	Fracture at 120 ft bls; yield fluctuates
	Fracture at 122 ft bls; yield fluctuates
	Fracture at 125 ft bls; yield fluctuates
	Fracture at 127 ft bls; yield fluctuates
	Hard at 133 ft bls
	Fracture at 138 ft bls with some phyllite
	Producing 20–25 gal/min by 142 ft bls
148–178	**GNEISS**, hornblende
	Hard at 156 ft bls
	Bottom of casing at 158 ft bls
	Producing 3–5 gal/min at 165 ft bls
	Producing 5–7 gal/min by 174 ft bls
	Soft at 177 ft bls
179–180	**SHALE/PHYLLITE,** producing 5–7 gal/min
181–190	**QUARTZ**, some phyllite
191–194	**GNEISS**, hornblende
195–205	**GNEISS**, quartz, plagioclase, feldspar, hornblende
206–214	**GNEISS**, hornblende, some phyllite
215–280	**GNEISS**, quartz, plagioclase, feldspar, hornblende
	Possible fracture at 247 ft bls
	Producing 5–7 gal/min
	Possible fracture at 263 ft bls; no cuttings
	Possible fracture at 275 ft bls
281–297	**GNEISS**, hornblende
298–302	**GNEISS,** quartz, plagioclase, feldspar, hornblende
	Producing about 15 gal/min by 302 ft bls

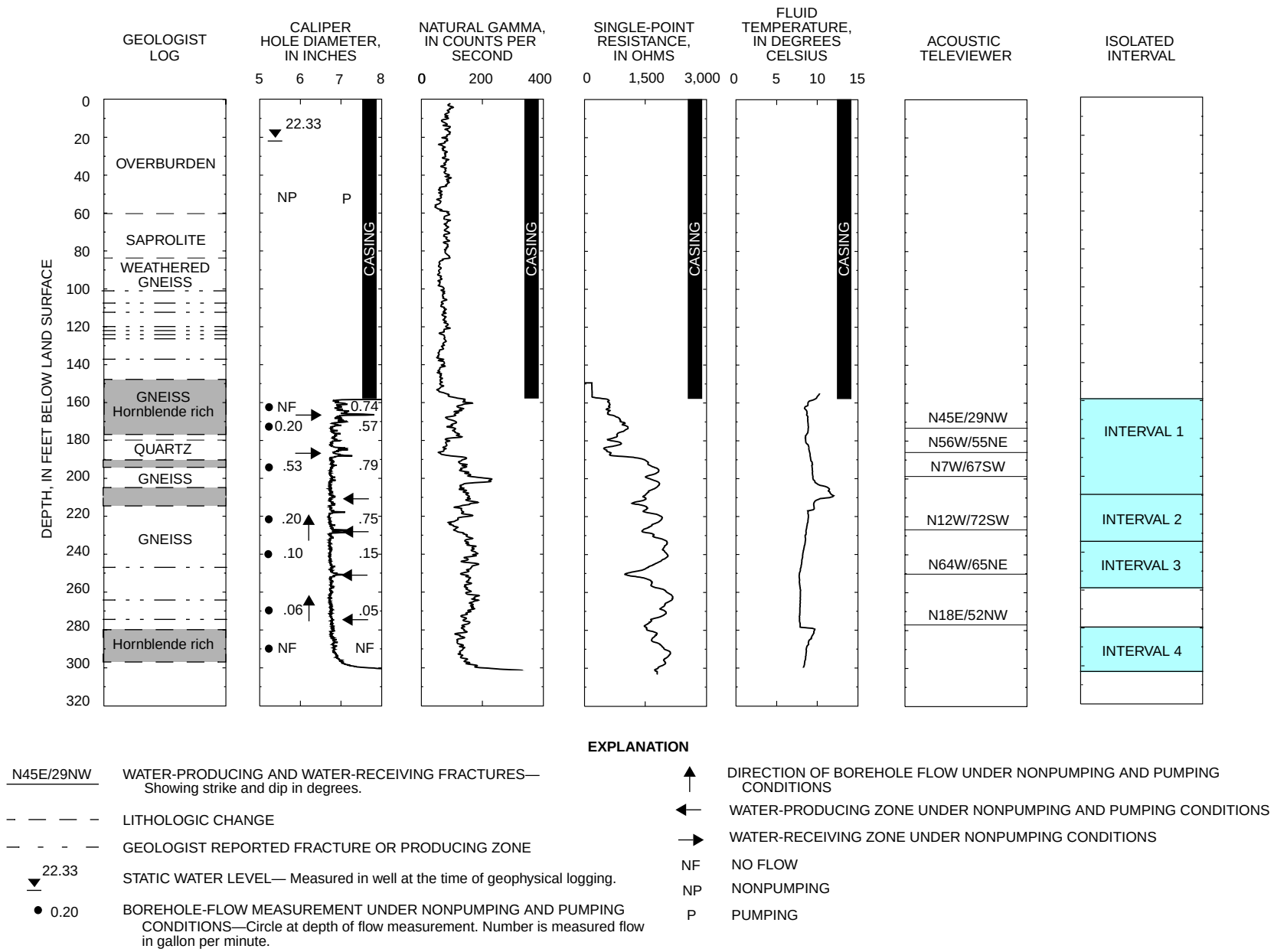


Figure 15. Geologist log, borehole geophysical logs, direction of flow, and isolated intervals within borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 20 through August 23, 2002. Borehole geophysical logs collected on September 10, 2002.)

Table 16. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1665 (TT26-D1), Sept. 10, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
170	N59E	60NW	228	N12W	72SW
172	N45E	29NW	230	N49W	70NE
176	N84E	27NW	243	0W	70SW
180	N65E	64NW	245	N62W	58NE
180	N80E	66NE	247	N69W	54NE
184	N69W	67NE	250	N64W	65NE
188	N56W	55NE	253	N10E	72NW
199	N7W	67SW	256	N33W	64SW
200	N15W	60NW	257	N19W	68SW
209	N11E	N69W	266	N56W	60NE
214	N15E	60NW	278	N18E	52NW
217	N25W	59SW	289	N74E	79NW
225	N70W	7NE			

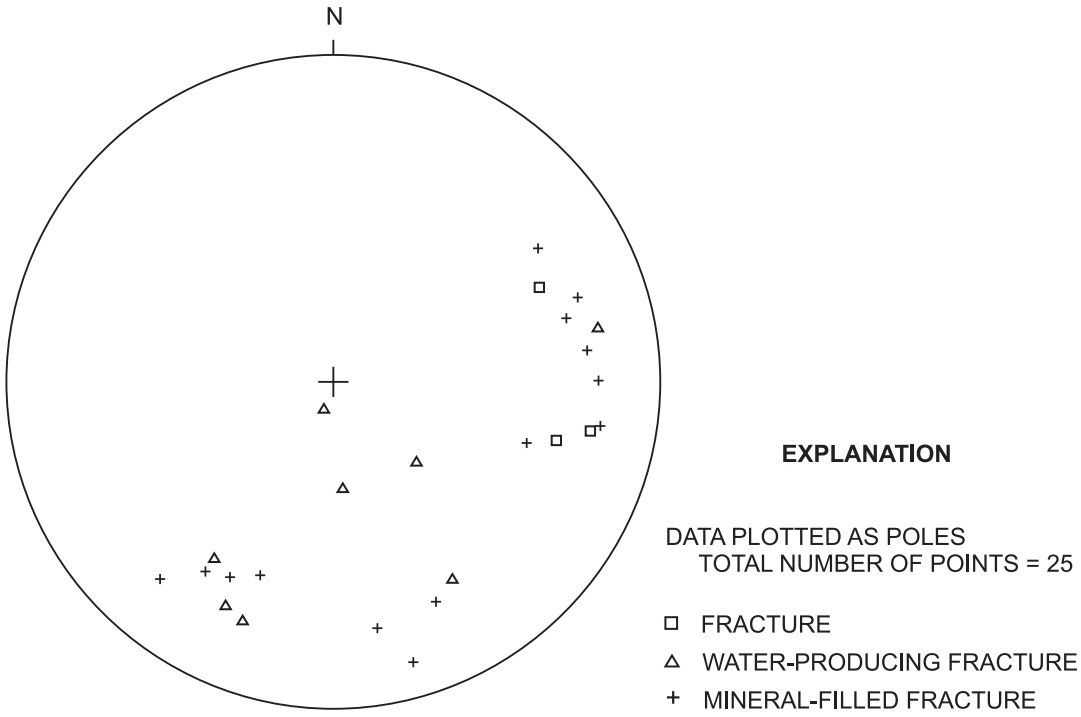


Figure 16. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to water-producing fracture planes in borehole BE-1665 (TT26-D1), Sept. 10, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

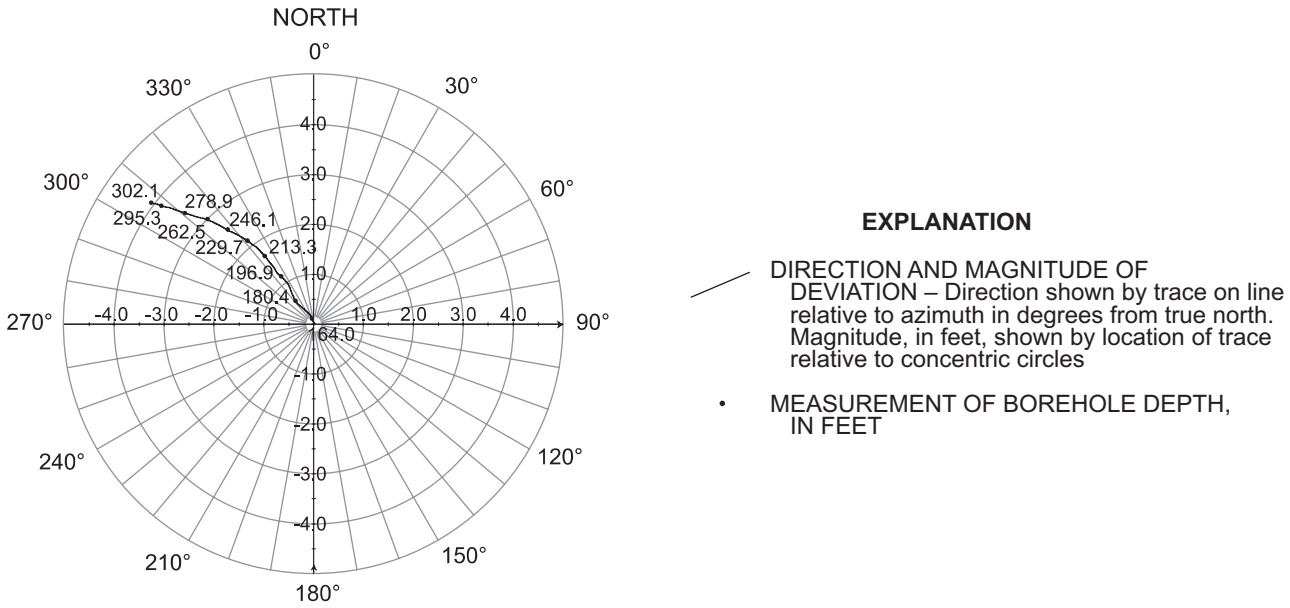


Figure 17. Magnitude and direction of deviation from vertical of borehole BE-1665 (TT26-D1), Sept. 10, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 173, 194, 222, 240, and 270 ft bls and no flow at 162 and 290 ft bls (table 17). Water flowed upward and exited the borehole through fractures at 166 and 184–188 ft bls. Upward borehole flow identifies BE-1665 as being in an area of deep ground-water discharge. The largest producing zone was at depth of approximately 204–217 ft bls (fig. 15). The water-producing and water-receiving zones were at or near changes in lithology as described in the geologist log.

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole. The pump was turned on, and the discharge rate averaged about 0.5 gal/min; the water level decreased from 23.62 to 23.91 ft bls over 55 minutes of pumping. Under pumping conditions, upward flow increased 0.05 gal/min at 240 ft bls, 0.55 gal/min at 222 ft bls, and 0.26 gal/min at 194 ft bls. Water may exit the borehole through the fractures at 182–189 ft bls, but the amount of water exiting or flowing past the fractures was not considered reliable because of a bad seal against the borehole wall. Water not being discharged through the pump exited the borehole through a fracture at the base of the casing. The greatest quantity of water entered the borehole through a fracture at 217–219 ft bls (fig. 15). The borehole was completed as a monitor well by placing a pvc plastic screen at 246–256 ft bls to include a water-producing fracture at 251 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 17. Summary of heatpulse-flowmeter measurements for borehole BE-1665 (TT26-D1), Sept. 10, 2002, Crossley Farm Superfund Site, Hereford Township, 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	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
162	no flow	not determined	0.74	up
173	0.20	up	.57	up
194	.53	up	.79	up
222	.20	up	.75	up
240	.10	up	.15	up
270	.06	up	.05	up
290	no flow	not determined	no flow	not determined

BE-1666 (TT26-D2)

Borehole BE-1666 was drilled into Precambrian gneiss (table 18). The geologist log notes the regolith is about 100 ft thick, produces 20–30 gal/min, and consists of clay, silt, sand, and weathered rock fragments of gneiss and phyllite. The bedrock is a sequence of hornblende-poor and hornblende-rich gneiss with some phyllite and slate. The geologist log also notes two possible fractures at 132 and 456 ft bls, a possible water-bearing zone at 230 ft bls, soft zones, and bottom of casing (table 18). The static water level at the time of logging was 21.08 ft bls. The caliper log shows the total depth of the borehole is 476 ft, and it is cased with 6-in.-diameter casing to 158 ft bls (fig. 18). The caliper log shows a major fracture at 158–159 ft bls and smaller fractures at 162, 170–175, 178, and 183–194 ft bls plus other small fractures throughout the open-hole interval. Some of the fractures at 162, 178, and 185–190 ft bls are at or near changes in lithology. The natural-gamma log exhibits spikes at 162–172 and 230–232 ft bls that may be related to the presence of phyllite or slate. The single-point-resistance log shows abrupt changes in slope that appear to be related to generally small fractures, and some of these fractures may be producing or receiving water (table 18 and fig. 18). The fluid-temperature log shows a sudden change in slope at 158–160 ft bls that correlates to a major fracture and the bottom of the casing. The acoustic-televiewer log shows 64 fractures (table 19). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of fracture planes and mineral-filled fractures strike N. 59° E. and dip 76° NW. The average orientation of water-producing fractures is a strike of N. 86° E. and a dip of 73° NW. (fig. 19). The borehole deviation log (fig. 20) shows the borehole deviates from vertical approximately 8 ft to the north.

Table 18. Geologist log for borehole BE-1666 (TT26-D2), Aug. 12-19, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–77	**OVERBURDEN,** sand, silt, clay; rock fragments beginning at 32 ft bls; moist
	Producing 1–2 gal/min at 38 ft bls
	Producing about 3 gal/min by 45 ft bls
	Producing 1–2 gal/min by 55 ft bls
	Producing 3–5 gal/min by 65 ft bls
78–100	**SAPROLITE**, weathered rock fragments, and phyllite; harder
	Producing water at 80 ft bls
	Producing 20–30 gal/min by 85 ft bls
	Very soft at 100 ft bls
101–147	**GNEISS**, quartz, plagioclase, feldspar; very weathered
	Producing about 30 gal/min by 103 ft bls
	Possible fracture at 132 ft bls
	Soft at 142 ft bls
	Harder at 147 ft bls
148–153	**GNEISS**, quartz, plagioclase, feldspar; fresher rock cuttings
154–161	**PHYLLITE,** soft
	Bottom of casing at 158 ft bls
162–165	**GNEISS**, with phyllite, harder
	Producing 2–3 gal/min
166–180	**GNEISS and PHYLLITE**
181–185	**GNEISS**, quartz, plagioclase, hornblende
186–197	**GNEISS**, hornblende
	Soft at 191 ft bls
	Producing 3–5 gal/min by 193 ft bls
198–202	**GNEISS**, quartz, plagioclase, feldspar, hornblende
203–223	**GNEISS**, hornblende
224–230	**PHYLLITE and SLATE,** soft
	Possible water-bearing zone at 230 ft bls; slight yield increase to 5 gal/min
231–250	**GNEISS**, hornblende
	Producing about 5 gal/min by 233 ft bls
251–290	**GNEISS**, quartz, plagioclase, feldspar, hornblende
291–298	**GNEISS**, hornblende
299–310	**GNEISS**, quartz, plagioclase, feldspar, hornblende
311–320	**GNEISS**, hornblende
321–353	**GNEISS**, quartz, plagioclase, feldspar, hornblende
354–370	**GNEISS**, hornblende
	Harder at 370 ft bls
371–403	**GNEISS**, quartz, plagioclase, feldspar, hornblende
404–443	**GNEISS**, hornblende
	Producing 5–7 gal/min by 435 ft bls
444–465	**GNEISS**, quartz, plagioclase, feldspar, hornblende
	Possible fracture at 456 ft bls
	Producing about 10 gal/min by 462 ft bls
466–476	**GNEISS**, hornblende

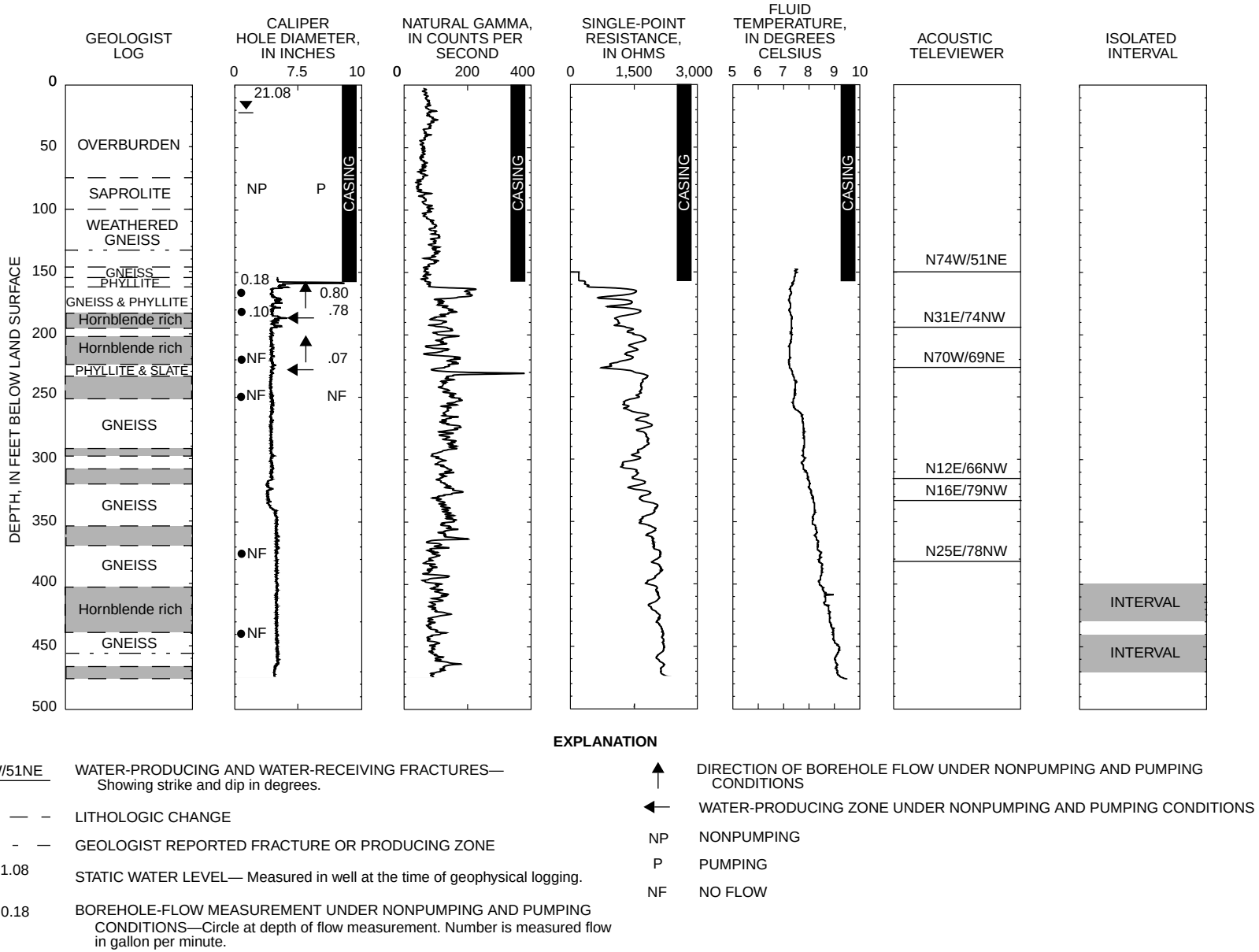


Figure 18. Geologist log, borehole geophysical logs, direction of borehole flow, and location of isolated intervals within borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 12 through August 19, 2002. Borehole geophysical logs collected on September 11, 2002.)

Table 19. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1666 (TT26-D2), Sept. 11, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
160	N74W	51NE	262	N24E	79NW
162	N75W	67NE	262	N76W	70NE
163	N83W	67NE	263	N60W	73NE
171	N52E	75NW	263	N9E	66NW
171	N74E	58NW	266	N7E	76NW
172	N73W	65NE	269	N10W	75SW
172	N84W	72NE	279	N3E	77NW
175	N49W	74NE	286	N23E	77NW
178	N57W	72NE	289	N14E	78NW
192	N72E	71NW	290	N20W	78SW
194	N31E	74NW	296	N24E	73NW
198	N12W	64SW	298	N56W	66NE
199	N60E	65NW	305	N26E	82NW
201	N26E	69NW	305	N85E	31SE
201	N26W	66SW	307	N37W	66NE
202	N21E	75NW	308	N77W	61NE
213	N32W	84NE	310	N27E	70NW
215	N45E	63NW	312	N14E	75NW
216	N83E	73NW	316	N58W	70NE
217	N7W	70SW	316	N12E	66NW
223	N85W	33NE	323	N16E	79NW
224	N70E	38NW	324	N19E	75NW
225	N57W	72NE	325	N24E	76NW
227	N73W	63NE	332	N49E	77NW
228	N70W	69NE	346	N47E	66NW
253	N45E	70NW	352	N53E	67NW
253	N74E	63NW	361	N66E	75NW
254	N4W	70SW	364	N20E	83NW
255	N16W	79SW	375	N28E	80NW
255	N44E	68NW	382	N20E	77NW
257	N65E	58NW	383	N25E	78NW
259	N64W	66NE	391	N36E	78NW

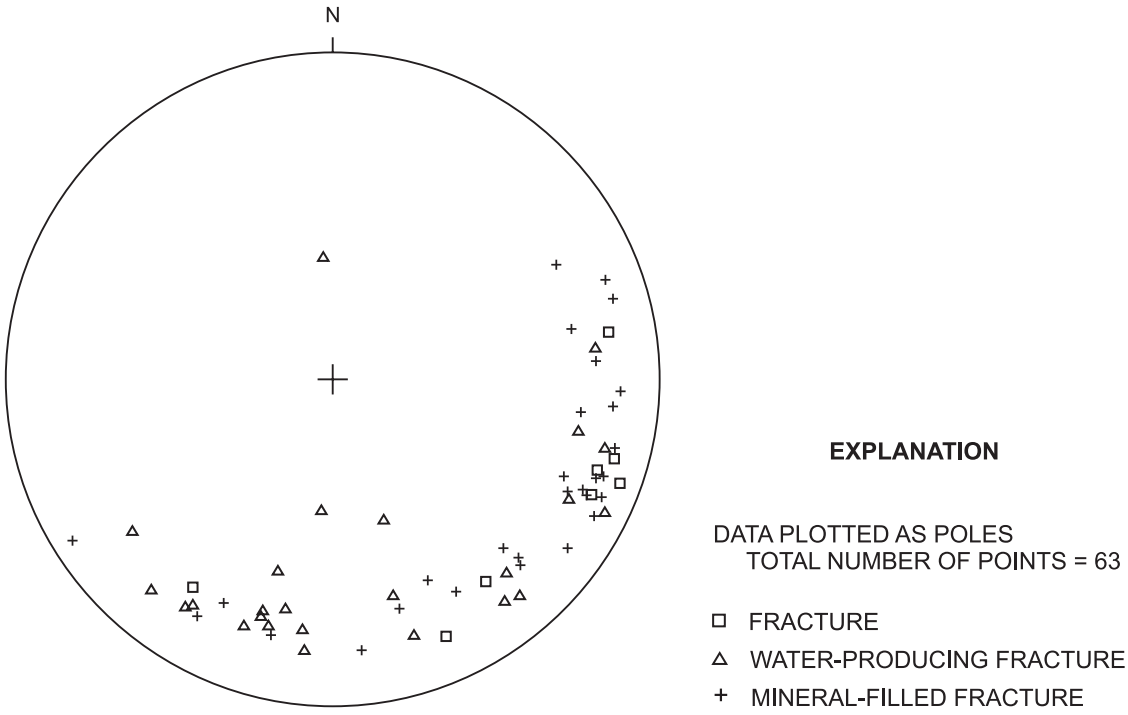


Figure 19. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1666 (TT26-D2), Sept. 11, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

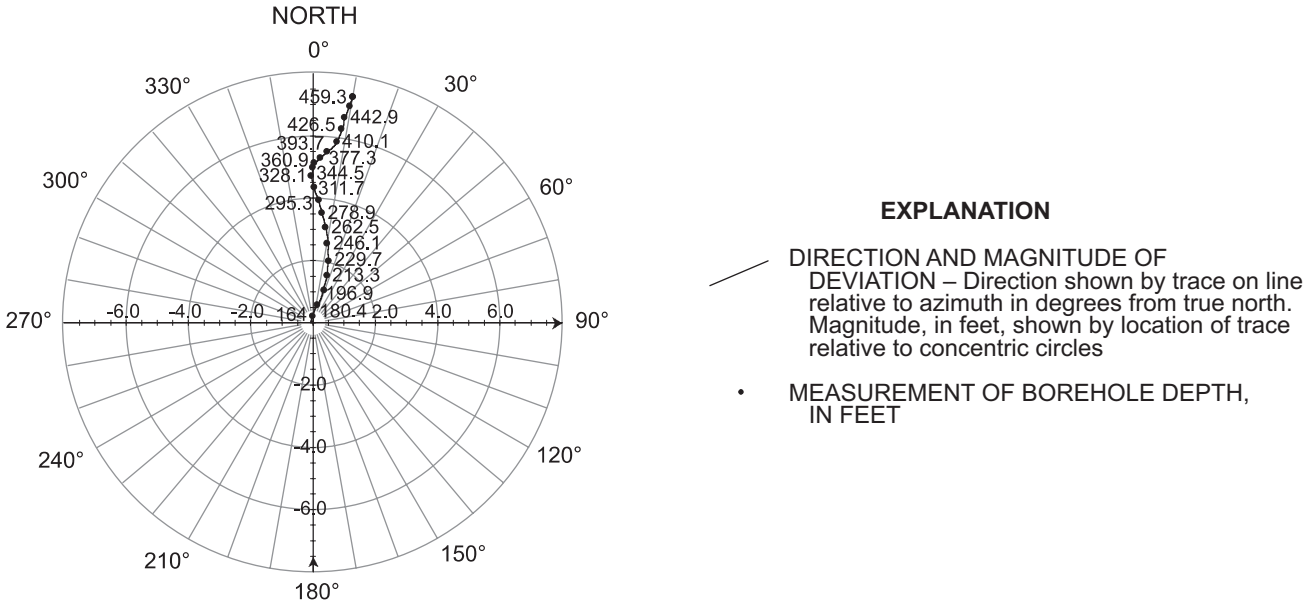


Figure 20. Magnitude and direction of deviation from vertical of borehole BE-1666 (TT26-D2), Sept. 11, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 166 and 182 ft bls and no flow at 220, 250, 385, and 440 ft bls (table 20; fig. 18). The largest water-producing zone was at 185–194 ft bls (fig. 18). The water-receiving zone at 158–159 ft bls was associated with a phyllite.

Upon completion of logging under ambient conditions, a submersible pump was placed in the borehole. The pump was turned on; the discharge rate averaged about 0.6 gal/min, and the water level decreased from 22.16 to 25.02 ft bls over 69 minutes of pumping. Under pumping conditions, upward flow increased 0.68 gal/min at 182 ft bls and 0.62 gal/min at 166 ft bls. Upward flow of 0.07 gal/min was measured at 220 ft bls. The greatest quantity of water entered the borehole through the fractures at 185–194 ft bls (table 20 and fig. 18). The borehole was completed as a monitor well by placing a pvc plastic screen at 185 to 205 ft bls to include the water-producing fractures at 185–194 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 20. Summary of heatpulse-flowmeter measurements for borehole BE-1666 (TT26-D2), Sept. 11, 2002, Crossley Farm Superfund Site, Hereford Township, 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	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
166	0.18	up	0.80	up
182	.10	up	.78	up
220	no flow	not determined	.07	up
250	no flow	not determined	no flow	not determined
385	no flow	not determined	no flow	not determined
440	no flow	not determined	no flow	not determined

BE-1667 (TT25-I)

Borehole BE-1667 was drilled into Precambrian gneiss (table 21). The geologist log notes the regolith is about 41 ft thick, produces less than 1 gal/min, and consists of clay, silt, sand, and weathered rock fragments of gneiss. The bedrock is a hornblende-poor gneiss. The geologist log notes a soft seam with a trace of phyllite at 52 ft bls and producing zones around 30 ft bls and 54 ft bls as well as the bottom of casing (table 21). The static water level at the time of logging was 29.59 ft bls. The caliper log shows the total depth of the borehole is 71 ft, and it is cased with 6-in.-diameter casing to 41 ft bls (fig. 21). The caliper log shows major fractures at 41, 42.5, and 54 ft bls plus numerous smaller fractures throughout the open-hole interval. The gamma log shows little if any change in lithology. The single-point resistance log shows abrupt changes in slope at 54 and 69 ft bls, only the former corresponds to a water-producing zone reported by the geologist. The fluid-temperature log shows sudden changes in temperature at the major fracture just below casing, indicating a possible water-producing zone. The acoustic-televiewer log shows 10 fractures (table 22). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of all fracture planes strike N. 14° E. and dip 70° SE. The average orientation of all water-producing fractures is a strike of N. 17° E. and a dip of 66° SE. (fig. 22). The borehole deviation log (fig. 23) shows the borehole deviates from vertical approximately 0.4 ft to the west-southwest.

Table 21. Geologist log for borehole BE-1667 (TT25-I), Sept. 16-17, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–27	**OVERBURDEN,** sand, silt, clay; moist
28–41	**SAPROLITE**, weathered gneiss
	Dusty at 27 ft bls
	Producing less than 1 gal/min at 30 ft bls
	Bottom of casing set at 41 ft bls
42–72	**GNEISS**
	Producing about 3 gal/min at 46 ft bls
	Soft seam, trace phyllite at 52 ft bls
	Producing zone at 54 ft bls
	Producing about 20 gal/min by 58 ft bls
	Producing 20–25 gal/min by 72 ft bls

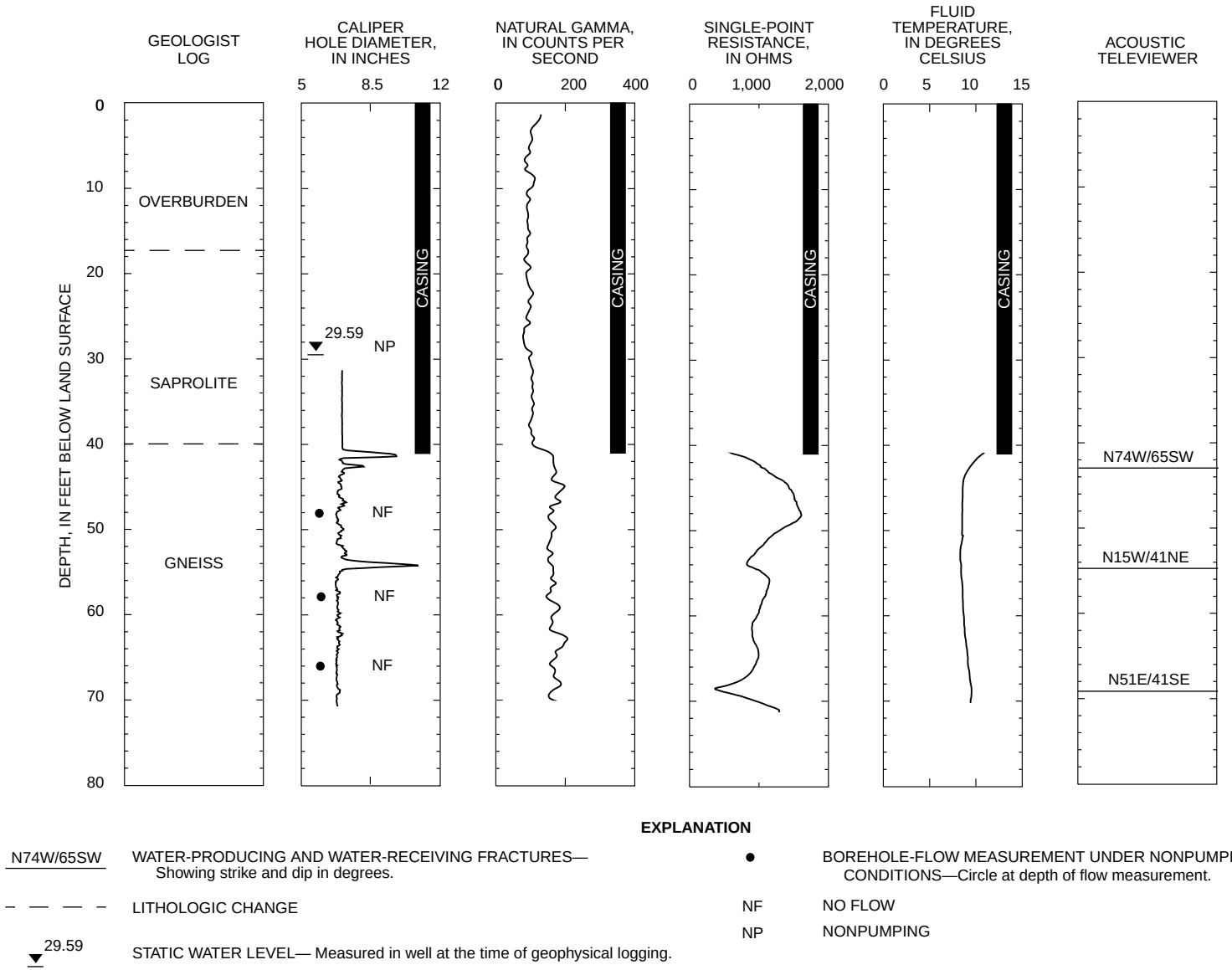


Figure 21. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1667 (TT25-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from September 16 through September 17, 2002. Borehole geophysical logs collected on September 20, 2002.)

Table 22. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1667 (TT25-I), Sept. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
42	N30W	10NE	57	N6E	73SE
44	N74W	65SW	59	N19W	71SW
52	N20W	82NE	63	N23E	70SE
52	N9W	78NE	67	N44E	68SE
55	N15W	41NE	69	N51E	41SE

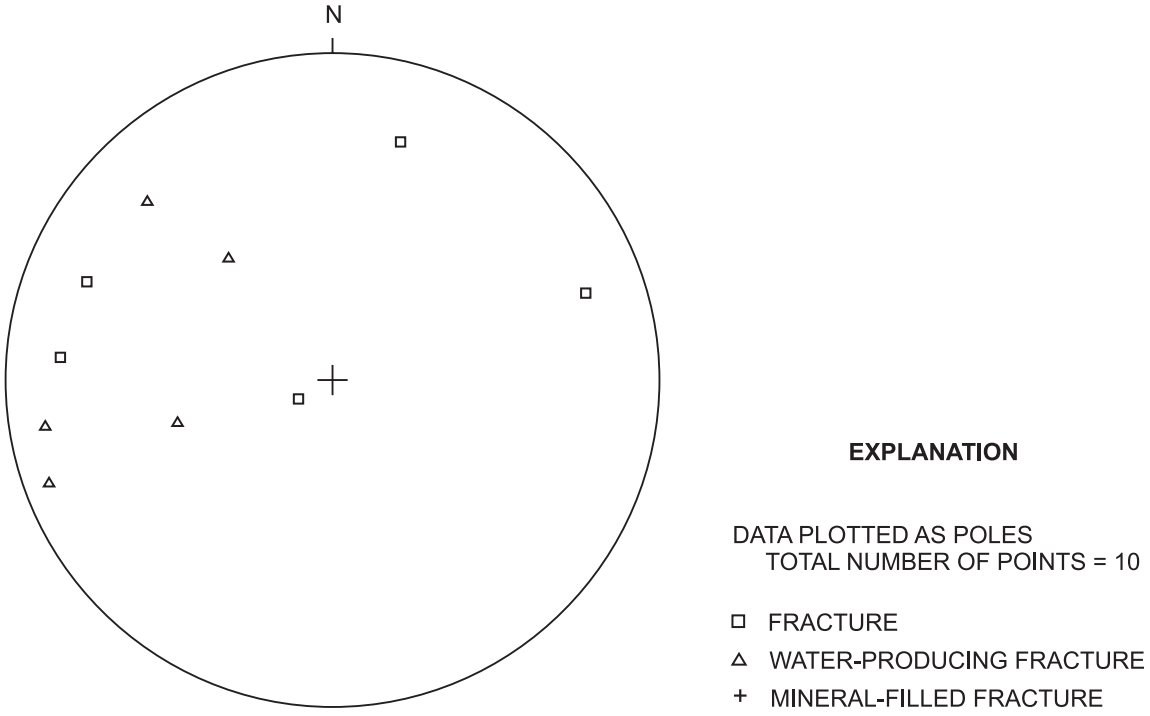


Figure 22. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1667 (TT25-I), Sept. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

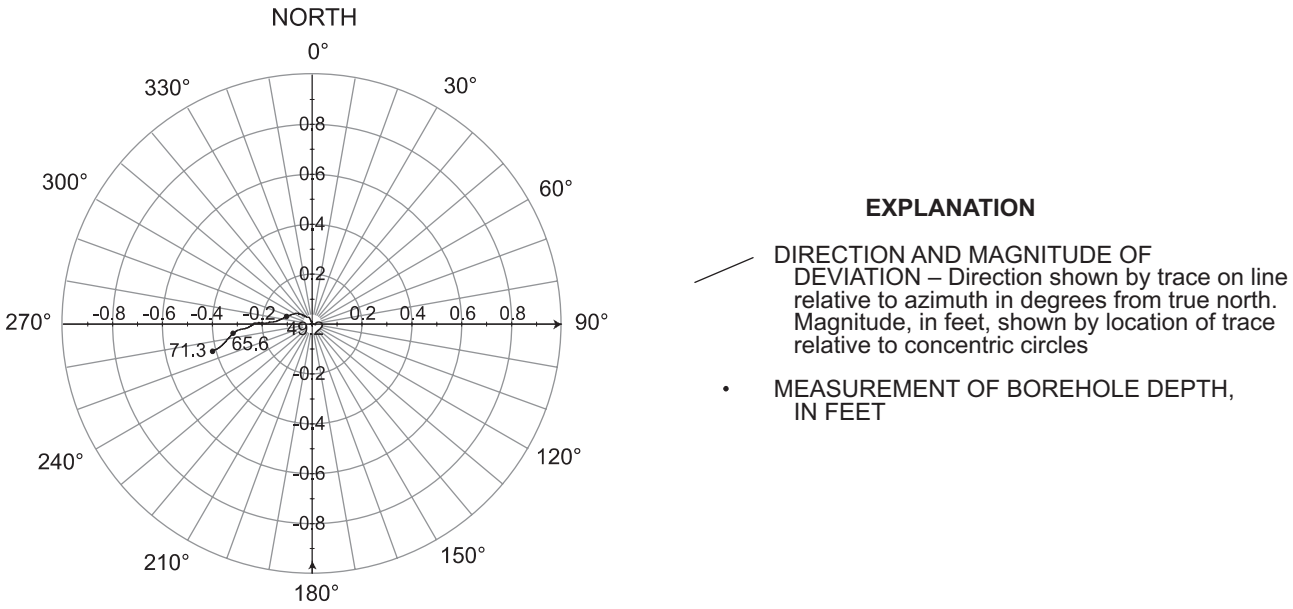


Figure 23. Magnitude and direction of deviation from vertical of borehole BE-1667 (TT25-I), Sept. 20, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 48, 58, and 66 ft bls (table 23 and fig. 21). The borehole was completed as a monitor well by placing a pvc plastic screen at 52 to 57 ft bls to include the water-producing zone identified by the geologist log at 54 ft bls. A second screen was placed at 67–72 ft bls to include a possible water-producing zone at 69 ft bls that was identified on the single-point-resistance log (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 23. Summary of heatpulse-flowmeter measurements for borehole BE-1667 (TT25-I), Sept. 20, 2002, Crossley Farm Superfund Site, Hereford Township, 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
48	no flow	not determined
58	no flow	not determined
66	no flow	not determined

BE-1668 (TT25-D1)

Borehole BE-1668 was drilled into Precambrian gneiss (table 24). The geologist log notes the regolith is about 44 ft thick, produces water, and consists of clay, silt, sand, and weathered rock fragments of gneiss. The bedrock is a gneiss with varying amounts of hornblende. The geologist log notes possible fractures at 67, 150, 267, and 285 ft bls with a soft zone at 183 ft bls. The bottom of casing is at a depth of 92 ft, which sealed off the shallow and more productive water-bearing zones (table 24). The static water level at the time of logging was 28.14 ft bls. The caliper log shows the total depth of the borehole is 303 ft, and it is cased with 6-in.-diameter casing to 92 ft bls (fig. 24). The caliper log shows a major fracture at 92–93 ft bls. Smaller fractures at 102–104, 153, and 269 ft bls may be the result of lithologic changes described in the geologist log. These lithologic changes are reflected by an increase (92–152, 182–191, 280–300 ft bls) or a decrease (152–154, 158, 165–182, 255–265 ft bls) in the counts per second of the gamma log. The single-point-resistance log shows changes in slope at 103, 153, and 269 ft bls that correspond to fractures on the caliper log. The fluid-temperature log shows a sudden change in temperature at the bottom of casing and slight changes at 107 and 269 ft bls that correlate to fractures on the caliper log. The acoustic-televiewer log shows 23 fractures (table 25). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of all fracture planes and mineral-filled fractures strike N. 18° W. and dip 76° SW. The average orientation of water-producing fractures is a strike of N. 72° E. and a dip of 67° SE. (fig. 25). The borehole deviation log (fig. 26) shows the borehole deviates less than 0.5 ft to the south from 98 to 131 ft bls, then turns 90 degrees toward the north, deviating about 1 ft to the northwest from 131 to 197 ft bls. From 197 to 230 ft bls, the borehole deviates about 2.2 ft to the west. The borehole then makes another 90 degree turn to the north, where it deviates over 2.5 ft to the north from 230 to 303 ft bls (fig. 26). The deviations in the borehole suggest changes in the orientation of the underlying rock, most likely as a result of a fault or series of faults.

Table 24. Geologist log for borehole BE-1668 (TT25-D1), Sept. 11-13, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–20	**OVERBURDEN,** sand, silt, clay; rock fragments beginning at 12 ft bls; damp to moist
21–44	**SAPROLITE**, silty sand and very weathered gneiss fragments
	Producing water at 40 ft bls
	Producing water at 43 ft bls; harder
45–57	**GNEISS**, weathered; some phyllite
	Wet at 47 ft bls
58–102	**GNEISS**, quartz, plagioclase, feldspar, hornblende; fresher rock cuttings
	Possible fracture at 67 ft bls
	Producing about 3 gal/min at 79 ft bls
	Producing about 25 gal/min at 85 ft bls
	Bottom of casing set at 92 ft bls
103–112	**GNEISS,** richer in hornblende
	Producing 7–10 gal/min at 104 ft bls
113–155	**GNEISS**, less hornblende, more feldspar
	Fracture at 150 ft bls
156–183	**GNEISS**, hornblende
	Producing 10–12 gal/min at 155 ft bls
184–192	**GNEISS**, less hornblende
	Softer at 183 ft bls
193–215	**GNEISS**, hornblende
216–252	**GNEISS**, little hornblende
253–260	**GNEISS**, hornblende
261–273	**GNEISS**, little hornblende
	Fractured at 267 ft bls; producing 12 to 15 gal/min
274–282	**GNEISS**, hornblende
283–302	**GNEISS**, varying amounts hornblende
	Possible fracture at 285 ft bls
	Producing about 15 gal/min by 297 ft bls

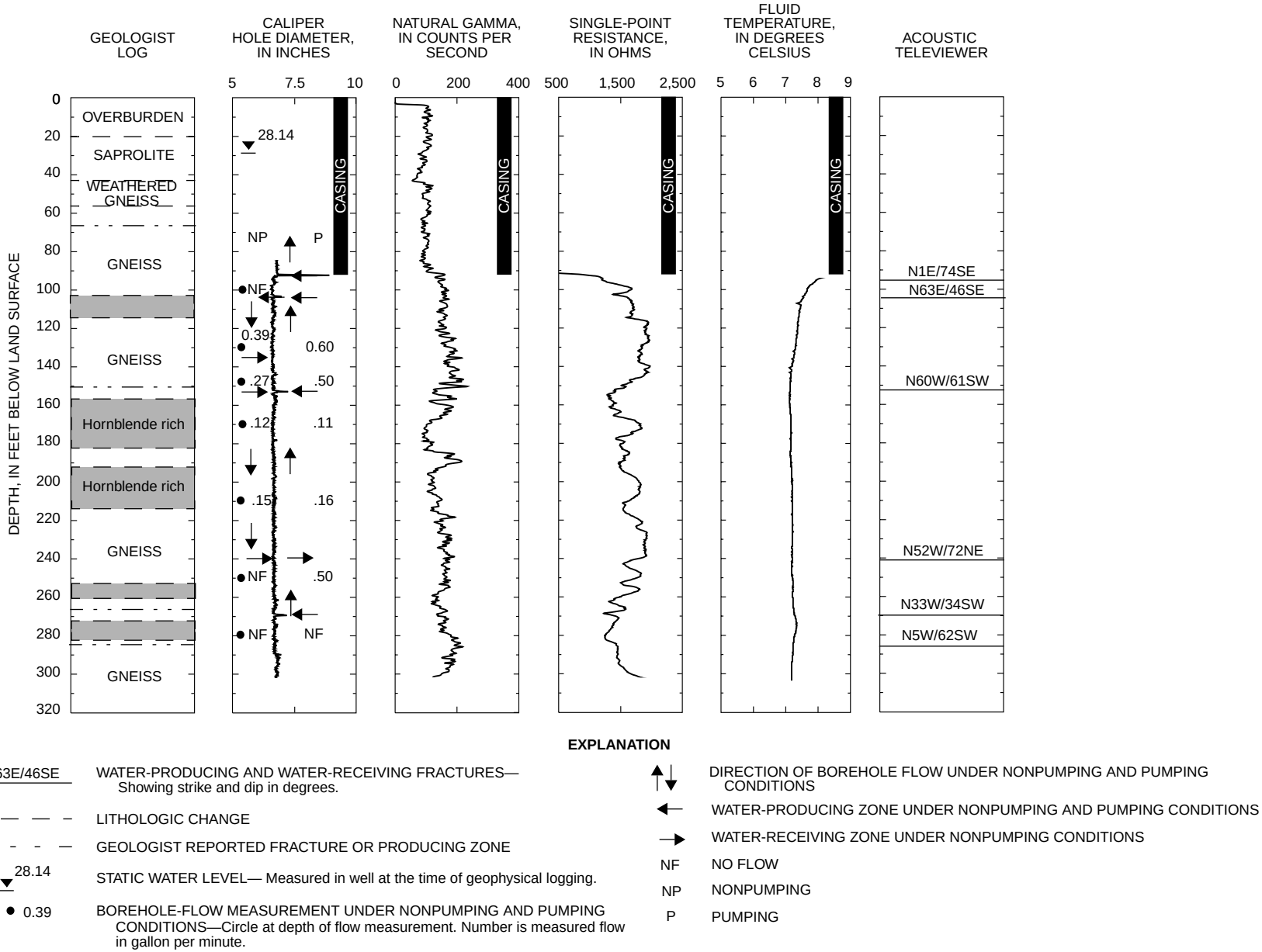


Figure 24. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1668 (TT25-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from September 11 through September 13, 2002. Borehole geophysical logs collected on September 23, 2002.)

Table 25. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1668 (TT25-D1), Sept. 23, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
94	N1E	74SE	178	N86E	46SE
94	N8W	64SW	181	N37E	53NW
103	N63E	46SE	184	N70W	72SW
123	N6W	67SW	241	N52W	72NE
123	N11W	68SW	253	N47W	77SW
153	N60W	61SW	262	N6W	77SW
157	N40E	82NW	263	N32W	70SW
161	N36E	70NW	265	N6W	54SW
166	N18E	46SE	269	N33W	34SW
171	N29E	62NW	286	N7W	61SW
174	N57E	66NW	286	N5W	62SW
178	N48E	61NW			

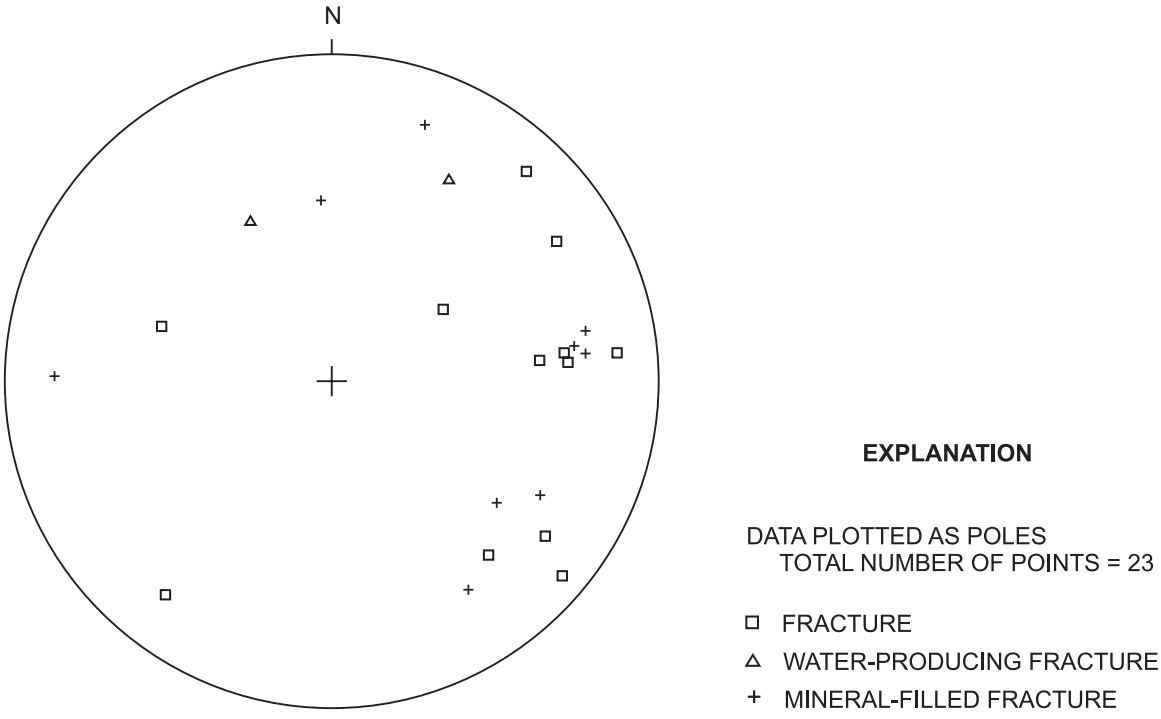


Figure 25. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1668 (TT25-D1), Sept. 23, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania

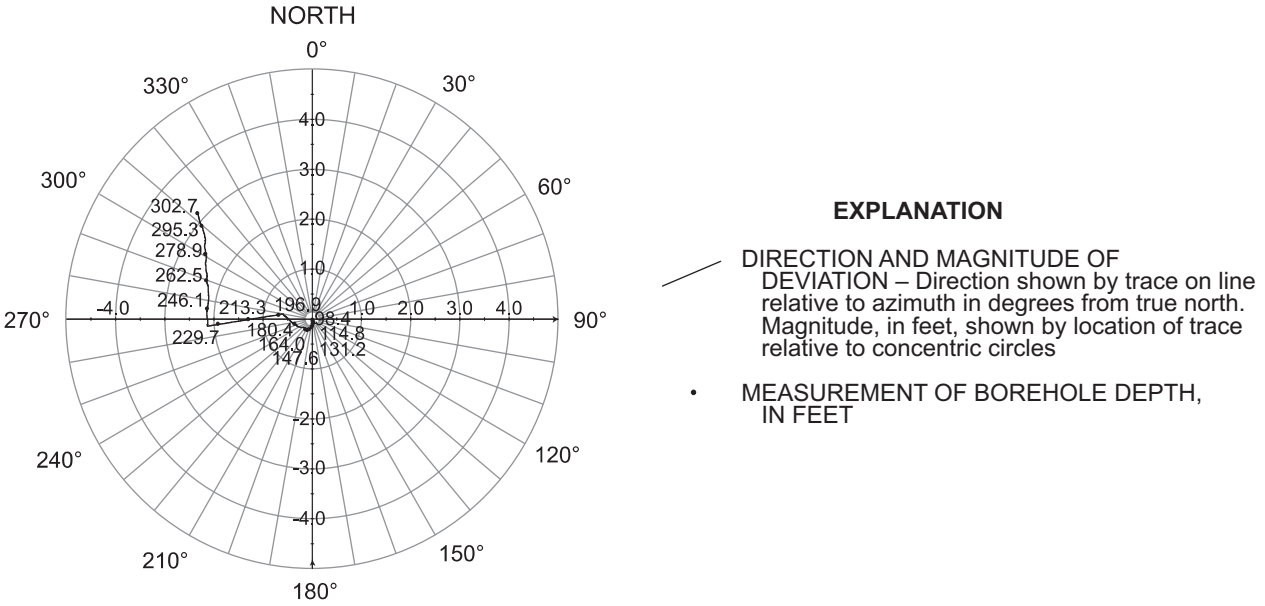


Figure 26. Magnitude and direction of deviation from vertical of borehole BE-1668 (TT25-DI), Sept. 23, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 130, 148, 170, and 210 ft bls and no flow at 100, 250, and 280 ft bls (table 26). The largest water-producing zone was at 103–104 ft bls, which is near a lithologic contact. The largest water-receiving zones were through a series of small fractures from 138 to168 ft bls (probably the small fractures at 143–144 and 153 ft bls) (fig. 24).

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole at a depth of 80 ft bls. The pump was turned on, and the discharge rate averaged about 1.5 gal/min. For the first 60 minutes, the water level decreased from 28.12 to 32.02 ft bls. To obtain flow from 250 to 280 ft bls, the pumping rate was increased to about 2.1 gal/min. Over the next 11 minutes, the water level decreased an additional 0.56 ft. Under pumping conditions, all downward flow at 130, 148, 170, and 210 ft bls became upward flow that varied from 0.11 to 0.60 gal/min. The water-receiving zones at 143–144 and 153 ft bls became water-producing zones. No flow at 250 ft bls became upward flow at 0.50 gal/min. The greatest quantity of water entered the borehole through the fractures at 92, 153, and 269 ft bls. The borehole was completed as a monitor well by placing a pvc plastic screen at 264–274 ft bls to include the deepest water-producing zone at 269 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 26. Summary of heatpulse-flowmeter measurements for borehole BE-1668 (TT25-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

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

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Pumping rate (gal/min)	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
100	no flow	not determined	—	—	—
130	0.39	down	1.5	0.60	up
148	.27	down	1.5	.50	up
170	.12	down	1.5	.11	up
210	.15	down	1.5	.16	up
250	no flow	not determined	2.1	.50	up
280	no flow	not determined	2.1	no flow	not determined

BE-1669 (TT25-D2)

Borehole BE-1669 was drilled into Precambrian gneiss (table 27). The geologist log notes the regolith is about 27 ft thick, consisting of clay, silt, sand, and weathered gneiss fragments. The gneiss exhibits variation in the amount of hornblende and feldspar, with some phyllite at 262–272 and 278–304 ft bls. The geologist log notes possible fractures at 65 and 102 ft bls with a soft zone at 290 ft bls and the bottom of casing. The static water level at the time of logging was 28.88 ft bls. The caliper log shows the total depth of the borehole is 502 ft, and it is cased with 6-in.-diameter casing to 77.5 ft bls (fig. 27). The caliper log shows major fractures at 78 and 101 ft bls plus small fractures throughout the open-hole interval. The natural-gamma log (fig. 27) shows zones of higher counts at depths of 77–130, 177–262, 304–320, and 497–502 ft bls that correlate well with differences in lithology described in the geologist log. The increase in natural-gamma counts at these depths and the spikes at 268–278 and 420–430 ft bls are probably because of higher concentrations of potassium feldspar within the gneiss. The single-point-resistance log shows changes in slope at 100 and 144 ft bls that correspond to small fractures on the caliper log and represent water-producing zones. Changes in slope at 159, 172, 260, 270, 320, 360, 380, 435, and 492 ft bls are related to differences in lithology described in the geologist log and shown on the natural-gamma log. The fluid-temperature log shows a sudden change in temperature near the bottom of casing at the major fracture at 78 ft bls indicating a possible water-producing zone. The fluid-temperature log also exhibits an increase in temperature beginning at a depth of about 200 ft bls and continuing to the bottom of the borehole. This increase is approximately equal to the geothermal gradient of 1.0^{o} F per 100 ft of well depth, which indicates no borehole flow. The acoustic-televiewer log shows 31 fractures (table 28). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the general orientation of all fracture planes and mineral-filled fractures strike N. 88° E. and dip 79° E. The average orientation of water-producing fractures is a strike of N. 72° W. and a dip of 55° SW. (fig. 28). The borehole deviation log (fig. 29) shows the borehole deviates over a depth of 280 ft approximately 8 ft to the west. From 280–503 ft bls, the borehole deviates 25 ft to the north (fig. 29). This indicates a change in the orientation of the gneiss beginning at 280 ft bls, possibly as a result of a fault, and is in agreement with acoustic data from adjacent well BE-1668.

Table 27. Geologist log for borehole BE-1669 (TT25-D2), Aug. 3-Sept. 11, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–19	**OVERBURDEN,** sand, silt, clay; damp
20–27	**SAPROLITE**, silty sand and very weathered gneiss fragments
28–70	**GNEISS**, very weathered
	Producing less than 1 gal/min at 33 ft bls
	Producing about 5 gal/min by 62 ft bls
	Fracture at 65 ft bls; producing about 20 gal/min
	Hard at 70 ft bls
71–130	**GNEISS**, quartz, plagioclase, feldspar, some hornblende; fresher cuttings
	Bottom of casing set at 77.5 ft bls
	Fracture at 102 ft bls; producing 3–5 gal/min
131–175	**GNEISS,** hornblende, very little feldspar
176–262	**GNEISS**, abundant feldspar
	Producing 5 gal/min by 207 ft bls
	Producing 6–7 gal/min by 222 ft bls
	Producing about 5 gal/min by 242 ft bls
263–272	**GNEISS**, hornblende and phyllite
273–278	**GNEISS,** less hornblende
279–304	**GNEISS**, hornblende, some phyllite
	Soft at 290 ft bls
305–320	**GNEISS,** more feldspar
321–365	**GNEISS**, hornblende
366–442	**GNEISS**, less hornblende
443–497	**GNEISS**, hornblende
	Producing 7–10 gal/min by 444 ft bls
	Producing 5–7 gal/min by 468 ft bls
498–502	**GNEISS**, more feldspar
	Producing 5–10 gal/min at 502 ft bls

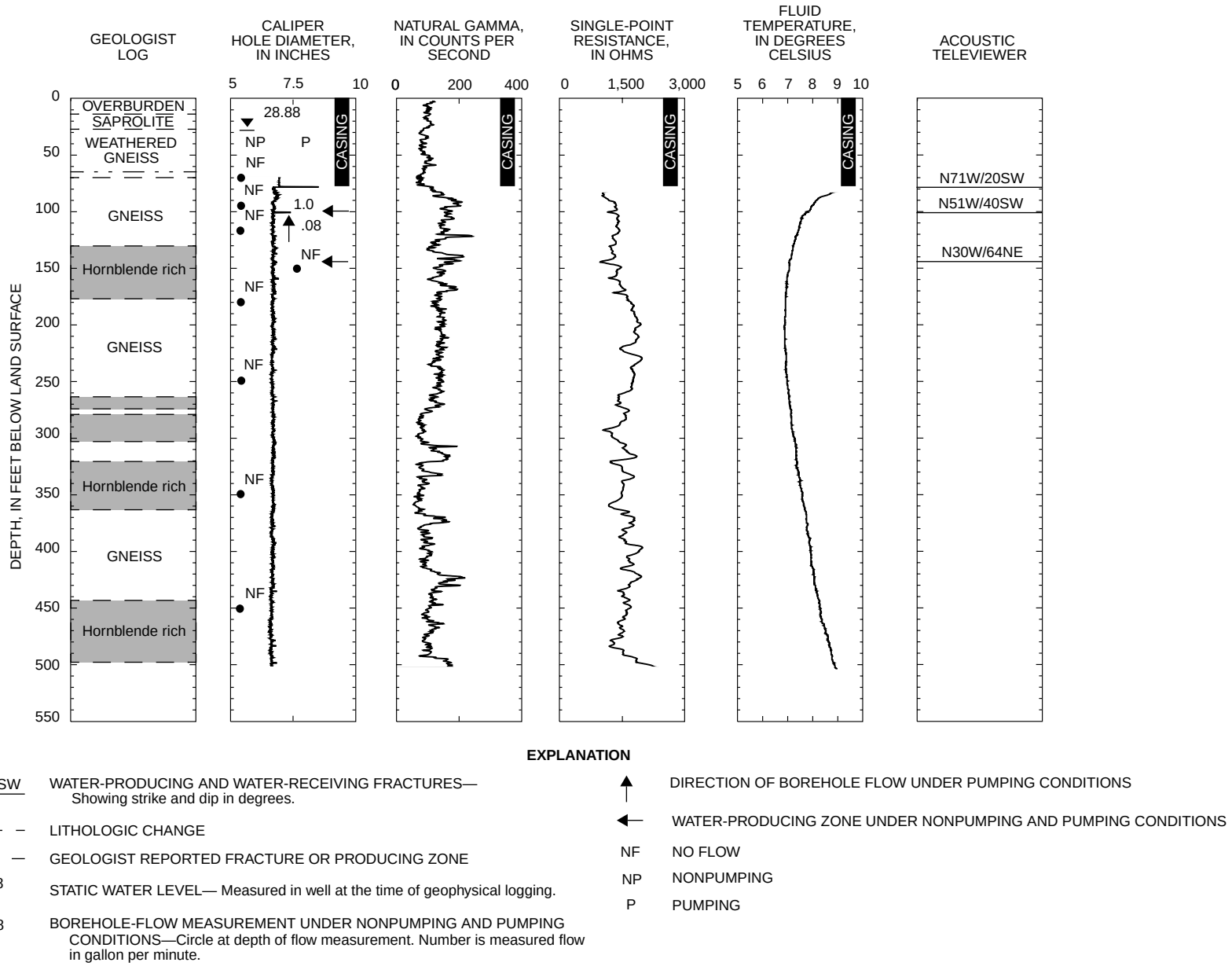


Figure 27. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1669 (TT25-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 3 through September 11, 2002. Borehole geophysical logs collected on September 24, 2002.)

Table 28. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1669 (TT25-D2), Sept. 24, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
78	N71W	20SW	197	N14E	81SE
82	N41W	29NE	208	N25W	82SW
85	N52W	83SW	293	N37W	70SW
86	N49W	85SW	293	N39W	72SW
87	N67W	73SW	364	N30W	80SW
87	N36W	80SW	366	N15W	78SW
91	N39W	85NE	372	N47W	81NE
101	N51W	40SW	424	N51E	51SE
103	N42E	73SE	435	N16E	58SE
144	N30W	64NE	445	N81E	68SE
145	N68W	26SW	445	N81E	65SE
147	N68E	52SE	455	N63E	56SE
151	N22W	77NE	458	N4E	59SE
159	N58W	64SW	481	N46W	86SW
171	N80W	76SW	498	N50E	32NW
172	N8W	73SW			

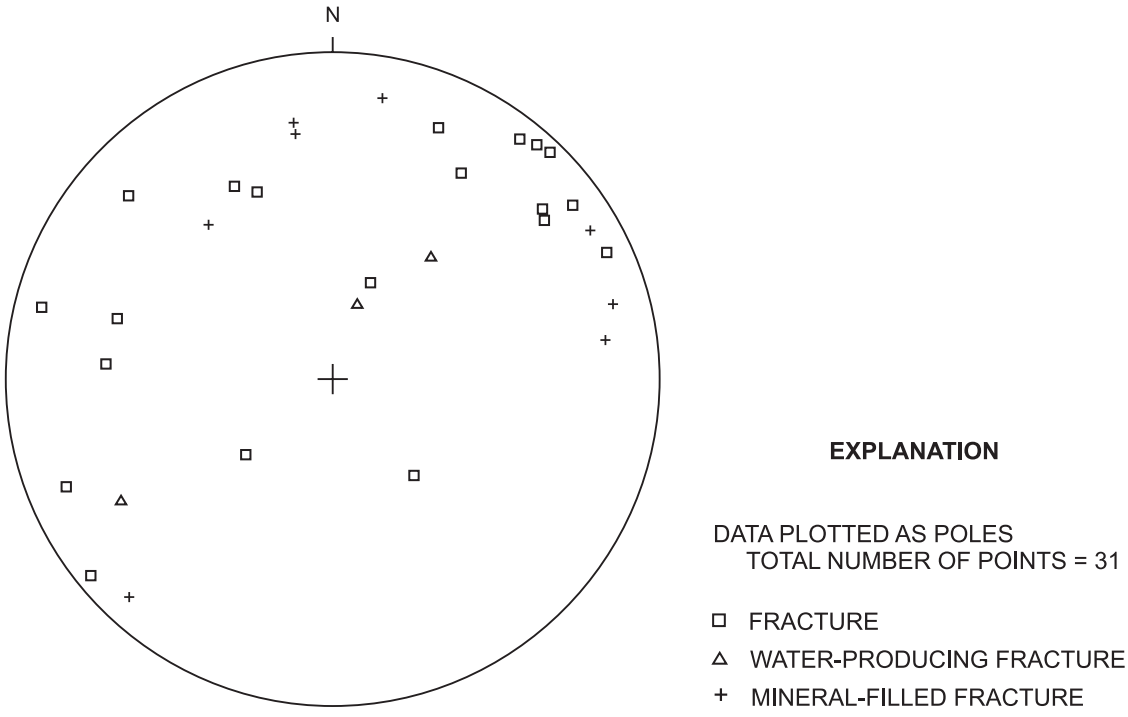


Figure 28. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1669 (TT25-D2), Sept. 24, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

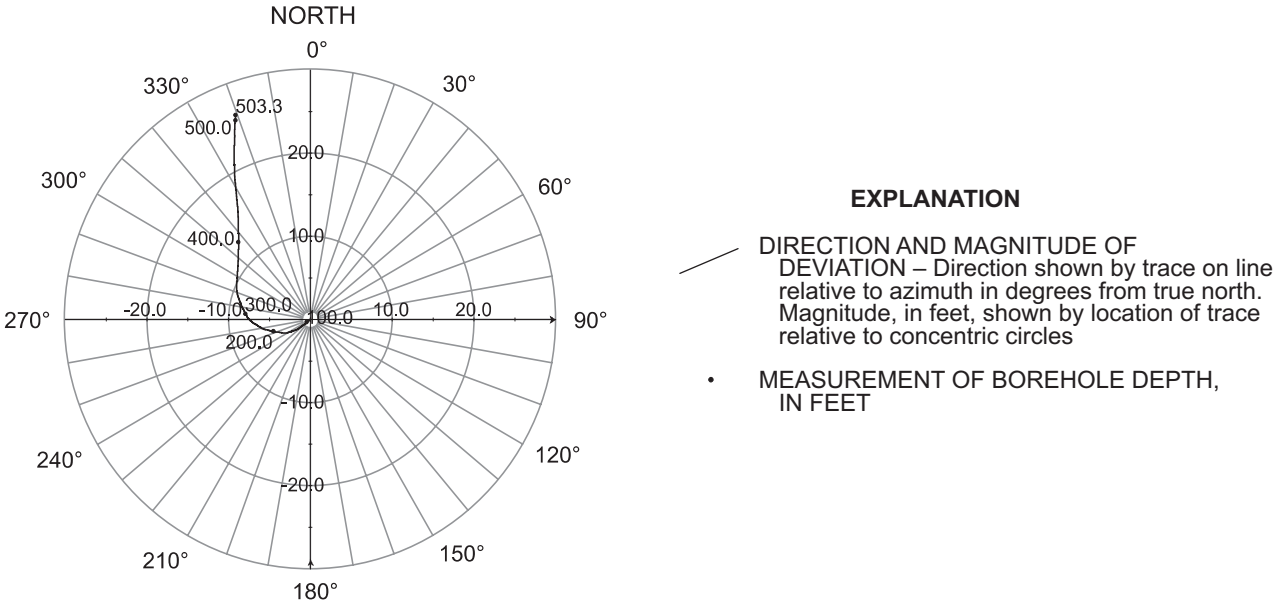


Figure 29. Magnitude and direction of deviation from vertical of borehole BE-1669 (TT25-D2), Sept. 24, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 70 (inside casing), 94, 116, 180, 250, 350, and 450 ft bls (fig. 27 and table 29).

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole. The pump was turned on, and the discharge rate varied from 0.51 to 0.69 gal/min. For the first 19 minutes, the water level decreased from 28.88 to 30.56 ft bls and upward flow was measured at 0.3 and 0.4 gal/min at 70 and 94 ft bls, respectively. To obtain flow from 115 to 150 ft bls, the pumping rate was increased and varied from about 1.3 to 1.4 gal/min. Over the next 19 minutes, the water level decreased an additional 1.28 ft, and upward flow was measured at about 0.08 gal/min at 116 ft bls. In an attempt to measure flow at 150 ft bls, the pumping rate was increased to about 2.1 gal/min. During the next 22 minutes, the water level decreased from 31.84 to 35.69 ft bls. Despite the increased pumping, the heatpulse flowmeter was unable to detect flow at a depth of 150 ft bls. The greatest quantity of water entered the borehole through the fracture at 101 ft bls (fig. 27). The borehole was completed as a monitor well by placing a pvc plastic screen at 95 to 105 ft bls to include the deepest water-producing zone at 101 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 29. Summary of heatpulse-flowmeter measurements for borehole BE-1669 (TT25-D2), Sept. 24, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

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

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Pumping rate (gal/min)	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
70	no flow	not determined	0.6	0.3	up
94	no flow	not determined	.6	.4	up
116	no flow	not determined	1.4	.08	up
150	—	—	2.1	no flow	no flow
180	no flow	not determined	—	—	—
250	no flow	not determined	—	—	—
350	no flow	not determined	—	—	—
450	no flow	not determined	—	—	—

BE-1670 (TT25-S)

Borehole BE-1670 was drilled into Precambrian gneiss (table 30). The geologist log notes the regolith is about 15 ft thick and consists of very weathered gneiss and phyllite. The gneiss exhibits variation in the amount of hornblende and feldspar, with some phyllite in the upper 15 ft. The geologist log notes possible water-producing fractures at 46 and 64 ft bls and the bottom of casing. The static water level at the time of logging was 28.48 ft bls. The caliper log shows the total depth of the borehole is 71 ft, and it is cased with 6-in.-diameter casing to 20 ft bls (fig. 30). The caliper log shows a large fracture at 58–60 ft bls plus numerous smaller fractures throughout the open-hole interval. Changes in lithology to a hornblende-rich gneiss at 15–25, 46–53, and 61–64 ft bls correlate to lower counts on the natural-gamma log (fig. 30). The spike in natural-gamma counts at 53–56 ft bls is probably because of higher concentrations of potassium feldspar within the gneiss. The single-point-resistance log shows changes in slope at 37, 40, 51, 55, 58, and 66 ft bls that correspond to fractures on the caliper log. The fluid-temperature log shows minor changes in temperature at 36 ft bls indicating a potential water-producing zone. The flat profile in the temperature log at depths greater than 36 ft bls indicates little or no flow within the open-hole interval under nonpumping conditions. The acoustic-televiewer log shows 16 fractures (table 31). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the orientation of all fracture planes and mineral-filled fractures strike N. 70° E. and dip 74° SE. The average orientation of known water-producing fractures is a strike of N. 68° E. and a dip of 65° SE. (fig. 31). The borehole deviation log (fig. 32) shows the borehole deviates from vertical 1.7 ft to the northeast.

Table 30. Geologist log for borehole BE-1670 (TT25-S), Sept. 17, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–4	**OVERBURDEN,** dry
5–15	**SAPROLITE**, very weathered gneiss and some phyllite
16–25	**GNEISS**, hornblende Bottom of casing set at 20 ft bls
26–46	**GNEISS**, less hornblende Fracture at 46 ft bls; producing 3–5 gal/min
47–53	**GNEISS,** hornblende
54–61	**GNEISS**, more feldspar
62–64	**GNEISS**, hornblende Possible fracture at 64 ft bls
65–70	**GNEISS,** less hornblende

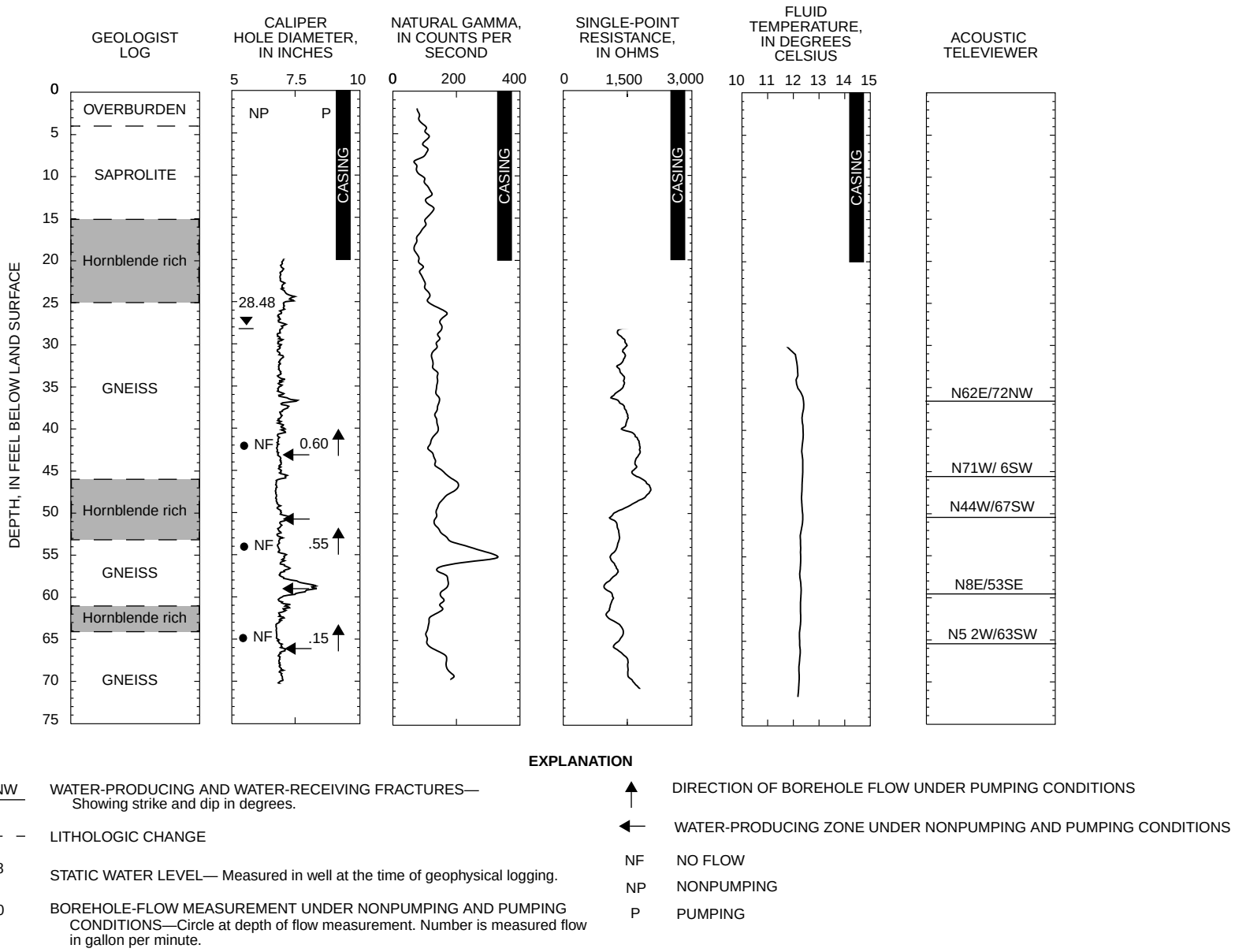


Figure 30. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1670 (TT25-S), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from September 17, 2002. Borehole geophysical logs collected on September 25, 2002.)

Table 31. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1670 (TT25-S), Sept. 25, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
31	N77W	68NE	46	N71W	6SW
37	N62E	72NW	49	N50W	75SW
38	N8W	62NE	50	N57W	72SW
39	N39E	73SE	51	N44W	67SW
40	N69E	46SE	54	N53W	70SW
40	N70E	50SE	59	N8E	53SE
43	N29W	82SW	63	N70E	47SE
46	N21W	26NE	66	N52W	63SW

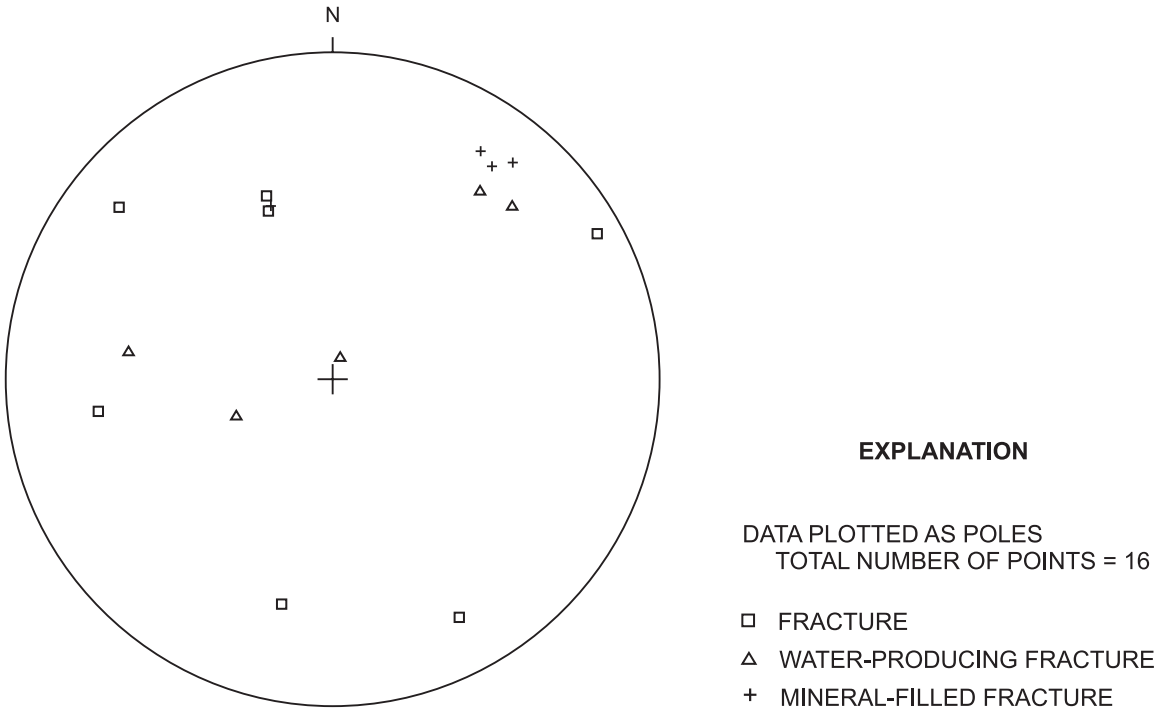


Figure 31. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1670 (TT25-S), Sept. 25, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

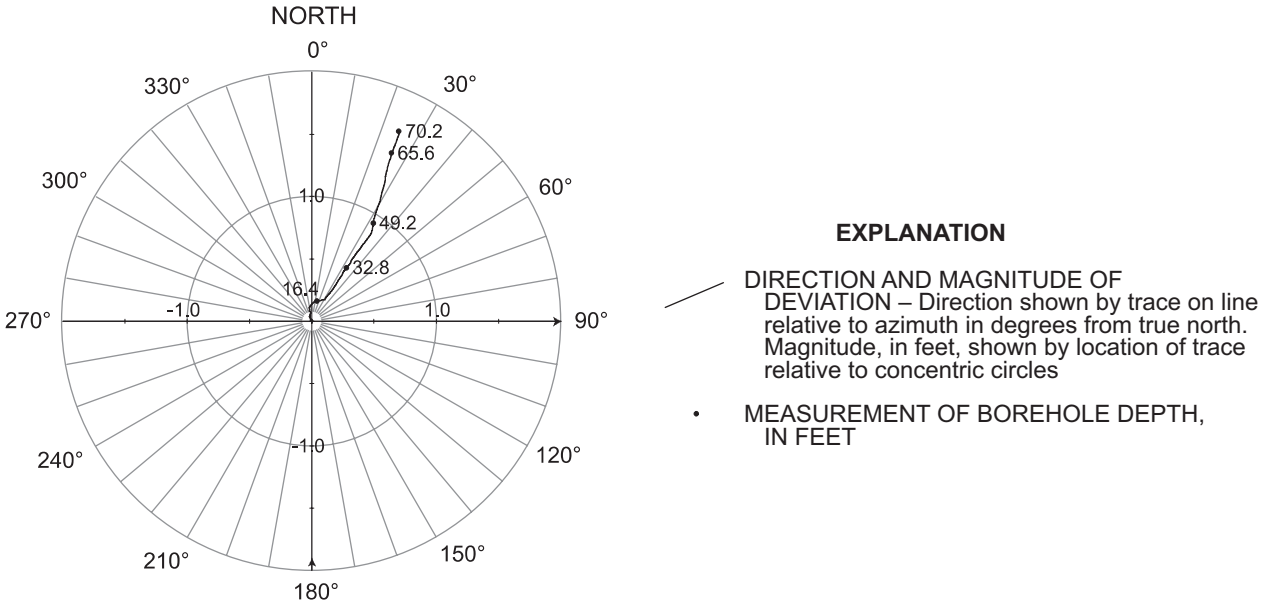


Figure 32. Magnitude and direction of deviation from vertical of borehole BE-1670 (TT25-S), Sept. 25, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 42, 54, and 65 ft bls (table 32).

Upon completion of logging under ambient conditions, a submersible pump was placed within the borehole at a depth of 35 ft. The pump was turned on, and the discharge rate varied from 0.55 to 0.69 gal/min. For 18 minutes, the water level decreased from 28.75 to 28.99 ft bls. Under pumping conditions, upward borehole flow was measured at 42, 54, and 65 ft bls (table 32). Small fractures at 44 and 51 (combined total of <0.1 gal/min), 58–60 (0.40 gal/min), and 66 ft bls (0.15 gal/min) produced varying amounts of water. The greatest quantity of water entered the borehole through the large fracture at 58–60 ft bls (fig. 30). The borehole was completed as a monitor well by placing a pvc plastic screen at 56–66 ft bls to include the water-producing zone at 58–60 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 32. Summary of heatpulse-flowmeter measurements for borehole BE-1670 (TT25-S), Sept. 25, 2002, Crossley Farm Superfund Site, Hereford Township, 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	Flow rate under pumping conditions (gal/min)	Pumping rate (gal/min)	Flow direction under pumping conditions
42	no flow	not determined	0.6	0.60	up
54	no flow	not determined	.55	.60	up
65	no flow	not determined	.15	.55	up

BE-1671 (TT24-I)

Borehole BE-1671 was drilled into Precambrian gneiss (table 33). The geologist log notes the regolith is about 54 ft thick, produces 1–2 gal/min, and consists of clay, silt, sand, and some quartz pebbles and very weathered to weathered gneiss. Hornblende increases in abundance with increasing depth. The geologist log notes possible water-producing fractures at 55 and 75 ft bls with soft zones at 80–85, 105, and 132 ft bls and the bottom of casing. The static water level at the time of logging was 15.35 ft bls. The caliper log shows the total depth of the borehole is 152 ft, and it is cased with 6-in.-diameter casing to 70 ft bls (fig. 33). The caliper log shows large fractures at 70.5, 74–75, 77–78, 108–110, 122, 132, and 142 ft bls plus numerous smaller fractures throughout the open-hole interval. Changes in lithology at 122 ft bls and rock integrity at 105, 132, and 145 ft bls correlate well to fractures on the caliper log. The natural-gamma log shows an increase in counts at 110–130 and 132–147 ft bls and a spike at 150 ft bls. The single-point-resistance log shows changes in slope at 77, 109, 122, 132, and 142 ft bls that correspond to fractures on the caliper log. The spike on the single-point-resistance log between 122 and 132 ft bls is probably related to changes in lithology because the geologist log notes an increase in hornblende and the natural-gamma log shows a corresponding decrease in counts. The fluid-temperature log shows a minor deflection in slope at 70 ft bls that corresponds to a fracture on the caliper log and indicates a water-producing zone. The acoustic-televiewer log shows 28 fractures (table 34). An equal-area stereonet produced from acoustic televiewer data, with poles plotted at right angles to the fracture planes, shows the orientation of all fracture planes and mineral-filled fractures strike N. 60° E. and dip 68° SE. The average orientation of known water-producing fractures is a strike of N. 44° E. and a dip of 44° SE. (fig. 34). The borehole deviation log (fig. 35) shows the borehole deviates from vertical approximately 0.2 ft to the northeast to about 100 ft, then turns to the west and deviates about 0.1 ft over the next 50 ft of borehole depth (fig. 35). This latter deviation indicates a change in the orientation of the gneiss, probably because of the presence of a fault.

Table 33. Geologist log for borehole BE-1671 (TT24-I), Aug. 29-Sept. 3, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–28	**OVERBURDEN,** clay, silt, sand, some quartz pebbles; moist to wet
29–54	**SAPROLITE**, very weathered gneiss, gneiss fragments, clayey silt; dry
	Slightly harder at 40 ft bls
	Producing 1–2 gal/min at 47 ft bls
55–122	**GNEISS**, very weathered; trace phyllite; harder
	Producing zone at 55 ft bls
	Producing 1–3 gal/min by 60 ft bls
	Producing 3–5 gal/min by 70 ft bls
	Bottom of casing set at 70 ft bls
	Producing zone at 75 ft bls
	Soft 80–85 ft bls
	Producing 5–7 gal/min by 85 ft bls
	Soft at 105 ft bls
123–137	**GNEISS**, weathered; more hornblende
	Producing 5–10 gal/min by 122 ft bls
	Harder at 130 ft bls
	Softer at 132 ft bls
	Harder at 145 ft bls
138–150	**GNEISS,** hornblende; still weathered
	Harder at 145 ft bls

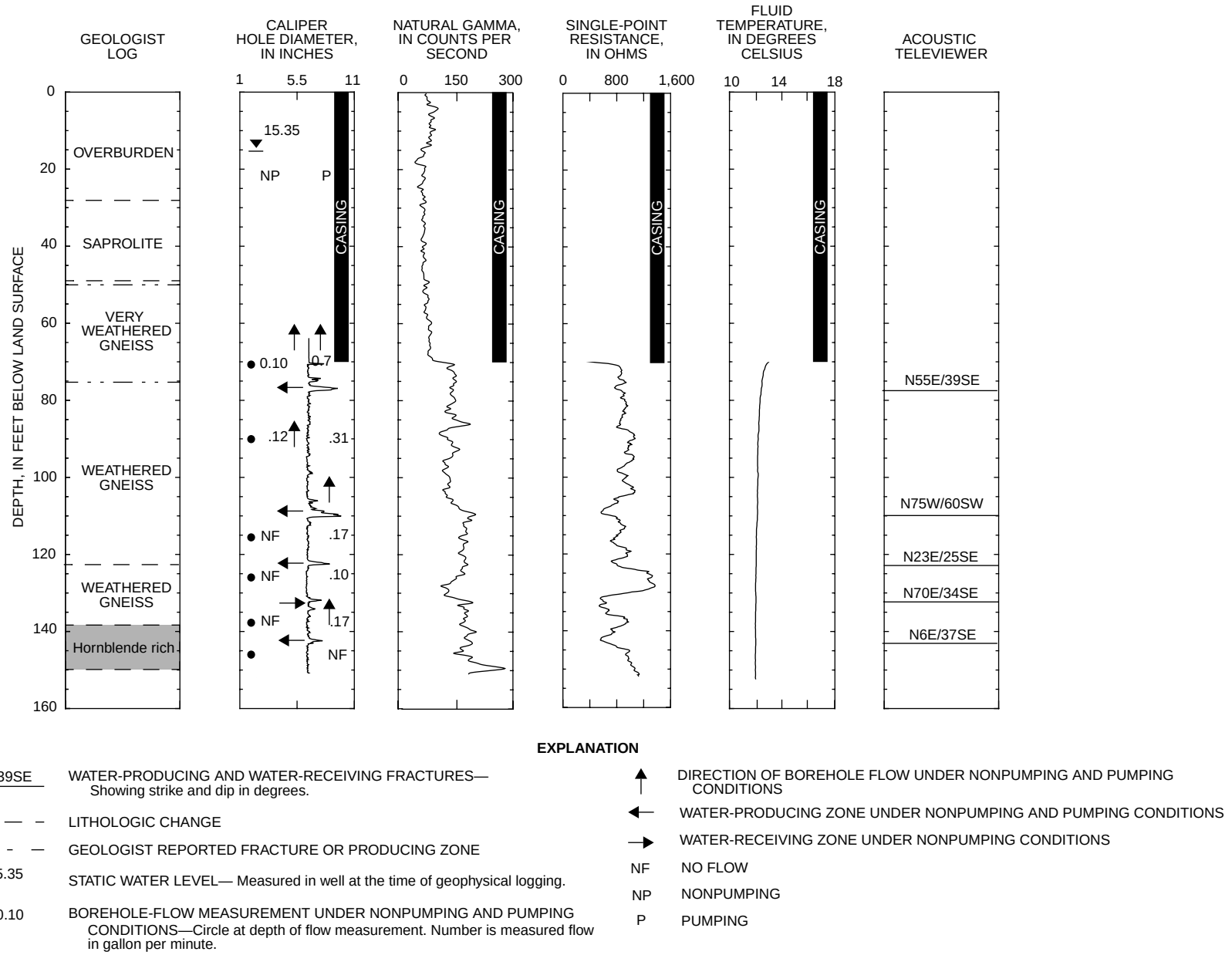


Figure 33. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1671 (TT24-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from August 29 through September 3, 2002. Borehole geophysical logs collected on September 26, 2002.)

Table 34. Locations of fractures and measurement of strike and dip determined from acoustic-televiewer log for borehole BE-1671 (TT24-I), Sept. 26, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; strike and dip in degrees]

Depth (ft bls)	Strike of fracture	Dip of fracture	Depth (ft bls)	Strike of fracture	Dip of fracture
75	N66E	59SE	116	N72W	72SW
77	N55E	39SE	122	N23E	25SE
88	N15E	77SE	124	N42E	43SE
90	N59W	73SW	132	N70E	34SE
94	N16W	13SW	134	N81W	41SW
98	N60E	78SE	135	N20E	64NW
99	N62E	59SE	136	N17E	37SE
104	N37E	79SE	136	N11E	36SE
106	N48E	23SE	140	N13W	39NE
110	N75W	60SW	143	N6E	37SE
112	N45E	59SE	145	N14W	28SW
112	N79W	61SW	146	N62W	76NE
115	N79W	70SW	147	N67W	72NE
115	N10W	64SW	147	N37E	70SE

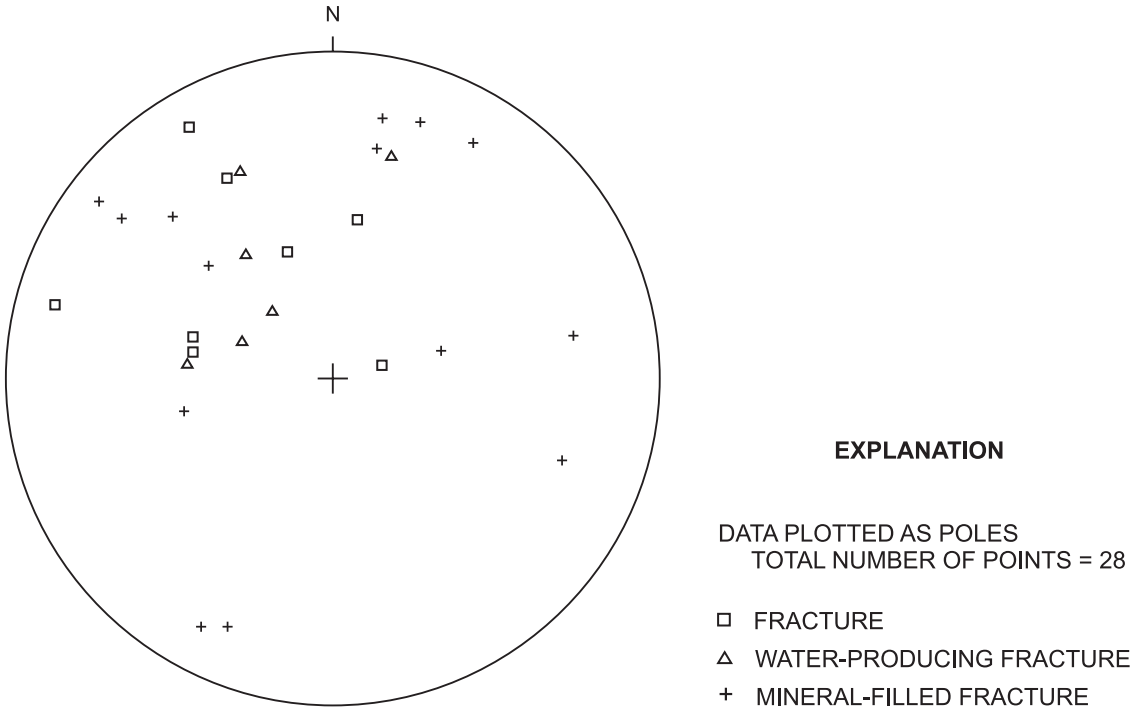


Figure 34. Equal-area lower-hemisphere (Lambert), stereographic projection of poles perpendicular to fracture planes in borehole BE-1671 (TT24-I), Sept. 26, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

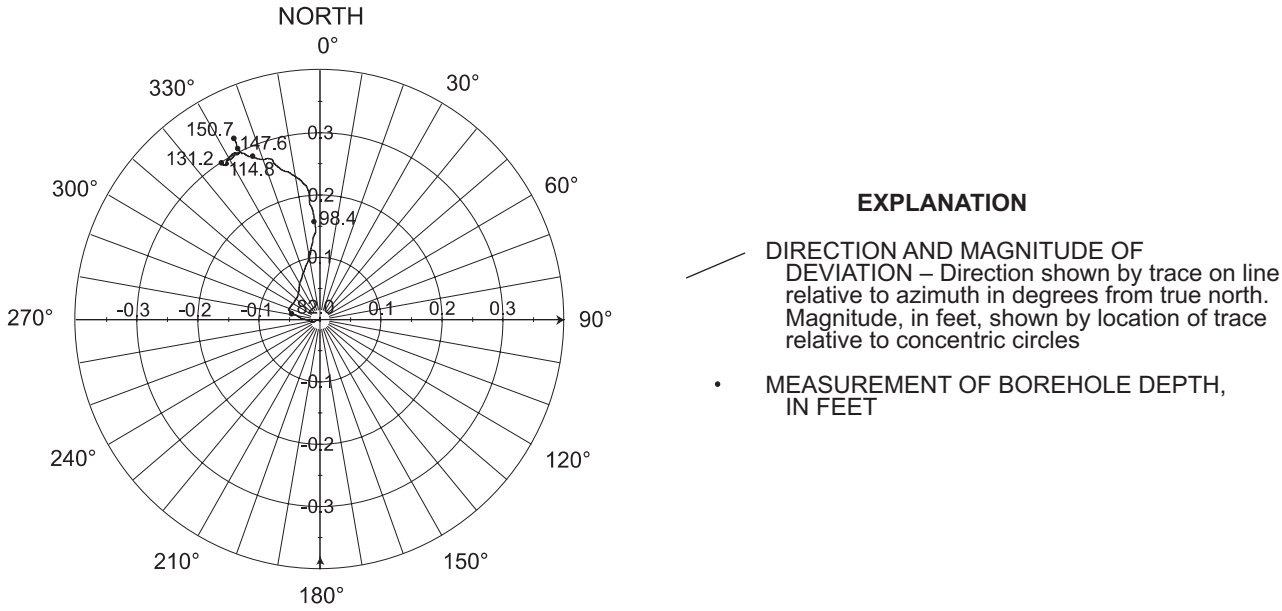


Figure 35. Magnitude and direction of deviation from vertical of borehole BE-1671 (TT24-I), Sept. 26, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 72 and 90 ft bls and no flow at 116, 126, and 138 ft bls (table 35). The largest water-producing zone was at 108–110 ft bls, which is a soft zone noted on the geologist log. The water-receiving zones were at 70.5, 74–75, and 77–78 ft bls.

Upon completion of logging under ambient conditions, a submersible pump was placed in the borehole. The pump was turned on, and the discharge rate averaged 0.55 gal/min. During the 40 minutes the pump was on, the water level decreased from 15.05 to 16.08 ft bls. Under pumping conditions, upward flow was again measured at 72 and 90 ft bls; there was no measurable flow at 146 ft bls. Areas that previously were no flow under nonpumping conditions now contributed water [116 ft bls (0.17 gal/min), 126 ft bls (0.10 gal/min), and 138 ft bls (0.17 gal/min)]. The fracture (soft zone on the geologist log) at 132 ft bls became a receiving zone. The borehole was completed as a monitor well by placing a pvc plastic screen at 132–152 ft bls to include the water-producing fracture at 142 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 35. Summary of heatpulse-flowmeter measurements for borehole BE-1671 (TT24-I), Sept. 26, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; gal/min, gallon per minute; <, less than; —, not measured]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Pumping rate (gal/min)	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
72	0.10	up	<1.0	0.70	up
90	.12	up	.55	.31	up
116	no flow	not determined	.55	.17	up
126	no flow	not determined	.55	.10	up
138	no flow	not determined	.55	.17	up
146	—	—	.55	no flow	—

BE-1672 (TT28-I)

Borehole BE-1672 was drilled into Precambrian gneiss (table 36). The geologist log notes the regolith is about 25 ft thick, consisting of silty sand, gravel, very weathered gneiss, and some phyllite. The geologist log also notes a possible fracture at 58 ft bls and possible producing zones at 47, 120, 138, and 140 ft bls and the bottom of casing. The static water level at the time of logging was 16.48 ft bls. The caliper log shows the total depth of the borehole is 150 ft, and it is cased with 10-in.-diameter casing to 30 ft bls (fig. 36). The caliper log shows a large fracture at 47–48 ft bls plus numerous smaller fractures throughout the open-hole interval. The natural-gamma log shows some variation in counts at 48–82 and 102–106 that are probably related to increases in the amount of potassium feldspar in the gneiss. The single-point-resistance log shows changes in slope at 38, 47, 57, and 62 ft bls that correlate well to fractures on the caliper log. Some of the other changes in slope may be related to changes in lithology. The fluid-temperature log shows minor deflections in slope at 42, 48, 62, 66, 82, 106, and 140 ft bls that correlate well to fractures on the caliper log and deflections on the single-point-resistance log, indicating possible water-producing or water-receiving zones. Acoustic televiewer data were not collected because the borehole diameter was too large.

Table 36. Geologist log for borehole BE-1672 (TT28-I), Nov. 14, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–3	**OVERBURDEN,** silty sand and gravel
4–25	**SAPROLITE**, very weathered gneiss, some phyllite; dry
26–35	**GNEISS**, weathered; some phyllite; harder
	Bottom of casing set at 30 ft bls
	Producing less than 2 gal/min at 32 ft bls
36–42	**GNEISS**, phyllitic
	Dry and dusty by 37 ft bls
43–62	**GNEISS**
	Producing about 3 gal/min at 43 ft bls
	Producing 3–5 gal/min at 45 ft bls
	Producing zone at 47 ft bls
	Producing less than 1 gal/min by 52 ft bls
	Possible fracture at 58 ft bls
	Producing about 3 gal/min by 62 ft bls
63–77	**GNEISS**, hornblende
	Producing less than 1 gal/min by 74 ft bls
78–103	**GNEISS**, hornblende and feldspar in about equal amounts
	Producing 3–5 gal/min by 102 ft bls
104–110	**GNEISS**, with shale and phyllite
	Producing about 1 gal/min by 109 ft bls
111–150	**GNEISS**, little hornblende
	Producing 3–5 gal/min by 114 ft bls
	Possible water-producing zone at 120 ft bls
	Producing 5–10 gal/min by 123 ft bls
	Producing zone at 138 ft bls
	Producing zone at 140 ft bls
	Producing 10–15 gal/min by 142 ft bls

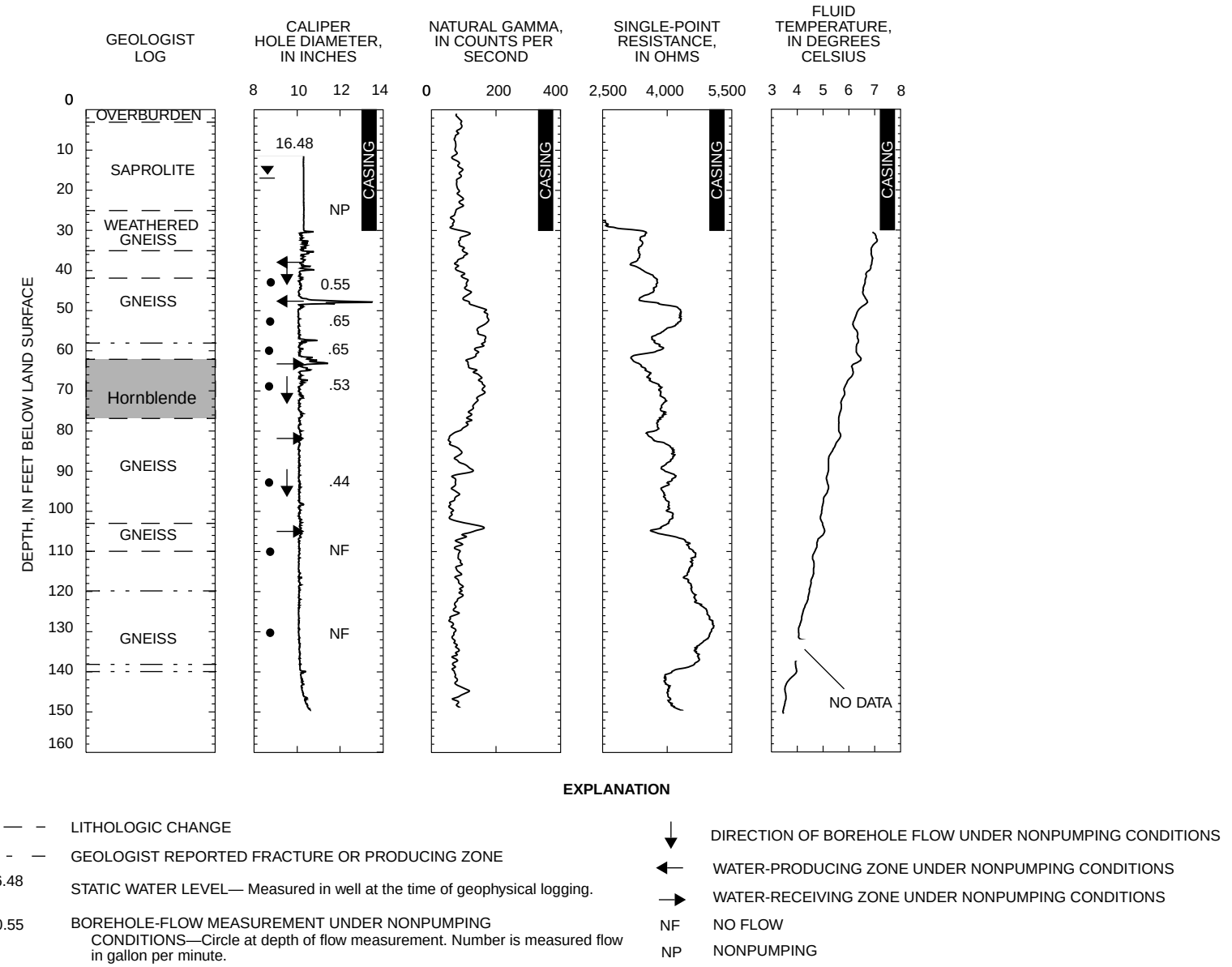


Figure 36. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1672 (TT28-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected November 14, 2002. Borehole geophysical logs collected on December 16, 2002.)

Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 43, 53, 60, 69, and 93 ft bls and no flow at 110 and 130 ft bls (table 37). The largest water-producing zone was from a series of fractures from 32 to 40 ft bls (fig. 36). Additional water was produced from the major fracture at 47–48 ft bls. The fracture at 62–64 ft bls was a water-receiving zone. Additional water-receiving zones were difficult to locate but may occur at about 80 and 106 ft bls (near changes in lithology). This borehole will be used to extract contaminated ground water and will remain an open hole from 30 to 150 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 37. Summary of heatpulse-flowmeter measurements for borehole BE-1672 (TT28-I), Dec. 16, 2002, Crossley Farm Superfund Site, Hereford Township, 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
43	0.55	down
53	.65	down
60	.65	down
69	.53	down
93	.44	down
110	no flow	not determined
130	no flow	not determined

BE-1673 (TT29-I)

Borehole BE-1673 was drilled into Precambrian gneiss (table 38). The geologist log notes the regolith is about 70 ft thick, produces about 5 gal/min, and consists of sand, silt, clay, very weathered gneiss, and some phyllite. Fresh gneiss was encountered at a depth of 146 ft bls. The geologist log also notes possible producing zones at 89, 109, 110, and 133 ft bls and the bottom of casing. The static water level at the time of logging was 8.38 ft bls. The caliper log shows the total depth of the borehole is 151 ft, and it is cased with 10-in.-diameter casing to 79.5 ft bls (fig. 37). The caliper log shows large fractures at 108–112 and 128–132 ft bls plus numerous smaller fractures throughout the open-hole interval. The natural-gamma log shows little variation, which suggests the gneiss is fairly homogeneous regarding its content of hornblende and feldspar. The single-point-resistance log shows a change in slope at 144 ft bls that corresponds to fresh gneiss described on the geologist log (table 38). The fluid-temperature log shows minor deflections in slope at 114, 132, and 136 ft bls that correlate to large fractures shown on the caliper log and producing zones reported by the geologist. Acoustic-televiewer data were not collected because the 10-inch diameter borehole was too large.

Table 38. Geologist log for borehole BE-1673 (TT29-I), Nov. 27-Dec. 4, 2004, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–50	**OVERBURDEN,** sand, silt, and clay; damp
	Harder at 35 ft bls
	Softer at 38 ft bls
	Producing about 3 gal/min by 40 ft bls
51–70	**SAPROLITE**, very weathered gneiss, some phyllite; dry
	Producing about 5 gal/min by 50 ft bls
71–146	**GNEISS**, very weathered
	Bottom of casing at 79.5 ft bls
	Producing about 1 gal/min at 89 ft bls
	Soft at 95 ft bls
	Producing 5–10 gal/min by 107 ft bls
	Producing zone at 109 ft bls
	Producing zone at 110 ft bls
	Producing about 25–30 gal/min by 112 ft bls
	Producing zone at 133 ft bls
	Producing 35–40 gal/min by 134 ft bls
	Soft at 139 ft bls
147–152	**GNEISS**, fresh rock

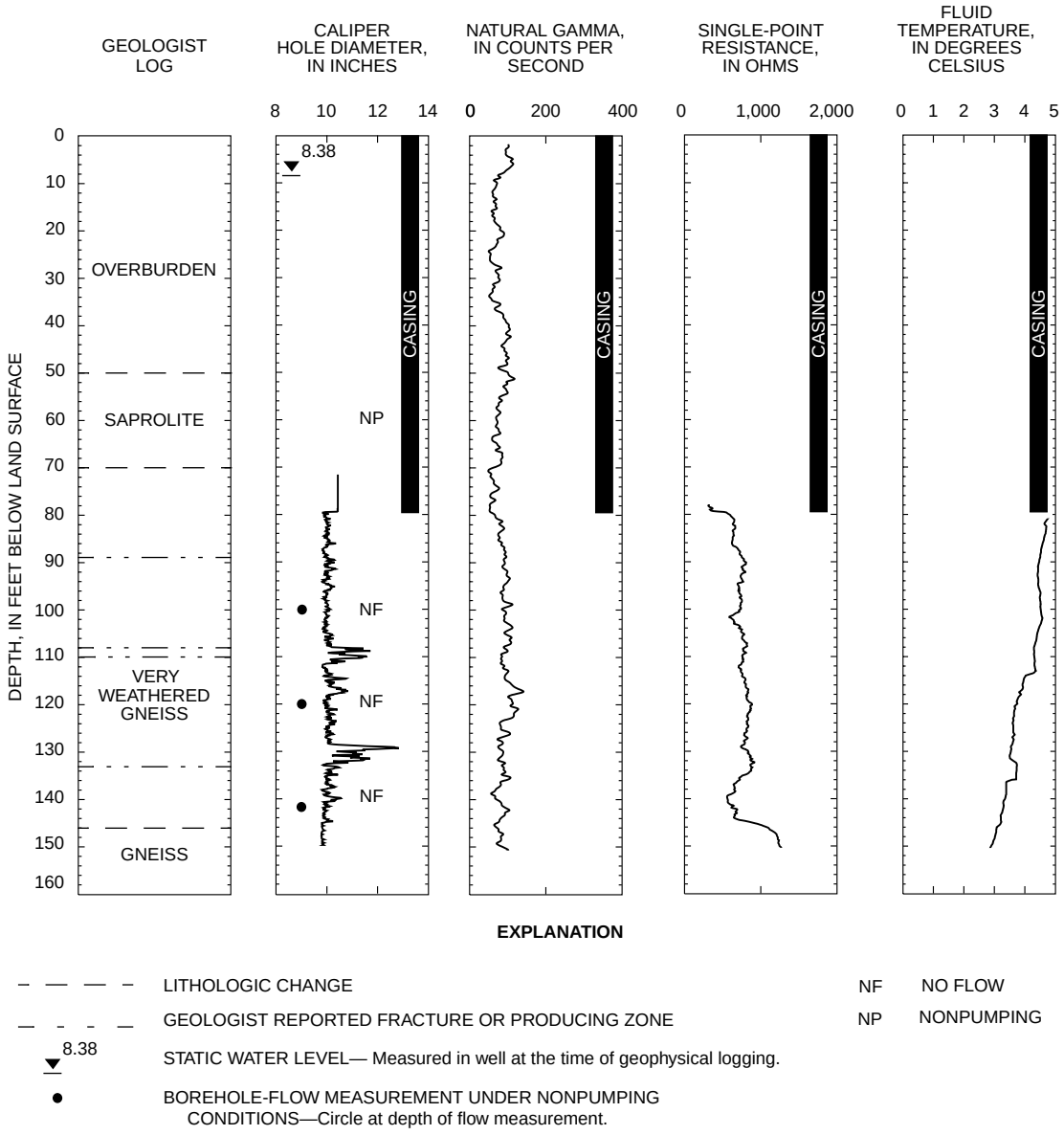


Figure 37. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1673 (TT29-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected November 27 through December 4, 2002. Borehole geophysical logs collected on December 16, 2002.)

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 100, 120, and 142 ft bls (table 39). This borehole will be used to extract contaminated ground water, but because of numerous fractures and possibility of collapse, a pvc plastic screen was immediately placed at 75 to 150 ft bls. (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 39. Summary of heatpulse-flowmeter measurements for borehole BE-1673 (TT29-I), Dec. 16, 2002, Crossley Farm Superfund Site, Hereford Township, 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
100	no flow	not determined
120	no flow	not determined
142	no flow	not determined

BE-1674 (TT28-D)

Borehole BE-1674 was drilled into Precambrian gneiss (table 40). The geologist log notes the regolith is about 12 ft thick, consisting of silty sand, very weathered gneiss, and some phyllite. Although gneiss and hornblende-rich gneiss are the predominant lithologies, the geologist observed some schist at 31–38 and 91–92 ft bls, shale and phyllite at 109–113 and 132–135 ft bls, and phyllite with schist at 152–198 ft bls in conjunction with the gneiss. The geologist log also notes possible producing zones and fractures at 28, 30, 42, 90, 117, and 219 ft bls and the bottom of casing. The static water level at the time of logging was 19.51 ft bls. The caliper log shows the total depth of the borehole is 338 ft, and it is cased with 10-in.-diameter casing to 157 ft bls (fig. 38). The caliper log shows a large fracture at 157 ft bls plus numerous smaller fractures throughout the open-hole interval. Changes in lithology to a hornblende-rich gneiss at 31–38, 59–70, 114–119, 132–135, 152–198, and 241–252 ft bls correlate well to lower counts on the natural-gamma log. The spike in counts on the natural-gamma log at 250–258 ft bls probably is related to a decrease in hornblende and an increase in the amount of potassium feldspar in the gneiss. The minor deflections in slope on the single-point-resistance log (175, 203, and 300 ft bls) correspond to small fractures on the caliper log. The fluid-temperature log shows a minor deflection in slope at 233 ft bls. The absence of a gradient on the fluid-temperature log suggests active flow exists in the borehole; this flow is either horizontal or at a rate below the capabilities of the heatpulse flowmeter. Acoustic televiewer data were not collected because the 10-in.-diameter borehole was too large.

Table 40. Geologist log for borehole BE-1674 (TT28-D), Nov. 18-26, 2002, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–3	**OVERBURDEN,** silty sand; dry
4–12	**SAPROLITE**, very weathered gneiss, some phyllite; dry
	Harder at 12 ft bls
13–30	**GNEISS**, weathered; dry
31–38	**GNEISS**, hornblende and schist
	Producing zone at 28 ft bls
	Producing zone at 30 ft bls
	Producing about 15 gal/min by 37 ft bls
39–58	**GNEISS**
	Producing zone at 42 ft bls
	Producing 5–10 gal/min by 43 ft bls
	Producing 15–20 gal/min at 53 ft bls
	Producing 20–25 gal/min at 57 ft bls
59–70	**GNEISS**, hornblende
71–90	**GNEISS**
	Producing zone at 90 ft bls
91–92	**GNEISS**, hornblende and schist
	Producing about 30 gal/min by 92 ft bls
93–108	**GNEISS**, more feldspar
109–113	**GNEISS**, shale and phyllite
114–119	**GNEISS**, hornblende
	Fracture at 117 ft bls, producing 30–35 gal/min
120–131	**GNEISS**
	Producing about 30 gal/min by 130 ft bls
132–135	**GNEISS**, hornblende, shale, and phyllite
136–151	**GNEISS,** less hornblende
	Producing 20–25 gal/min by 136 ft bls
	Producing 20 gal/min by 140 ft bls
152–198	**Phyllite/Schist/Gneiss**, hornblende; grades into Gneiss by 196 ft bls
	Bottom of casing set at 157 ft bls
199–240	**GNEISS**
	Possible fracture at 219 ft bls
241–252	**GNEISS**, hornblende
253–338	**GNEISS**, varying amounts hornblende (20 percent or less by 280 ft bls)
	Producing less than 1 gal/min by 280 ft bls
	No water in hole by 298 ft bls
	Producing 2–3 gal/min at 303 ft bls
	Producing 3–5 gal/min at 305 ft bls
	Producing 5 gal/min at 314 ft bls
	Producing 5–6 gal/min at 318 ft bls
	Producing 7 gal/min at 327 ft bls

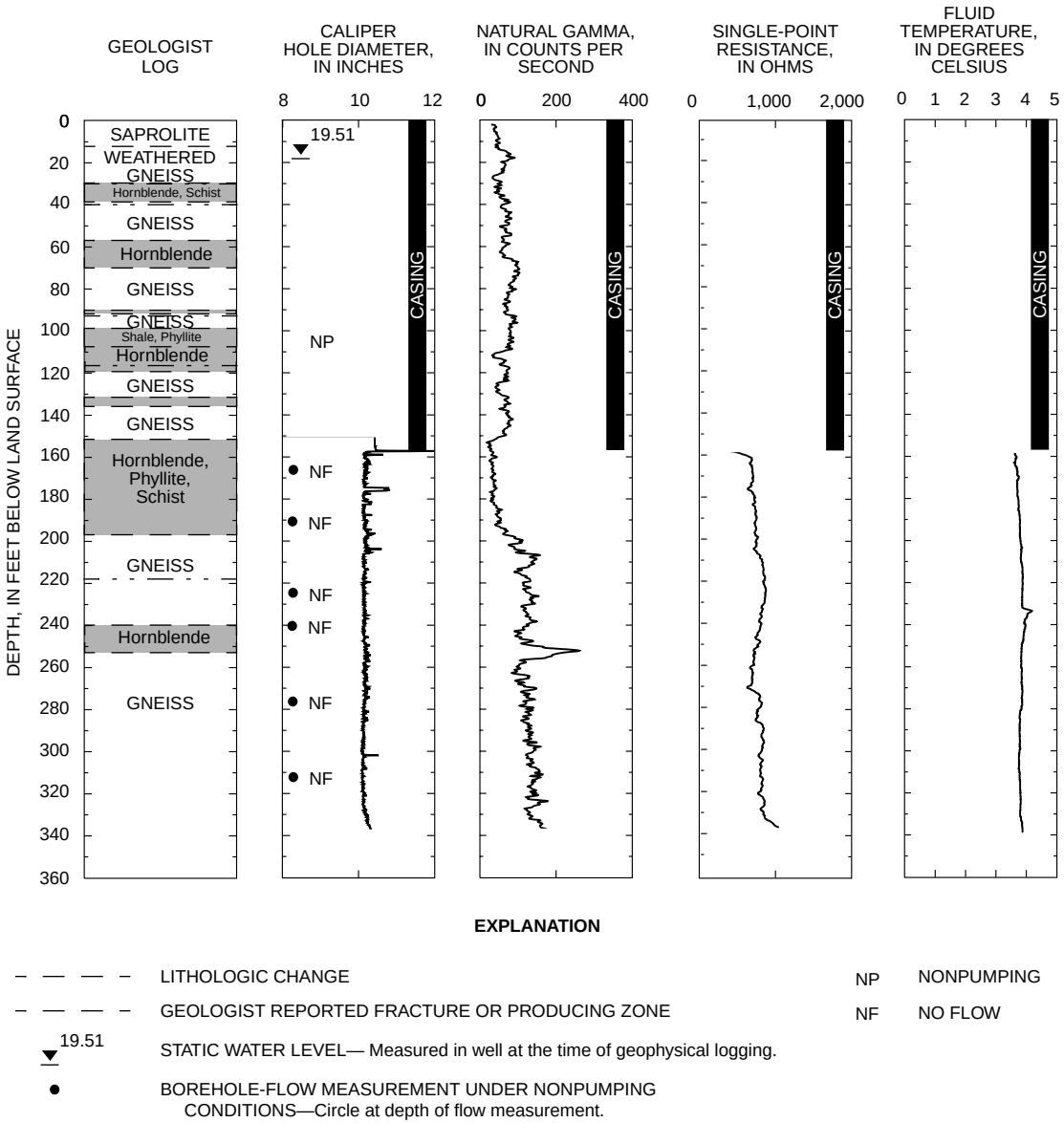


Figure 38. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1674 (TT28-D), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected November 18 through November 26, 2002. Borehole geophysical logs collected on December 17, 2002.)

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 166, 190, 224, 240, 277, and 312 ft bls (table 41). This borehole will be used to extract contaminated ground water and will remain an open hole from 157 to 338 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 41. Summary of heatpulse-flowmeter measurements for borehole BE-1674 (TT28-D), Dec. 17, 2002, Crossley Farm Superfund Site, Hereford Township, 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
166	no flow	not determined
190	no flow	not determined
224	no flow	not determined
240	no flow	not determined
277	no flow	not determined
312	no flow	not determined

BE-1675 (TT31-I)

Borehole BE-1675 was drilled into Precambrian gneiss (table 42). The geologist log notes the regolith is about 60 ft thick, produces about 5 gal/min, and consists of gravel, sand, silt, and very weathered gneiss. At about 90 ft bls, the gneiss becomes less weathered and becomes hornblende rich at a depth of 150 ft. The geologist log also notes possible producing zones or fractures at 50, 63, 68, 83, 96, 108, 126, and 132 ft bls and the bottom of casing. The static water level at the time of logging was 23.50 ft bls. The caliper log shows the total depth of the borehole is 152 ft, and it is cased with 10-in.-diameter casing to 39.5 ft bls (fig. 39). The caliper log shows large fractures at 51–52, 107, and 125–127 ft bls plus numerous smaller fractures throughout the open-hole interval. The general increase in counts shown on the natural-gamma log beginning at 66 ft bls is probably related to less weathered feldspar being present in the gneiss. Deflections in the single-point-resistance log correlate well to fractures shown on the caliper log and described in the geologist log. The temperature log shows changes in slope at 41, 42–46, 66, 98, 102–103, 112, and 126 ft bls that correlate to fractures shown on the caliper log and are probably indicative of water-producing zones. Acoustic-televiewer data were not collected because the 10-in.-diameter borehole was too large.

Table 42. Geologist log for borehole BE-1675 (TT31-I), Jan. 16-17, 2003, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–39	**OVERBURDEN**, clay, silt, sand, gravel
	Flowing wet mud at 39 ft bls
40–60	**SAPROLITE**, very weathered gneiss, occasional sand
	Bottom of casing set at 39.5 ft bls
	Producing 2–3 gal/min by 45 ft bls
	Possible fracture at 50 ft bls
	Producing 5 gal/min by 52 ft bls
61–94	**GNEISS**, weathered
	Possible fracture at 63 ft bls
	Possible fracture at 68 ft bls
	Possible fracture at 83 ft bls
	Grading into fresher rock 90–94 ft bls
95–150	**GNEISS**
	Producing 8–10 gal/min by 95 ft bls
	Fracture at 96 ft bls
	Fracture at 108 ft bls
	Producing 10–15 gal/min by 110 ft bls
	Large fracture at 126 ft bls producing about 20 gal/min
	Small fracture at 132 ft bls
	Producing more than 20 gal/min by 145 ft bls
151–152	**GNEISS**, hornblende

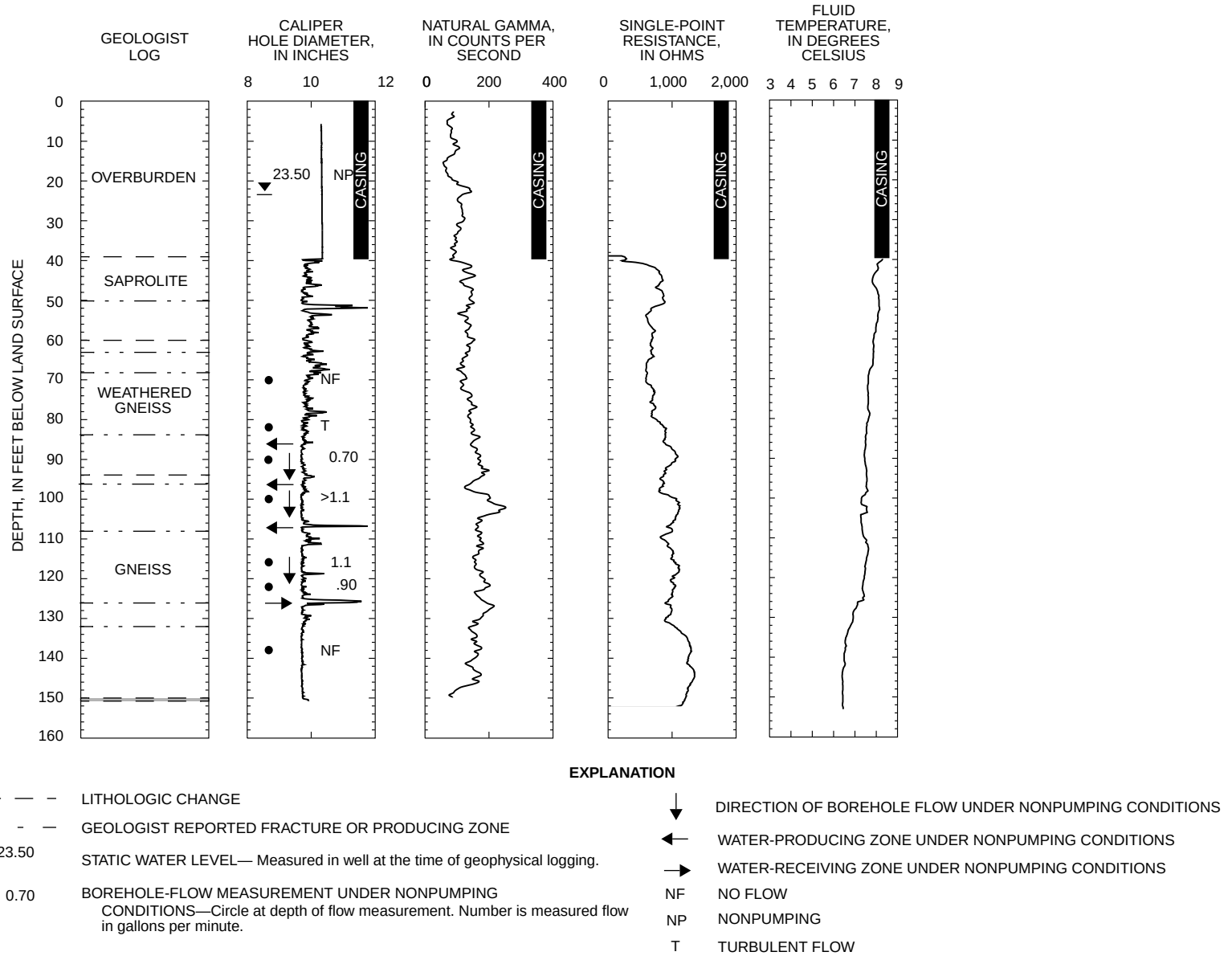


Figure 39. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1675 (TT31-I), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected January 16 and 17, 2003. Borehole geophysical logs collected on January 21, 2003.)

Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow at 90, 100 116, and 122 ft bls, and no flow at 70 and 138 ft bls; some turbulent flow was identified at 82 ft bls (table 43). The largest amount of water entered the borehole through small fractures at 83 or 86 and 94 ft bls (fig. 39). The fracture at 94 ft bls was near the contact between weathered and fresher gneiss. Water exited the borehole through the large fractures at 107 and 125–127 ft bls; a smaller amount of water exited the borehole through a small fracture at 119 ft bls. This borehole will be used to extract contaminated ground water, but because of numerous fractures and possibility of collapse, a pvc plastic screen was placed at 85 to 150 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 43. Summary of heatpulse-flowmeter measurements for borehole BE-1675 (TT31-I), Jan. 21, 2003, Crossley Farm Superfund Site, Berks County, Hereford Township, Pennsylvania.

[ft bls, feet below land surface; gal/min, gallons per minute; >, greater than]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
70	no flow	not determined
82	turbulent	not determined
90	0.70	down
100	>1.1	down
116	1.1	down
122	.90	down
138	no flow	not determined

BE-1676 (TT29-D)

Borehole BE-1676 was drilled into Precambrian gneiss (table 44). The geologist log notes the regolith is about 69 ft thick, consisting of clay, silt, sand, and very weathered gneiss. The geologist noted hornblende at 166–187 and 213–347 ft bls in the gneiss. The geologist log also notes possible producing zones at 79, 85, 125, 145, 197, 207, 277, and 332 ft bls with a soft zone at 151 ft bls and the bottom of casing. The static water level at the time of logging was 8.77 ft bls. The caliper log shows the total depth of the borehole is 357 ft, and it is cased with 10-in.-diameter casing to 169 ft bls (fig. 40). The caliper log shows large fractures at 205–206 and 208–211 ft bls plus numerous small fractures throughout the open-hole interval. On the basis of the geologist log, some of the variation in the counts on the natural-gamma log are probably related to increases in the amount of hornblende. Deflections in the single-point-resistance log at 190, 197, 210, 226, 278, 286, and 320 ft bls correlate well to fractures shown on the caliper log and described in the geologist log. The deflection in slope at 345 ft bls may be related to a lithologic contact. The fluid-temperature log shows little variation throughout most of the borehole, indicating the presence of some vertical flow. Beginning at a depth of about 328 ft bls, however, there is a slight, but continuous rise in temperature. This temperature rise suggests no borehole flow below 328 ft bls. Acoustic televiewer data was not collected because the 10-in.-diameter borehole was too large.

Table 44. Geologist log for borehole BE-1676 (TT29-D), Dec. 9, 2002-Jan. 9, 2003, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–52	**OVERBURDEN**, clay, silt, sand; damp to moist
53–69	**SAPROLITE**, silt and very weathered gneiss; wet
70–166	**GNEISS**, very weathered
	Producing about 10 gal/min by 70 ft bls
	Producing zone at 79 ft bls
	Producing zone at 85 ft bls
	Producing 20–30 gal/min by 86 ft bls
	Producing 20–25 gal/min by 100 ft bls
	Producing zone at 125 ft bls
	Producing 30–40 gal/min by 126 ft bls
	Possible water-producing zone at 145 ft bls
	Soft at 151 ft bls
	Producing about 40 gal/min by 155 ft bls
	Bottom of casing set at 169 ft bls
167–187	**GNEISS**, hornblende; dry
188–213	**GNEISS**
	Possible water-producing zone at 197 ft bls
	Possible water-producing zone at 207 ft bls
214–347	**GNEISS**, hornblende, alternating in amount; dry
	Producing zone at 277 ft bls
	Producing 1–2 gal/min by 278 ft bls
	Possible water-producing zone at 332 ft bls
348–355	**GNEISS**
	Producing about 3 gal/min by 355 ft bls

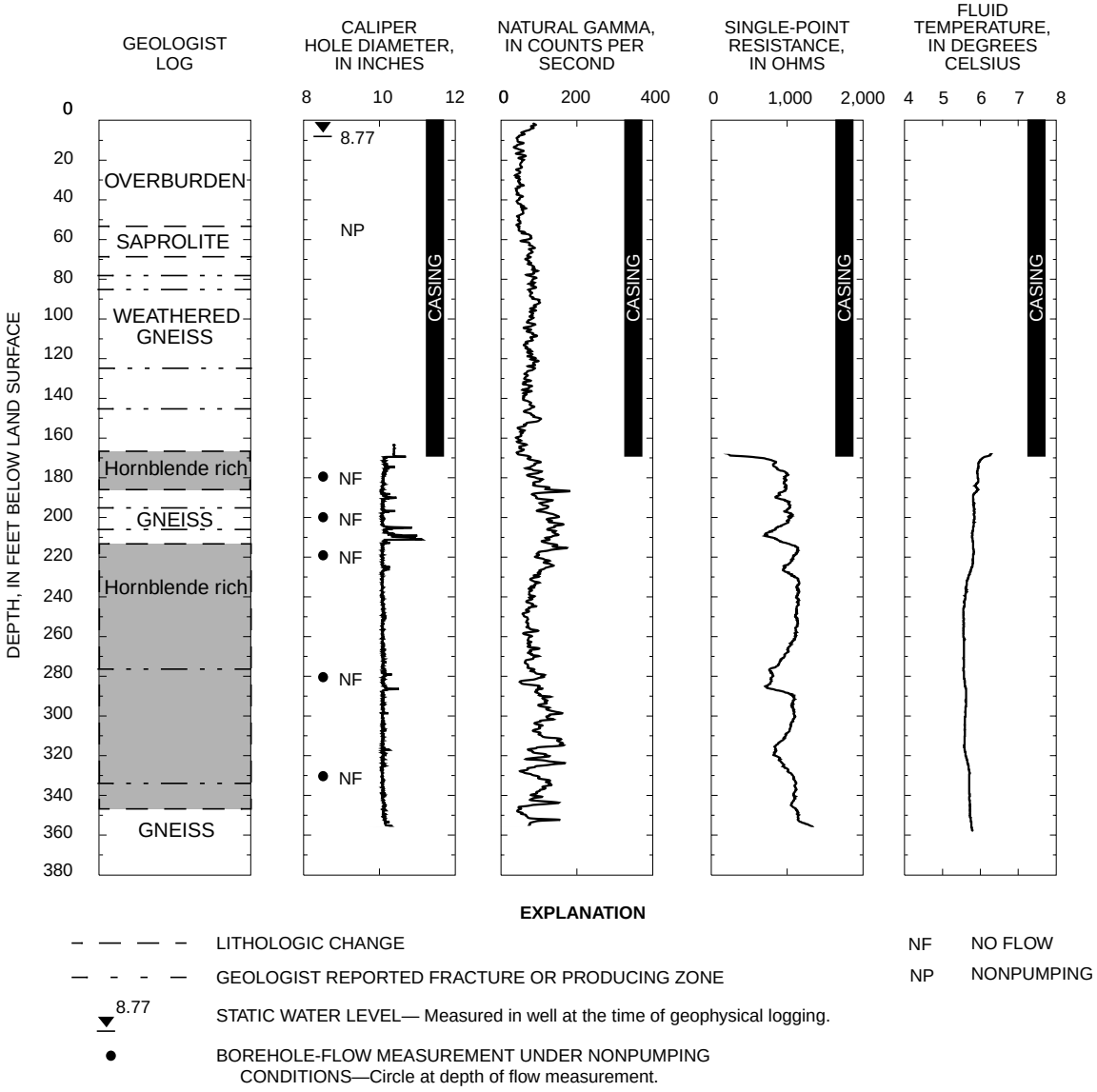


Figure 40. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1676 (TT29-D), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected December 9, 2002, through January 9, 2003. Borehole geophysical logs collected on January 21, 2003.)

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 180, 200, 220, 280, and 330 ft bls (table 45). This borehole will be used to extract contaminated ground water and will remain an open hole from 169 to 357 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 45. Summary of heatpulse-flowmeter measurements for borehole BE-1676 (TT29-D), Jan. 21, 2003, Crossley Farm Superfund Site, Hereford Township, 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
180	no flow	not determined
200	no flow	not determined
220	no flow	not determined
280	no flow	not determined
330	no flow	not determined

BE-1677 (TT30-D)

Borehole BE-1677 was drilled into Precambrian gneiss (table 46). The geologist log notes the regolith is about 75 ft thick, consisting of clay, silt, sand, gravel, and rock fragments. Hornblende was identified at 76–158, 174–221, 259–290, 376–398, and 404–408 ft bls in the gneiss. The geologist log also notes possible producing zones at 100, 105, 197, 325, 359, and 394 ft bls and the bottom of casing. The static water level at the time of logging was 25.63 ft bls. The caliper log shows the total depth of the borehole is 419 ft, and it is cased with 10-in.-diameter casing to 157 ft bls (fig. 41). The caliper log shows large fractures at 172, 195, 225, 254–262, and 320 ft bls plus numerous smaller fractures throughout the open-hole interval. Fractures at 172, 225, 254–262, and 378 ft bls occur at or near changes in lithology described on the geologist log. The decrease in counts on the natural-gamma log from about 250–280 ft bls is probably related to an increase in the amount of hornblende in the gneiss. Deflections in the single-point-resistance log correlate well to fractures shown on the caliper log. The deflections at 195, 225, 250–264, and 400 ft bls are considerable, suggesting possible water-producing zones, water-receiving zones, or the effect of lithologic changes. The temperature log shows marked changes in slope at 250 and at 400 ft bls that suggest the presence of water-producing or water-receiving zones. The increase in temperature from 250 ft bls to about 400 ft bls suggests the absence of borehole flow. Acoustic televiewer data were not collected because the 10-in.-diameter borehole was too large.

Table 46. Geologist log for borehole BE-1677 (TT30-D), Dec. 16, 2002-Jan. 15, 2003, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania (Tetra Tech NUS, Inc., written commun., 2003).

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

Depth (ft bls)	Comment
0–65	**OVERBURDEN**, clay, silt, sand, some gravel and rock fragments; damp to moist
66–75	**SAPROLITE**, silty sand and rock fragments; damp
76–158	**GNEISS**, hornblende, weathered
	Producing zone at 100 ft bls
	Producing about 5 gal/min at 102 ft bls
	Producing zone at 105 ft bls
	Producing 10–15 gal/min by 105 ft bls
	Harder at 132 ft bls
	Bottom of casing set at 157 ft bls
159–173	**GNEISS**, very hard; dry
174–221	**GNEISS**, hornblende, alternating in amount
	Possible water-producing zone at 197 ft bls
222–258	**GNEISS**
259–290	**GNEISS**, hornblende
291–375	**GNEISS**
	Possible producing zone at 325 ft bls
	Producing zone at 359 ft bls
376–398	**GNEISS**, hornblende
	Producing less than 1 gal/min by 388 ft bls
	Producing zone at 394 ft bls
	Producing about 1 gal/min by 398 ft bls
399–403	**GNEISS**
	Producing about 1 gal/min by 398 ft bls
404–408	**GNEISS**, hornblende
409–418	**GNEISS**
	Producing about 2 gal/min by 418 ft bls

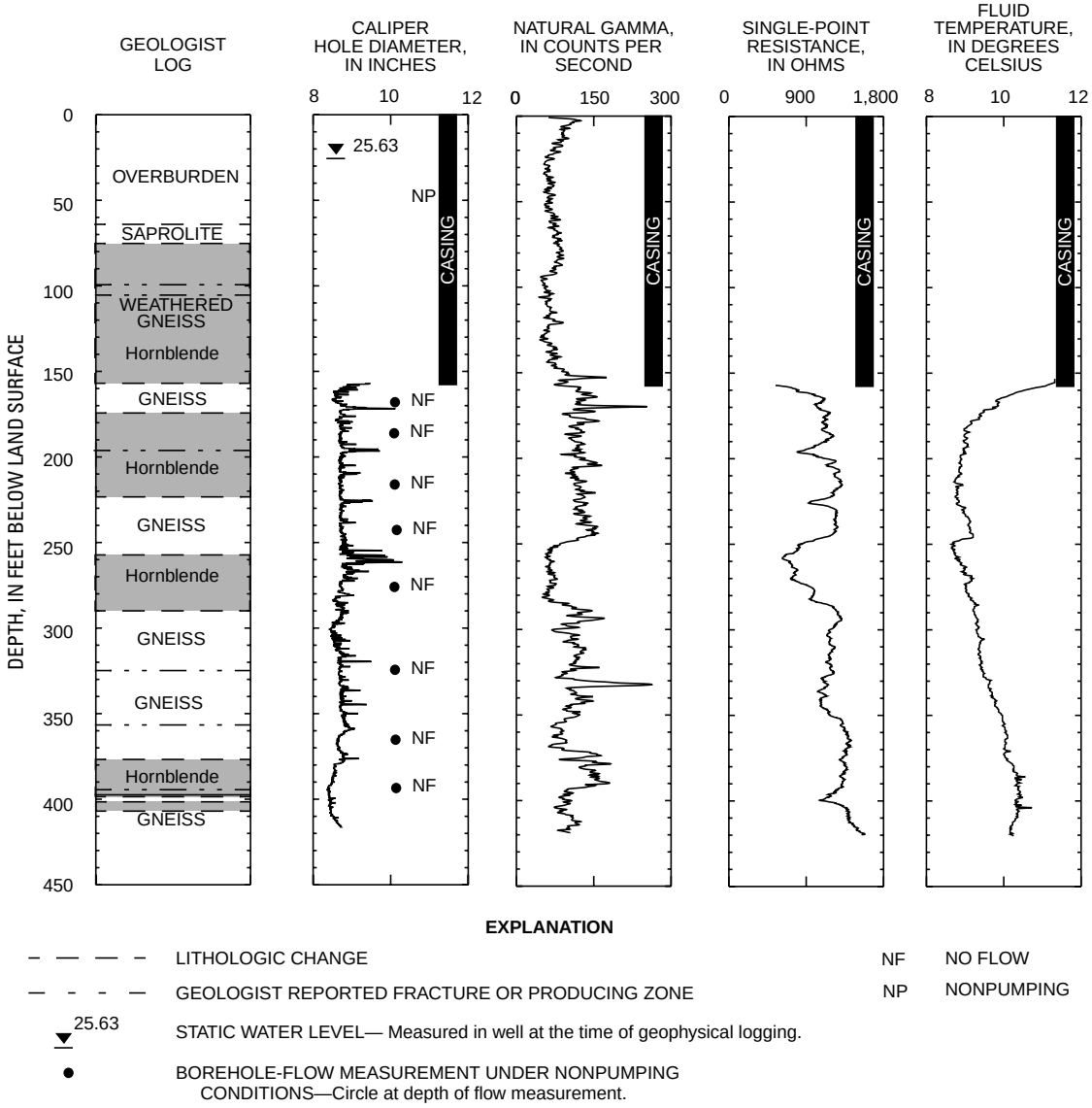


Figure 41. Geologist log, borehole geophysical logs, and direction of flow within borehole BE-1677 (TT30-D), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Geologist log collected from December 16, 2002, through January 15, 2003. Borehole geophysical logs collected on January 27, 2003. Heatpulse-flowmeter log collected May 12, 2003.)

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 166, 188, 216, 242, 276, 324, 366, and 394 ft bls (table 47). This borehole will be used to extract contaminated ground water and will remain an open hole from 157 to 419 ft bls (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

Table 47. Summary of heatpulse-flowmeter measurements for borehole BE-1677 (TT30-D), Jan. 27, 2003, Crossley Farm 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
166	no flow	not determined
188	no flow	not determined
216	no flow	not determined
242	no flow	not determined
276	no flow	not determined
324	no flow	not determined
366	no flow	not determined
394	no flow	not determined

BE-1678 (RI-2)

Borehole BE-1678 was drilled into Precambrian gneiss (fig. 1). The caliper log shows the total depth of the borehole is 137 ft, and it is cased with 10-in.-diameter casing to 37 ft bls (fig. 42). The static water level at the time of logging was 14.03 ft bls. The caliper log shows large fractures at 38–40, 43–44, 52, 58–60, 65–66, 71–73, 76–78, 83, and 134–135 ft bls plus numerous smaller fractures throughout the open-hole interval. This borehole will be used to inject treated ground water from the on-site extraction wells and was screened from 62 to 137 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

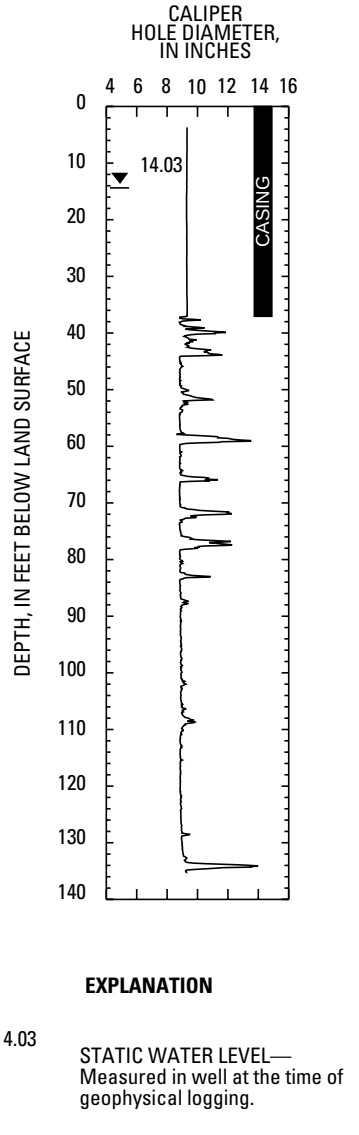


Figure 42. Borehole geophysical log within borehole BE-1678 (RI-2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on February 5, 2004.)

BE-1679 (RI-3)

Borehole BE-1679 was drilled into Precambrian gneiss (fig. 1). The caliper log shows the total depth of the borehole is 168 ft, and it is cased with 10-in.-diameter casing to 41.5 ft bls (fig. 43). The static water level at the time of logging was 7.39 ft bls. The caliper log shows large fractures at 42–44, 52, 58–62, 68–78, 110–112, 117, 120–122, 124, 128–129, and 146–147 ft bls plus numerous smaller fractures throughout the open borehole. The unusual square shape of the large fractures at 58–62 and 68–76 ft bls is the result of their width (distance the fracture extends from the borehole and into the bedrock) exceeding the length of the arms on the caliper log. When this occurs, the arms of the caliper log flex into a horizontal position that results in a vertical line on the caliper log. This pattern will continue until the arms once again contact the borehole wall. This borehole will be used to inject treated ground water from the on-site extraction wells and was screened from 90 to 160 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

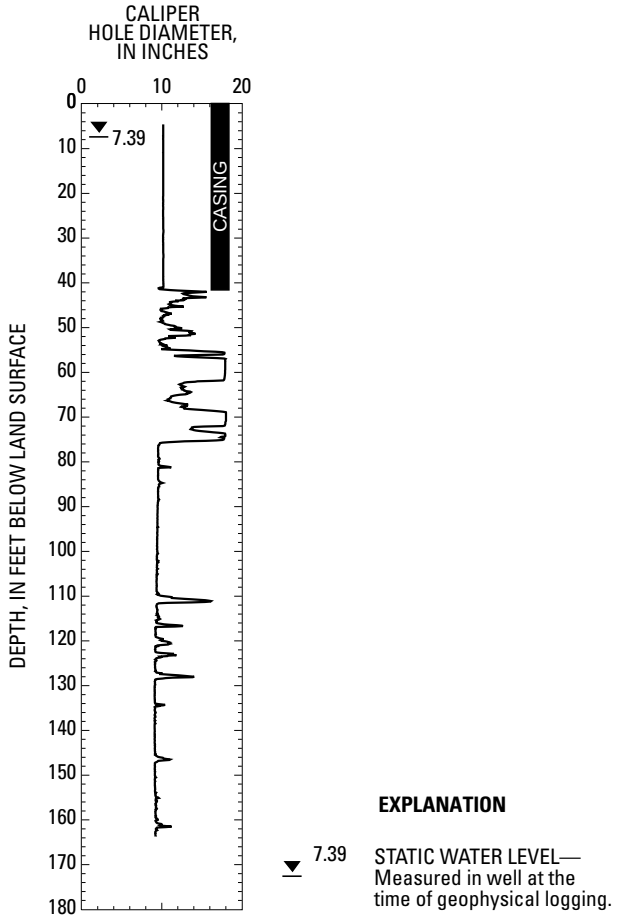


Figure 43. Borehole geophysical within borehole BE-1679 (RI-3), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on February 10, 2004.)

BE-1680 (RI-4)

Borehole BE-1680 was drilled into Precambrian gneiss (fig. 1). The caliper log shows the total depth of the borehole is 156.5 ft, and it is cased with 10-in.-diameter casing to 54 ft bls (fig. 44). The static water level at the time of logging was 7.30 ft bls. The caliper log shows large fractures at 54–59 and 64–70 ft bls that exceed the length of the arms on the caliper. Additional large fractures occur at 79–82, 93–94, and 97–99 ft bls plus smaller fractures throughout the open-hole interval. This borehole will be used to inject treated ground water from the on-site extraction wells and was screened from 78 to 153 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

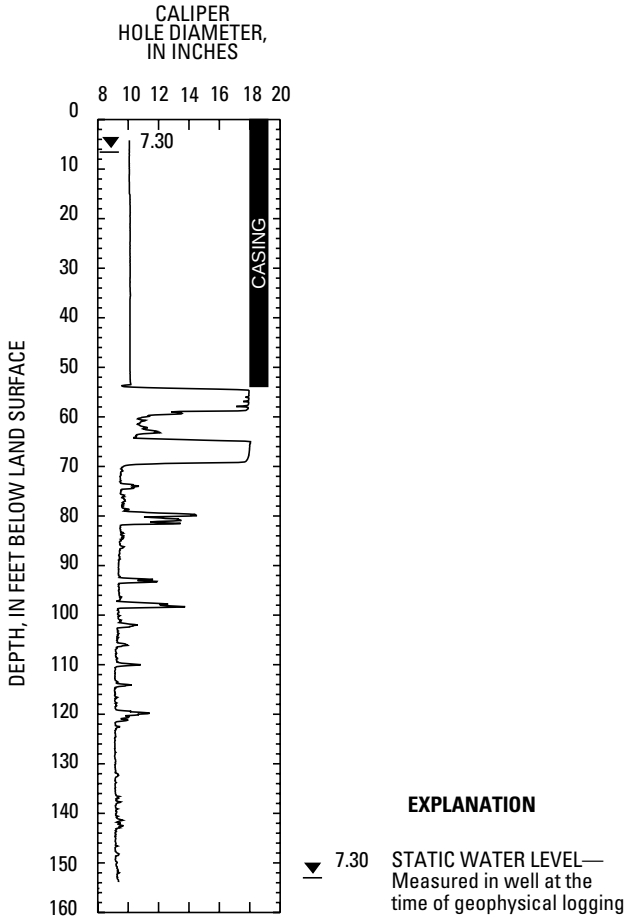


Figure 44. Borehole geophysical log for borehole BE-1680 (RI-4), Crossley Farm Superfund Site. Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on February 13, 2004.)

BE-1681 (P-1)

Borehole BE-1681 was drilled into Precambrian gneiss (fig. 1) The caliper log shows the total depth of the borehole is 160 ft, and it is cased with 6-in.-diameter casing to 58 ft bls (fig. 45). The static water level at the time of logging was 9.54 ft bls. The caliper log shows large fractures at 108, 115, and 119–121 ft bls plus smaller fractures throughout the open-hole interval. The caliper log also shows a narrowing of the borehole at 72 and 75 ft bls. This borehole may be used to extract contaminated ground water and was screened from 105 to 155 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

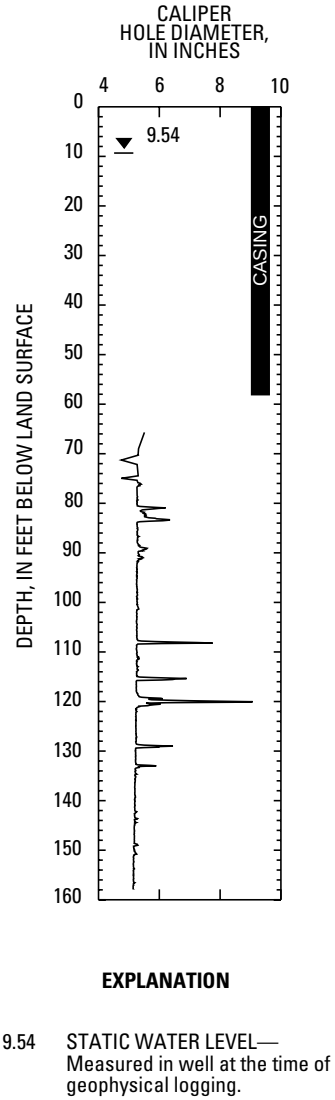


Figure 45. Borehole geophysical log for borehole BE-1681(P-1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on February 24, 2004.)

BE-1682 (P-2)

Borehole BE-1682 was drilled into Precambrian gneiss (fig. 1). The caliper log shows the total depth of the borehole is 135.6 ft, and it is cased with 6-in.-diameter casing to 58 ft bls (fig. 46). The static water level at the time of logging was 9.00 ft bls. The caliper log shows large fractures at 59–60, 65–68 and 72–74 ft bls plus smaller fractures throughout the open-hole interval. This borehole will be used to extract contaminated ground water and was screened from 82 to 127 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

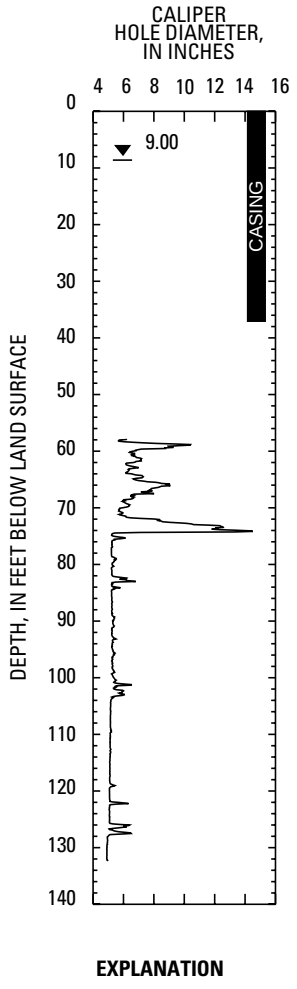


Figure 46. Borehole geophysical log for BE-1682 (P-2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on February 26, 2004.)

BE-1683 (P-3)

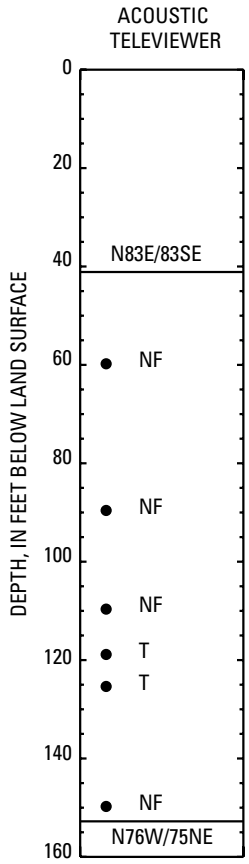
Borehole BE-1683 was drilled into Precambrian gneiss (fig. 1). The static water level at the time of logging was 24.14 ft bls. The diameter of the surface steel casing was measured at 6 in. The acoustic-televiewer log shows the depth of the borehole is 162 ft, with the steel casing set at a depth of 39 ft bls (fig. 47). The acoustic-televiewer log shows a large high-angle fracture at 42 ft bls that strikes N. 83° E. and dips 83° SE., and a fracture at 155 ft bls that strikes N. 76° W. and dips 75° NE.

Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 60, 90, 110, and 150 ft bls (table 48). Turbulent flow was identified at 119 and 126 ft bls. This borehole may be used to extract contaminated ground water and was screened from 35 to 50 ft bls (Donald Whalen, Tetra Tech NUS, Inc., written commun., 2004).

Table 48. Summary of heatpulse-flowmeter measurements for borehole BE-1683 (P-3), Apr. 3, 2004, Crossley Farm Superfund Site, Hereford Township, 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
60	no flow	not determined
90	no flow	not determined
110	no flow	not determined
119	turbulent	not determined
126	turbulent	not determined
150	no flow	not determined



EXPLANATION

N83E/83SE	FRACTURE—Showing strike and dip in degrees.
●	BOREHOLE-FLOW MEASUREMENT UNDER NONPUMPING CONDITIONS—Circle at depth of flow measurement.
NF	NO FLOW
T	TURBULENT

Figure 47. Borehole acoustic televiewer for BE-1683 (P-3), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania. (Borehole geophysical log collected on April 3, 2004.)

Aquifer-Isolation Tests

Water enters open-borehole wells through discrete openings, zones, or fractures. In the unweathered to moderately weathered gneiss, ground-water flow and contaminant movement is through secondary openings that consist of one or more fractures. The fractures commonly occur at or near lithologic contacts between hornblende-rich and hornblende-poor (feldspar-rich) gneiss. Water-producing zones or fractures also have been identified at faults, soft zones, and within nondescript parts of the gneiss. By isolating these discrete zones and fractures with inflatable packers, hydraulic properties and chemical characteristics of individual zones and the extent of vertical hydraulic connection between zones can be determined. This determination provides data on the vertical distribution of hydraulic properties and ground-water contamination. Two boreholes were selected for aquifer-isolation tests on the basis that they were downgradient from the drum disposal area, adjacent to a large fault, and produced higher concentrations of contamination than the other boreholes.

The USGS performed single-well, aquifer-interval-isolation (packer) tests on boreholes BE-1665 and BE-1666. The objectives of the packer tests were to (1) provide information on hydraulic heads and specific capacities of discrete vertical intervals and the hydraulic connection between intervals, and (2) provide water samples from discrete water-producing zones to allow the USEPA to characterize the vertical extent of contamination in each well.

Borehole BE-1665 (TT26-D1)

On the basis of geophysical logs and heatpulse-flowmeter data, four intervals that contained either water-producing or water-receiving zones were selected for an aquifer-isolation test in borehole BE-1665. Packers were set at depths from 222 to 260 ft bls. Results of the tests are summarized in table 49. Details about the testing of each isolated interval are described in the following section.

Table 49. Intervals isolated and specific capacities for borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval	Isolated depth interval (feet below land surface)	Total water pumped (gallons)	Specific capacity (gallon per minute per foot)
1	158–222	254	0.34
2	210–235	133	.21
3	235–260	118	.04
4	260–302	102	.02

Interval 1 (158–222 feet below land surface)

Isolated interval 1 was 158–222 ft bls. To isolate this interval, the center of the top packer was placed at 222 ft bls and the packer was inflated; the bottom packer was not inflated (table 50). The static water level in the open borehole prior to inflation was 24.88 ft bls. Approximately 62 minutes after the top packer was inflated, the water level was 24.91 ft bls in the upper interval and 24.06 ft bls in the lower interval (fig. 48). This result was consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the lower interval had a higher head (upward flow) than the water-bearing fractures above.

The upper interval was pumped at 3 gal/min for 83 minutes (table 50). Drawdown in the upper interval was 8.81 ft, and drawdown in the lower interval was 3.89 ft. The large drawdown in the isolated interval indicated good hydraulic connection between the upper and lower interval. The specific capacity for the upper interval was 0.34 (gal/min)/ft.

Table 50. Activity and pumping rates for aquifer-isolation test of interval 1 (222–302 feet below land surface) in borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Time (minutes)	Action
74	Inflate top packer
136	Pump on, at 3 gal/min
211	Sampled water from isolated interval
218	Pump off
255	Deflated bottom packer

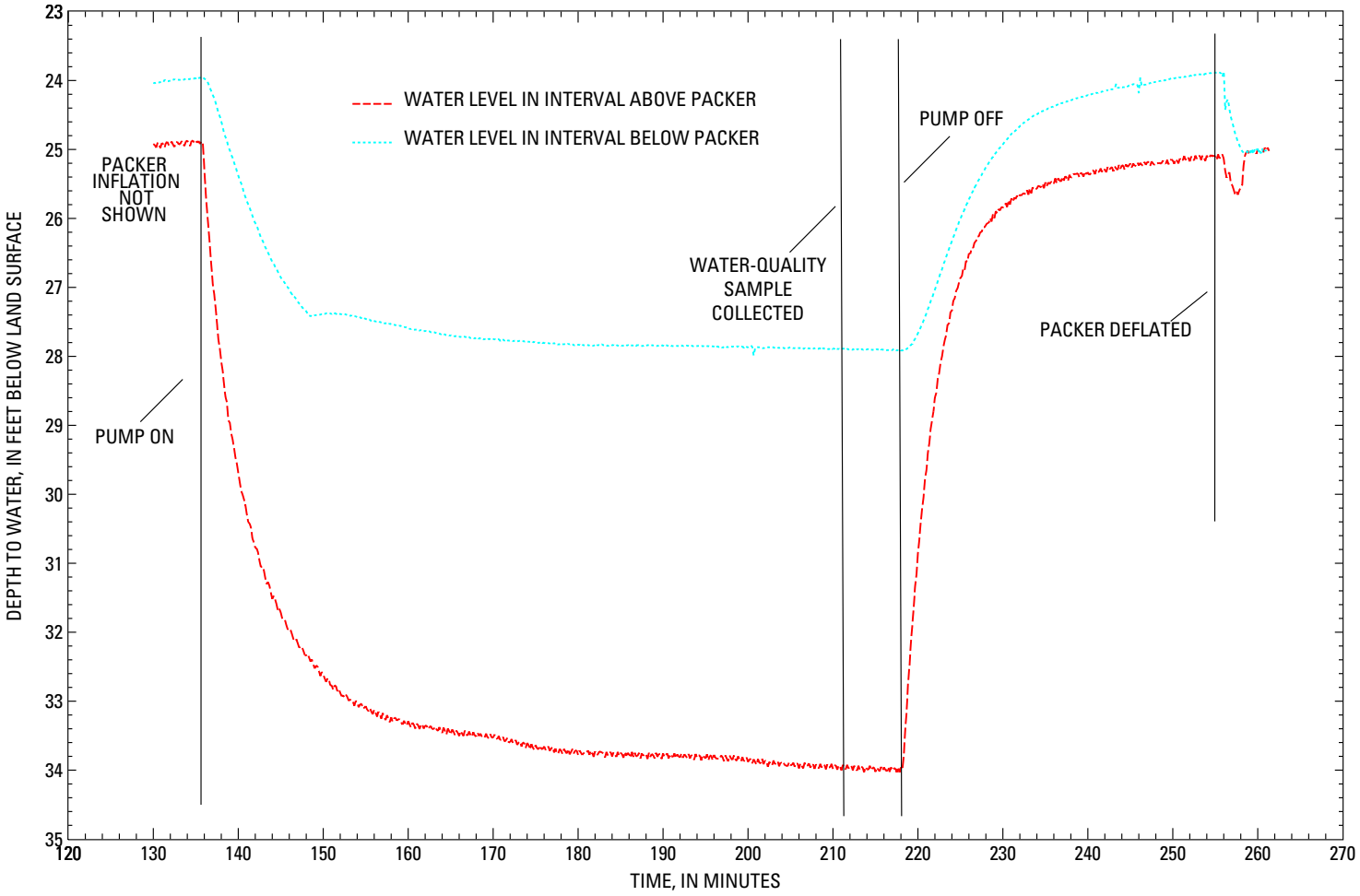


Figure 48. Hydrograph from aquifer-isolation test of interval 1 (158-222 feet below land surface) in borehole BE-1665 (TT26-D1), Crossly Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval 2 (210–235 feet below land surface)

Isolated interval 2 was 210–235 ft bls. To isolate this interval, the center of the top packer was placed at 210 ft bls and the packer was inflated; the center of the lower packer was placed at 235 ft bls and the packer was inflated (fig. 49). The static water level in the open borehole prior to inflation was 24.70 ft bls. Both upper and lower packers were left inflated overnight. Prior to pumping, the water level was 24.68 ft bls in the upper interval, 24.53 ft bls in the isolated interval, and 23.85 ft bls in the lower interval. This result was consistent with the interpretation of the borehole geophysical logs and heat-pulse-flowmeter measurements, which indicated the lower interval had a higher head (upward flow) than the water-bearing fractures above it.

The isolated interval was pumped at 3 gal/min for 34 minutes (table 51). Drawdown in the isolated interval was 14.60 ft, drawdown in the upper interval was 6.54 ft, and drawdown in the lower interval was 9.68 ft bls. Figure 49 shows good hydraulic connection between all three intervals, especially between the isolated and lower interval. The specific capacity for interval 210–235 was 0.21 (gal/min)/ft.,

Table 51. Activity and pumping rates for aquifer-isolation test of interval 2 (210–235 feet below land surface) in borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Time (minutes)	Action
	October 9, 2002
7	Bottom packer inflated
10	Top packer inflated
23	Stopped work for day
	October 10, 2002
972	Begin work, packer inflations good
995	Pump on, at 3 gal/min
1031	Sampled water from isolated interval
1039	Pump off
1074	Packers deflated

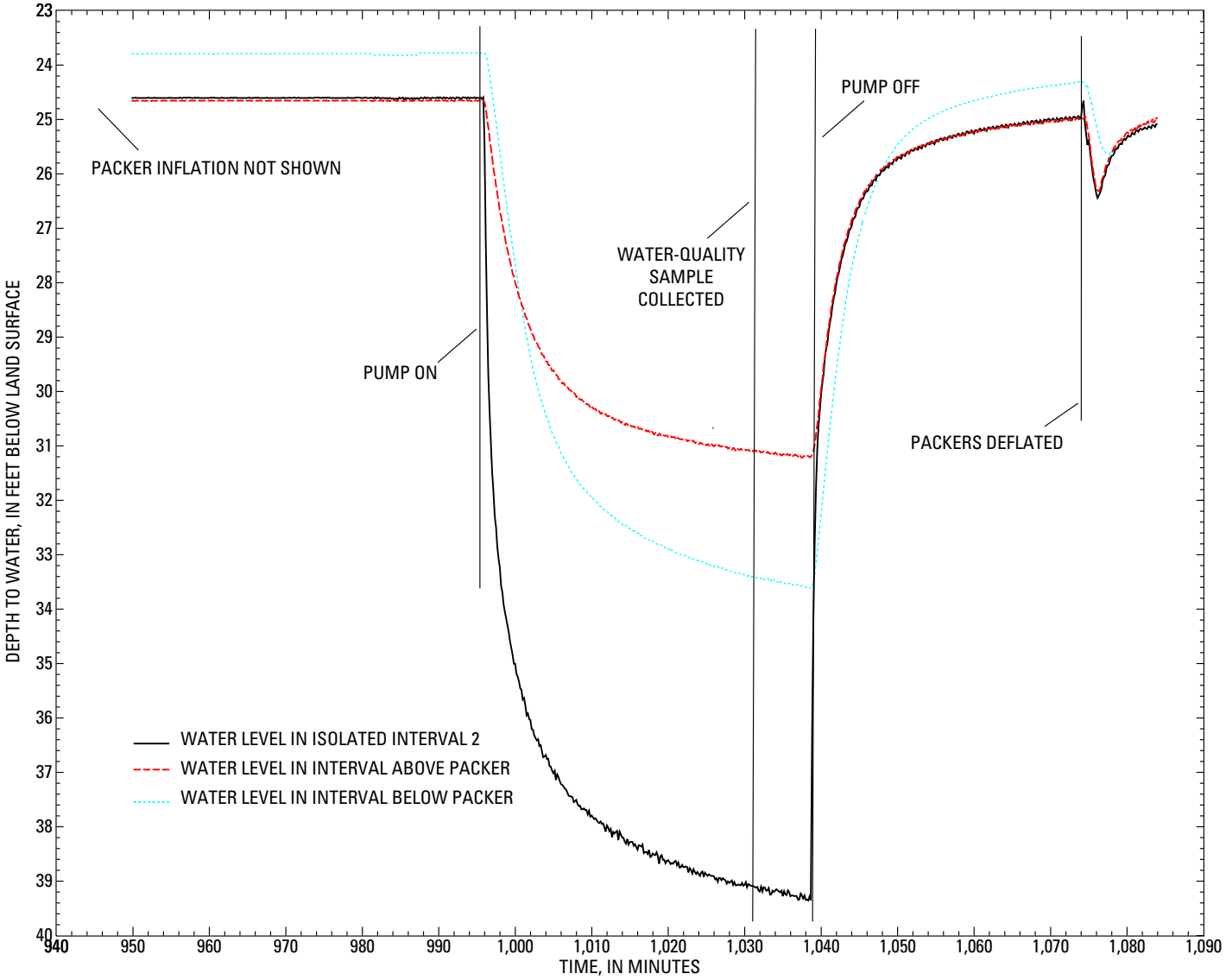


Figure 49. Aquifer-isolation test of interval 2 (210-235 feet below land surface) in borehole BE-1665 (TT26-D1),Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval 3 (235–260 feet below land surface)

Isolated interval 3 was 235–260 ft bls. To isolate this interval, the center of the top packer was placed at 235 ft bls and the packer was inflated; the center of the lower packer was placed at 260 ft bls and the packer was inflated. The static water level in the open borehole prior to inflation was 24.70 ft bls. Approximately 36 minutes after inflation, the water level was 24.47 ft bls in the isolated interval, 24.70 ft bls in the upper interval, and 24.55 ft bls in the lower interval (fig. 50). This was consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated interval had a higher head (upward flow) than the water-bearing fractures above it.

The pumping rate was adjusted periodically to compensate for rapid drawdown to an average of 1.9 gal/min for 78 minutes (table 52). Drawdown in the isolated interval was 57.38 ft, drawdown in the lower interval was 45.59 ft, and the drawdown in the upper interval was 2.32 ft. This indicated excellent hydraulic connection between the isolated and lower intervals, with little to no connection between the isolated and upper intervals (fig. 50). The specific capacity for interval 235–260 was 0.04 (gal/min)/ft

Table 52. Activity and pumping rates for aquifer-isolation test of interval 3 (235–260 feet below land surface) in borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Time (minutes)	Action
10	Inflate bottom packer
18	Inflate top packer
42	Pump on, at average of 1.9 gal/min
114	Sampled water from isolated interval
120	Pump off
163	Top and bottom packers deflated

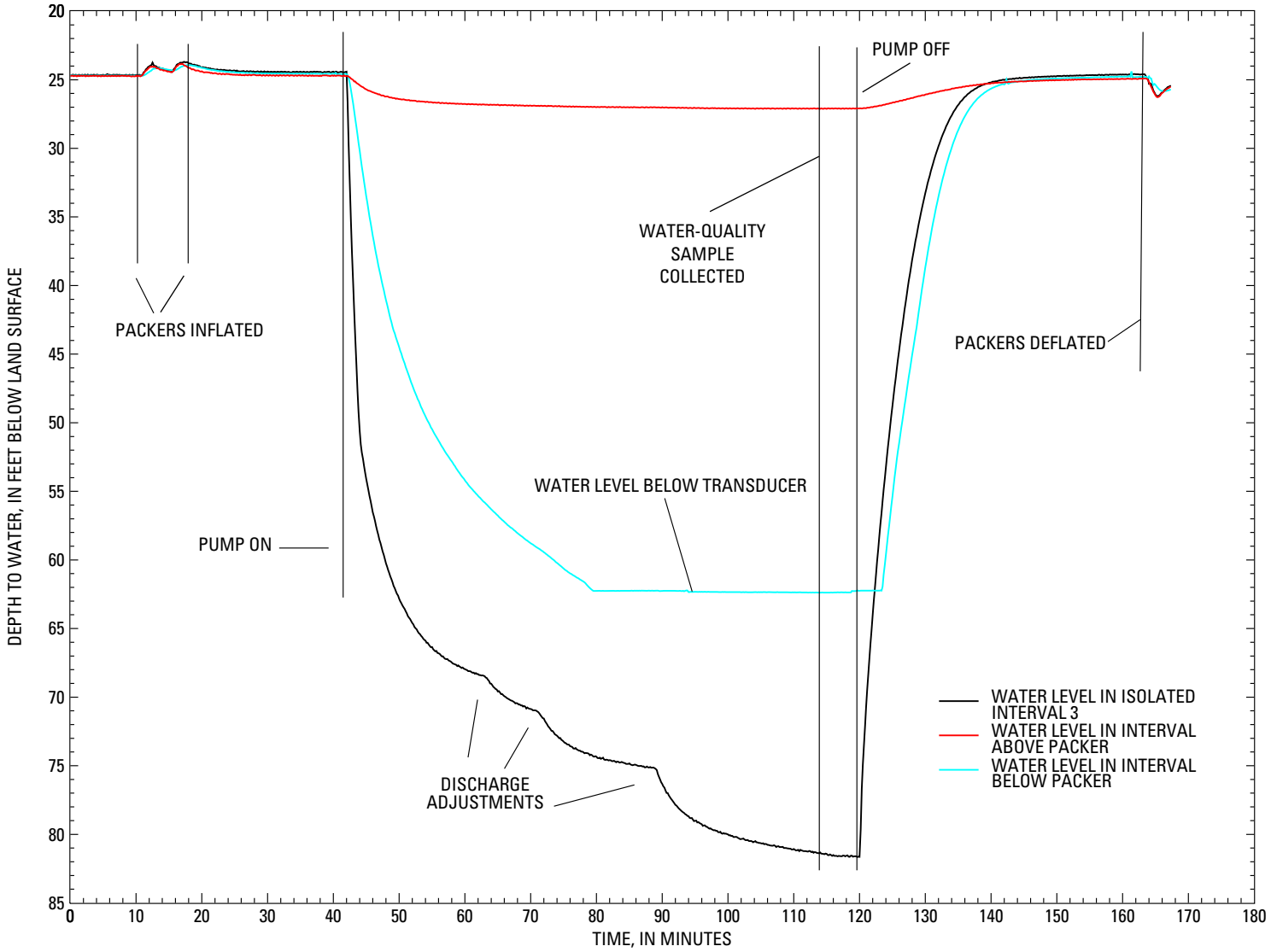


Figure 50. Aquifer-isolation test of interval 3 (235-260 feet below land surface) in borehole BE-1665 (TT26-D1),Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval 4 (260–302 feet below land surface)

Isolated interval 4 was 260–302 ft bls. To isolate this interval, the center of the top packer was placed at 260 ft bls and the packer was inflated; the lower packer was not inflated. The static water level in the open borehole prior to inflation was 24.70 ft bls. Approximately 25 minutes after inflation, the water level was 24.65 ft bls in the isolated interval and 24.73 ft bls in the upper interval (fig. 51). This result was consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated interval had a higher head (upward flow) than the water-bearing fractures above it.

The pumping rate varied because of rapid drawdown but averaged 1.5 gal/min over the pumping interval of 42 minutes (table 53). Total drawdown in the isolated interval was 84.13 ft, and drawdown in the upper interval was 3.32 ft. This indicated small hydraulic connection between the upper and lower intervals. The specific capacity for interval 260–302 ft bls was 0.02 (gal/min)/ft.

Table 53. Activity and pumping rates for aquifer-isolation test of interval 4 (260–302 feet below land surface) in borehole BE-1665 (TT26-D1), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[gal/min, gallons per minute]

Time (minutes)	Action
11	Inflate top packer
26	Pump on at 0.9 gal/min
44	Increase pumping to 2.0 gal/min
86	Pump off
121	Sampled water from isolated interval
128	Top packer deflated

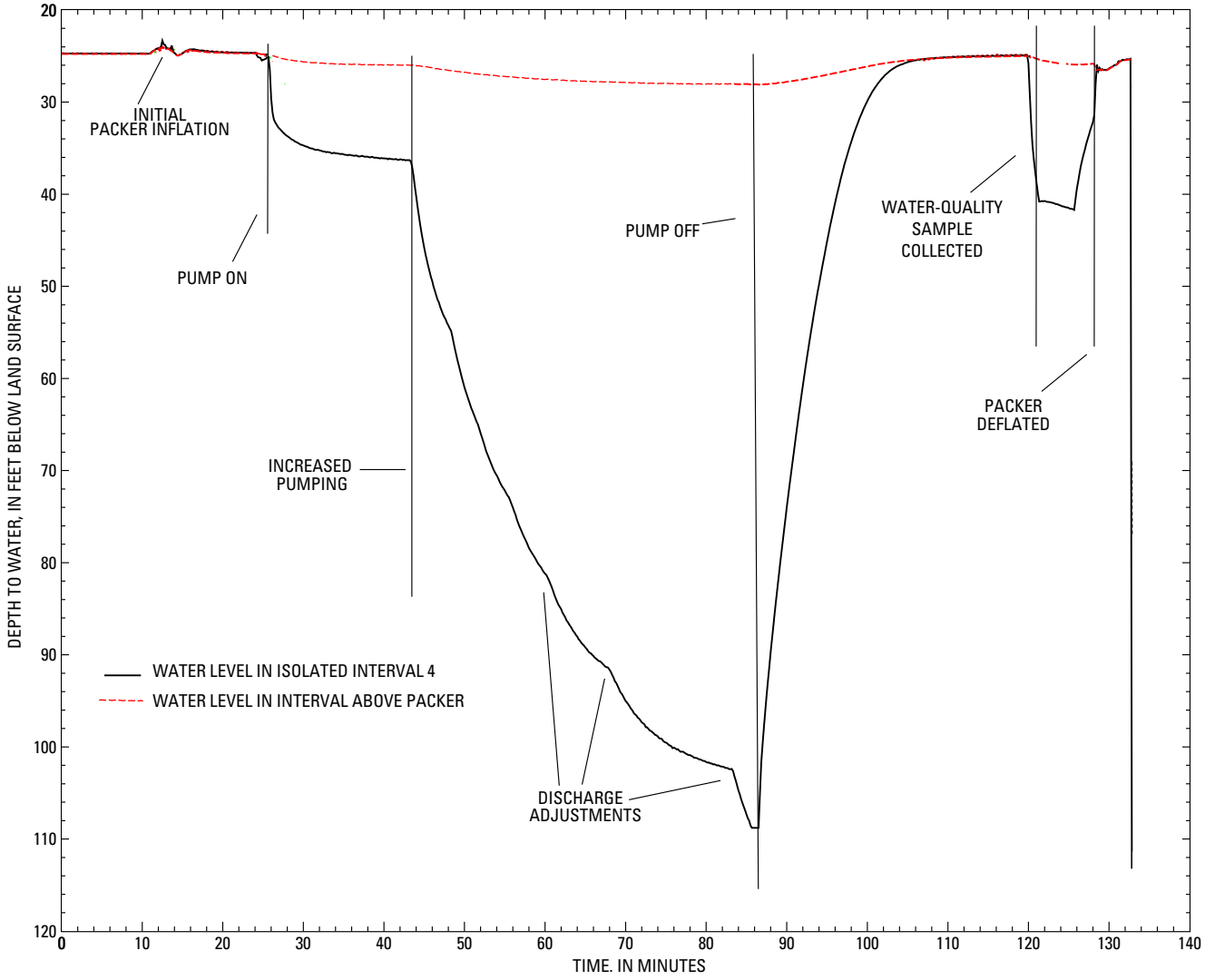


Figure 51. Aquifer-isolation test of interval 4 (260-302 feet below land surface) in borehole BE-1665 (TT26-D1),Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Borehole BE-1666 (TT26-D2)

Two zones were isolated for testing in borehole BE-1666 to determine contaminant concentration at depth. Packers were set at depths from 400 to 476 ft bls. Results of the tests are summarized in table 54. Details about the testing of each isolated interval are described in the following section.

Table 54. Intervals isolated and specific capacities for borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval	Isolated depth interval (feet below land surface)	Total water pumped (gallons)	Specific capacity (gallon per minute per foot)
1	400–425	60	0.03–.07
2	440–476	78	.03–.08

Interval 1 (400–425 feet below land surface)

Isolated interval 1 was 400–425 ft bls. To isolate this interval, the center of the top packer was placed at 400 ft bls and the packer was inflated; the lower packer was set at 425 ft bls and the packer was inflated. The static water level in the open borehole prior to inflation was 21.74 ft bls. Approximately 21 minutes after the packers were inflated, the water level was 21.84 ft bls in the upper interval, 22.65 ft bls in the isolated interval, and 21.74 ft bls in the lower interval. This indicates the lower interval has greater hydraulic head (upward flow) than the isolated and upper intervals and was inconsistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated no vertical borehole flow.

The pumping rate was approximately 0.6 gal/min for 28 minutes (table 55). Drawdown in the upper interval was 6.13 ft, drawdown in the isolated interval was 16.02 ft, and drawdown in the lower interval was 9.85 ft. For step 2, packer-inflation pressure was increased in both packers to insure a better seal, and the pumping rate was increased to 2.7 gal/min for 16 minutes. Drawdown in the isolated interval was estimated to be 87.56 ft, drawdown in the upper interval was 8.60 ft, and drawdown in the lower interval was 39.24 ft (fig. 52). Total drawdown (water level of intervals once packers inflated) in the isolated interval was estimated to be 103.58 ft bls; for the lower interval, total drawdown was 49.09 ft bls, and for the upper interval, total drawdown was 14.73 ft bls. The packer tests indicated limited hydraulic connection between the upper interval and the isolated interval, and good hydraulic connection between the isolated interval and the lower interval. The specific capacity for interval 400–425 ft bls was 0.07 (gal/min)/ft in step 1 and 0.03 (gal/min)/ft in step 2. ,

Table 55. Activity and pumping rates for aquifer-isolation test of interval 1 (400–425 feet below land surface) in borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Time (minutes)	Action
10	Inflate top packer
22	Inflate bottom packer
43	Pump on, Step 1 at 0.6 gal/min
71	Pump rate increased, Step 2 at 2.7 gal/min
86	Pump off
106	Sampled water from isolated interval
108	Deflated packers

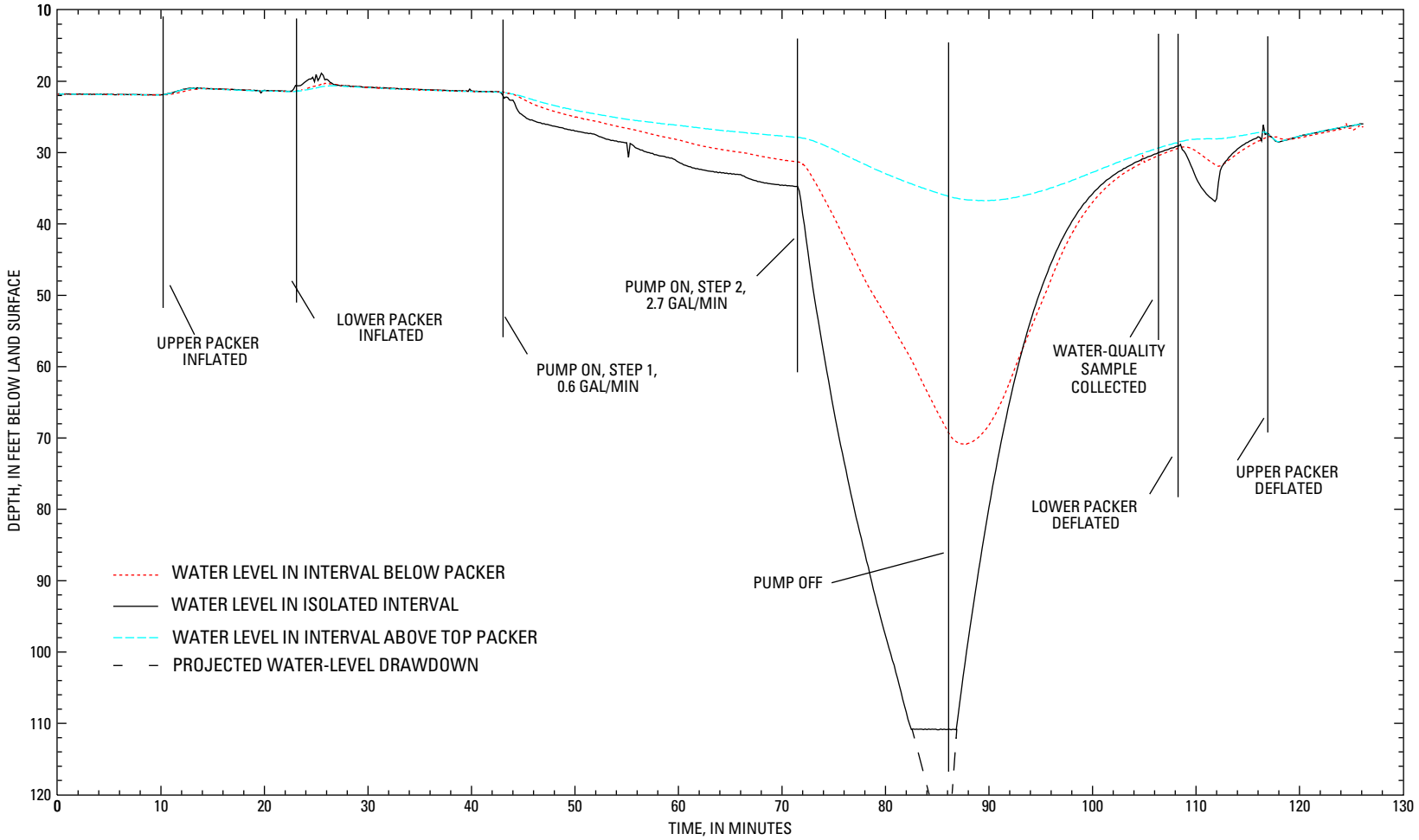


Figure 52. Aquifer-isolation test of interval 1 (400-425 feet below land surface) in borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Interval 2 (440–476 feet below land surface)

Isolated interval for zone 2 was 440–476 ft bls. To isolate this interval, the center of the top packer was placed at 440 ft bls and the packer was inflated; the lower packer was not inflated. The static water level in the open borehole prior to inflation was 22.39 ft bls. Approximately 6 minutes after inflation, the water level was 22.10 ft bls in the upper interval and 22.16 ft bls in the isolated interval. This result indicates the isolated interval has lower hydraulic head (downward flow) and was inconsistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated no vertical borehole flow.

The pumping rate for step 1 was approximately 1 gal/min for 36 minutes (table 56). Drawdown was 12.24 ft in the isolated interval, and 5.08 ft in the upper interval. For step 2, the pumping rate was increased to approximately 3 gal/min for 14 minutes. Total drawdown in the isolated interval was estimated to be 110.62 ft and 7.92 ft in the upper interval. The hydrographs (fig. 53) indicate fair hydraulic connection between the isolated and upper intervals. The specific capacity was 0.06 (gal/min)/ft for step 1 and 0.03 (gal/min)/ft for step 2.

Table 56. Activity and pumping rates for aquifer-isolation test of interval 2 (440–476 feet below land surface) in borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Time (minutes)	Action
9	Inflate top packer
14	Inflate bottom packer
36	Pump on, Step 1 at 1.0 gal/min
66	Pump rate increased, Step 2 at 3.0 gal/min
81	Pump off
97	Pump on for sampling water from isolated interval
102	Pump off
110	Deflated packers

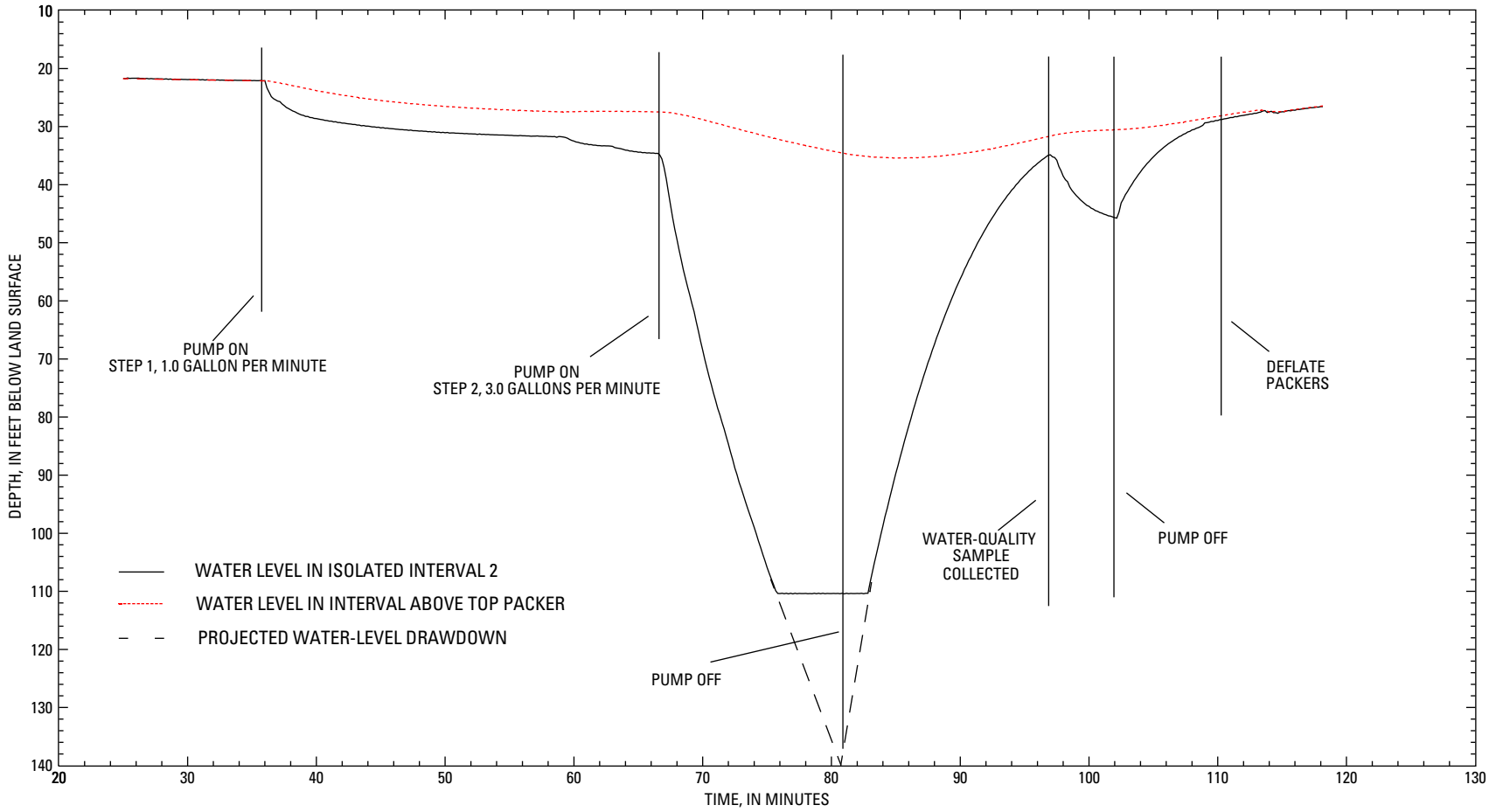


Figure 53. Aquifer-isolation test of interval 2 (440-476 feet below land surface) in borehole BE-1666 (TT26-D2), Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

Water Quality

A water sample was collected at the end of pumping of each packer test. The water sample was collected from the isolated interval and was tested for selected VOCs (table 57) (Kevin Kilmartin, Tetra Tech NUS, Inc., written commun., 2003).

The concentrations of VOCs differed between the isolated intervals of the boreholes and between boreholes (table 57). For well BE-1665, the highest concentrations of PCE, TCE, and trichlorofluoromethane (FC-11) were measured in interval 3 (235–260 ft bls). For well BE-1666, the highest concentrations of PCE and TCE were measured in interval 1 (400–425 ft bls).

Table 57. Concentrations of selected volatile organic compounds in samples collected from isolated intervals at the end of pumping in boreholes BE-1665 and BE-1666, Crossley Farm Superfund Site, Hereford Township, Berks County, Pennsylvania.

[ft bls, feet below land surface; µg/L, micrograms per liter; PCE, tetrachloroethene; FC-11, trichlorofluoromethane; TCE, trichloroethylene; <, less than; >, greater than]

Well and interval sampled	Depth of interval sampled (ft bls)	PCE (µg/L)	TCE (µg/L)	FC-11 (µg/L)
BE-1665 - Interval 1	158–222	3,300	150,000	1,200
BE-1665 - Interval 2	211–235	4,200	180,000	1,900
BE-1665 - Interval 3	235–260	4,700	260,000	2,700
BE-1665 - Interval 4	> 260	4,100	210,000	< 2,000
BE-1666 - Interval 1	400–425	3,200	290,000	2,200
BE-1666 - Interval 2	440–476	2,600	280,000	2,400

Summary and Conclusions

Borehole geophysical logs were run in 23 boreholes and aquifer-isolation tests were conducted in 2 boreholes completed in Precambrian gneiss at the Crossley Farm Superfund Site, Hereford Township, Berks County, Pa., from August 2002 to March 2004. Boreholes ranged in depth from 71 to 503 ft. Geologist logs were available for 17 boreholes. Geologist logs noted the thickness of the regolith, lithologic changes, casing depth, water-producing zones, and soft zones. Geologist logs also noted that the saprolite and weathered bedrock or regolith contained most of the water-producing zones. In some boreholes, driller-reported yields exceeded 30 gal/min, but once casing was set the reported yield of the open borehole declined dramatically; in some boreholes, the decline was by an order of magnitude.

Caliper logs were collected in 22 wells. The caliper logs provided information on the depth of casing, fractures, potential water-producing and water-receiving zones, and appropriate intervals to set the bladders for packer tests. Natural-gamma logs were collected in 17 wells and provided supplemental information on the depth of casing and changes in lithology. Single-point-resistance logs were collected in 17 wells and provided information on lithologic changes, as well as possible water-producing and water-receiving zones. Temperature logs were collected in 17 wells and provided information on the depth to potential water-producing and water-receiving zones and possible vertical flow in the borehole. Heatpulse-flowmeter logs provided information on the direction and rate of vertical flow within the borehole in 18 wells as well as the presence of turbulent flow. Under ambient conditions, the heatpulse flowmeter identified seven boreholes that exhibited upward vertical flow ranging in depth from 55–493 ft bls. The heatpulse flowmeter measured downward vertical flow in three boreholes under nonpumping conditions at depths ranging from 43–210 ft bls. Measurable flow rates ranged from 0.06 gal/min in BE-1665 to greater than 1.1 gal/min in BE-1675. The heatpulse flowmeter was not able to quantify vertical flow in seven boreholes. Acoustic logs provided information on depth to casing and the orientation of fractures in 13 boreholes. Of the 36 water-producing or water-receiving zones identified by borehole geophysical logs or the heatpulse-flowmeter log under nonpumping conditions, 24 (67 percent) were at or near lithologic contacts identified either on the geologist or natural-gamma logs. Deviation logs were run on 11 boreholes. Difference from vertical ranged from 0.3 to 25 ft. Borehole deviation logs identified three boreholes that deviated to the southwest, five that deviated to the northwest, and three that deviated to the northeast. The greatest deviation was to the northwest in borehole BE-1669 (TT25-D2) and was the result of the drill penetrating a fault at 180 ft bls. The information from borehole geophysical and geologist logs was later used to help place screens at depths of interest and to place packers in boreholes BE-1665 and BE-1666 that were used to determine horizontal and vertical distribution of contaminated ground water migrating from known or suspected sources.

Borehole BE-1665 was packed off at four intervals: interval 1, 158–222 ft bls; interval 2, 210–235 ft bls; interval 3, 235–260 ft bls; and interval 4, 260–302 ft bls. The aquifer-isolation test of interval 1 showed good connection between the upper and the isolated interval; total drawdowns were 3.89 and 8.81 ft bls, respectively. The aquifer-isolation test of interval 2 showed good connection between the upper, isolated, and lower intervals; total drawdowns were 6.54, 14.60, and 9.68 ft bls, respectively. The aquifer-isolation test of interval 3 showed excellent connection between the isolated and lower intervals, but poor connection with the upper interval; total drawdowns were 45.59, 57.38, and 2.32 ft bls, respectively. The aquifer-isolation test of interval 4 showed very poor connection between the upper and isolated intervals; total drawdowns were 3.32 and 84.13 ft bls, respectively.

Borehole BE-1666 (approximately 15 ft southwest of BE-1665) was packed off at two intervals: interval 1, 400–425 ft bls; and interval 2, 440–476 ft bls. The aquifer-isolation test of interval 1 showed good connection between the lower and isolated intervals, but poor connection with the upper interval; total drawdowns were 49.09, 103.58, and 14.73 ft bls, respectively. The aquifer-isolation test of interval 2 showed poor connection between the upper and isolated intervals with total drawdowns of 7.92 and 110.62 ft bls, respectively. Water-quality data indicate the entire water column is severely contaminated at the two boreholes.

In general, the most productive water-bearing zones are in the upper part of the gneiss but were sealed off by setting casing. Vertical flow in the borehole and yield of water from the Precambrian gneiss depends on chance penetration of interconnected water-producing fractures and proximity to a prominent thrust fault onsite. The most productive water-bearing zones were encountered in boreholes downgradient from the drum burial site (near the thrust fault) where more fractures exist, creating more water conduits and, therefore, higher water yields and subsequent higher concentrations of volatile organic compounds.

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