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Evaluation of Geophysical Logs and Slug Tests, Phase II, at AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania

by Randall W. Conger, Daniel J. Goode, and Ronald A. Sloto

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
acre	0.4047	hectare
	Transmissivity	
feet squared per day (ft^2 / d)	0.0929	meters squared per day
	Flow rate	
gallon per minute (gal / min)	0.00006309	cubic meter per second
	Temperature	
degree Celsius (°C)	°F=1.8 °C+32	degree Fahrenheit

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

EVALUATION OF GEOPHYSICAL LOGS AND SLUG TESTS, PHASE II, AT AIW FRANK/MID-COUNTY MUSTANG SUPERFUND SITE, CHESTER COUNTY, PENNSYLVANIA

by Randall W. Conger, Daniel J. Goode, and Ronald A. Sloto

ABSTRACT

Between September 1997 and October 1998, nine monitor wells were drilled at the AIW Frank / Mid-County Mustang Superfund Site in Chester County, Pa., to determine the horizontal and vertical distribution of contaminated ground water migrating from known contaminant sources. The U.S. Geological Survey conducted borehole geophysical logging and borehole television surveys in these boreholes to identify water-producing zones so that appropriate intervals could be screened in each borehole. Caliper logs and borehole television surveys were used to locate fractures; inflections on fluid-temperature and fluid-resistivity logs were used to locate possible water-bearing fractures, and heatpulse-flowmeter measurements verified these locations. The borehole television surveys indicated that locally, the rocks of the Conestoga Limestone and Ledger Dolomite that underlie the site strike generally from northeast-southwest to east-west and dip steeply to the southeast and south approximately 63° to 76°. Slug tests were conducted at six boreholes to estimate transmissivity. Transmissivity from slug tests ranged from 21 feet squared per day in borehole CH-5669 to greater than 12,000 feet squared per day in boreholes CH-5665 and CH-5667. After interpretation of geophysical logs, borehole television surveys, and driller's logs, all boreholes were screened such that water-level fluctuations could be monitored and discrete water samples collected from one or more water-producing zones in each borehole.

INTRODUCTION

The AIW Frank / Mid-County Mustang Superfund Site is located in West Whiteland Township, Chester County, Pa., on U.S. Route 30 (fig. 1). The 15-acre site consists of two adjoining properties. The AIW Frank Property is located at 717 East Lincoln Highway (Route 30) and the Mid-County Mustang property (presently Rex Carle Automotive) is located at 891 East Lincoln Highway (Halliburton NUS, 1991).

The AIW Frank Corporation occupied a small facility used to manufacture styrofoam products and commercial refrigeration units. The site is no longer active. In 1962, the AIW Frank Corporation first leased the property from Louis Frame, the property owner, and in 1975, AIW Frank purchased the property. AIW Frank operated the facility as a styrofoam products manufacturing plant from 1962 until declaring bankruptcy in 1981. AIW Frank reportedly used trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) to clean equipment. After bankruptcy, the site was bought and operated by Continental Refrigerator Corporation (CRC). From 1983 to about 1988, CRC manufactured refrigerators, freezers, and warming cabinets for the food-service industry. The front building (no longer existing) was used for manufacturing by AIW Frank and as an office by CRC. The rear building was used for warehousing by AIW Frank and for manufacturing by CRC. Solvents may have been used by CRC to clean metal components of the refrigeration units (Halliburton NUS, 1991).

The U.S. Environmental Protection Agency (USEPA) requested the U.S. Geological Survey (USGS) provide technical assistance to the hydrological investigation being conducted at the AIW Frank / Mid-County Mustang Superfund Site. The USGS conducted borehole geophysical logging and slug tests to (1) locate subsurface fractures; (2) identify, where possible, important water-bearing fractures; (3) identify zones of potential borehole flow; (4) measure direction and rate of vertical borehole flow; and (5) estimate horizontal transmissivity.

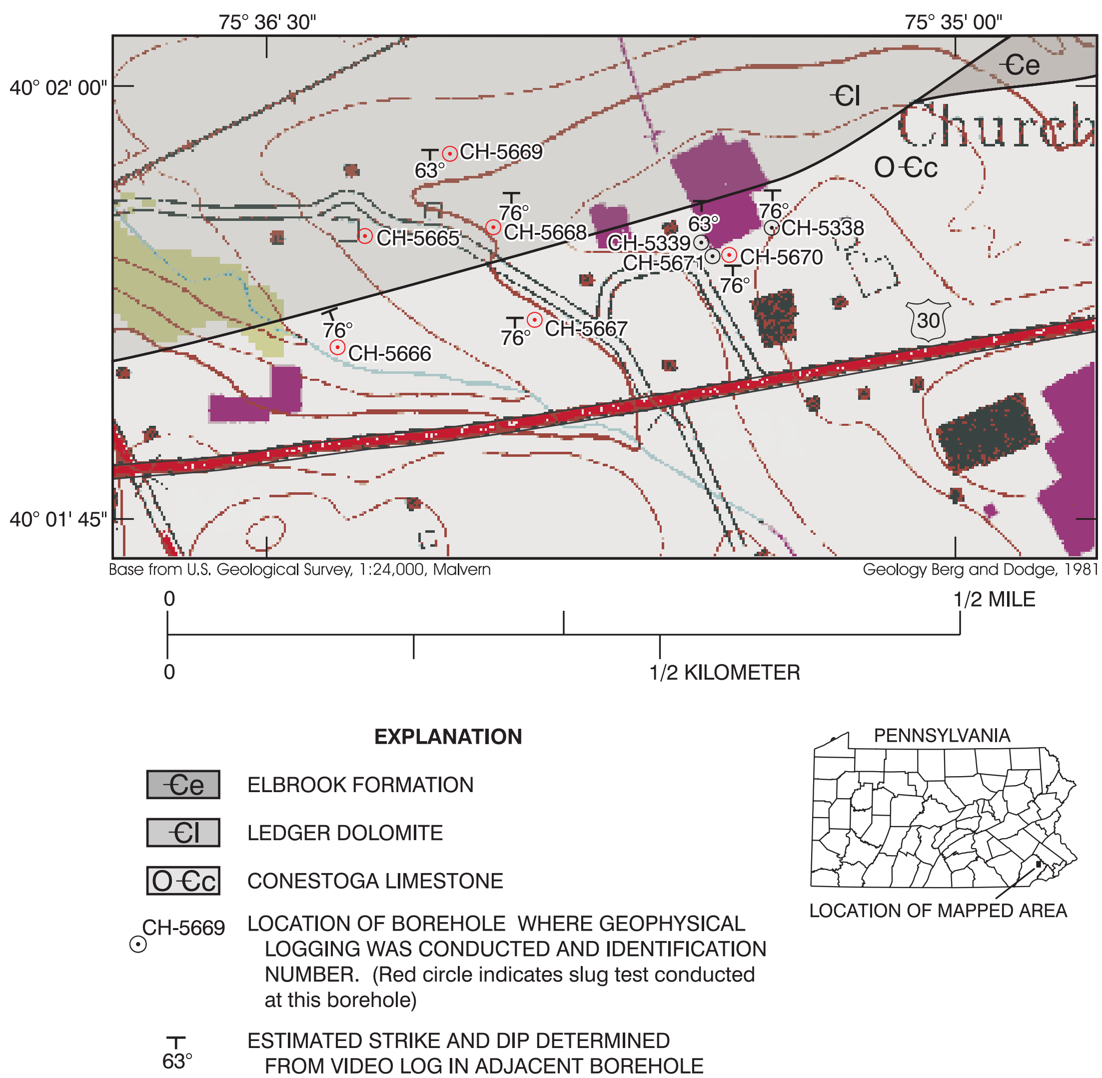

Figure 1. Location of boreholes where geophysical logging and slug testing were conducted near the AIW Frank/Mid-County Mustang Superfund Site, West Whiteland Township, Chester County, Pennsylvania.

Purpose and Scope

This report describes and evaluates borehole geophysical logs and borehole television surveys collected by the USGS in nine boreholes at AIW Frank / Mid-County Mustang Superfund Site from October 1997 to November 1998, and slug tests conducted in six boreholes from November 4-12, 1997 (table 1 and fig. 1). One or more water-producing zone(s) in each borehole is identified on the basis of geophysical logs and borehole television surveys, and the horizontal conductance is estimated on the basis of slug-test data. Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs were run, and heatpulse-flowmeter measurements were made in eight boreholes. Borehole television surveys also were conducted in the eight boreholes. Fluid-temperature and fluid-resistivity logs were run and heatpulse-flowmeter measurements were made in one screened borehole. Slug-test data were collected and analyzed from six boreholes. A cross-reference between USGS borehole-identification numbers and Tetra Tech NUS, Inc., borehole-identification numbers are shown in table 1.

Table 1. *Boreholes logged at AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

U.S. Geological Survey borehole-identification number	Tetra Tech NUS Inc. identification number.	Length of casing below land surface (feet)	Depth to water below land surface (feet)	Depth logged (feet)	Date water level measured	Slug test date
CH-5338	OB-1	19	29.21	193	10/20/98	None
CH-5339	OB-2	14	26.35	183	10/20/98	None
CH-5665	MW-113	25	24.76	175	10/27/97	11/4/97
CH-5666	MW-110	25	12.03	101	10/27/97	11/6/97
CH-5667	MW-114	40	21.5	188	10/28/97	11/12/97
CH-5668	MW-112	21	27.12	202	10/27/97	11/6/97
CH-5669	MW-115	20	29.85	201	10/29/97	11/6/97
CH-5670	MW-111	72	23.47	262	10/30/97	11/12/97
CH-5671	EW-1	134	14.21	134	11/18/98	None

Location and Physiography

The site is located in the Piedmont Physiographic Province and is underlain by the Ordovician-age Conestoga Limestone and Cambrian-age Ledger Dolomite (fig. 1). These carbonate units consist of bluish-grey limestone and dolomite (Sloto, 1994). From geophysical logs collected previously by the USGS, overburden is estimated to range from 4 to more than 44 ft thick throughout the study area.

Ground water moves through the carbonate rocks through a network of secondary openings enlarged by solution. Solution is the primary weathering process in carbonate rock and permeability of carbonate rock is predominantly the result of solution-enlarged fractures (Sloto, 1994). In carbonate rocks, some fractures are several feet wide; however, most are only a fraction of an inch but are capable of transmitting large quantities of water.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS

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

Principles and Methods of Borehole Logging

Geophysical logs can provide many types of data. Information on location of fractures can be determined from caliper logs and borehole television surveys. Water-producing zones, water-receiving zones, and intervals of vertical borehole flow can be identified with fluid-resistivity and fluid-temperature logs. Borehole flow can be quantified with heatpulse-flowmeter measurements. Lithologic data can be provided by gamma and single-point resistance logs. In addition, borehole-construction details can be determined from caliper and single-point resistance logs.

Caliper logs record the average borehole diameter, which may be related to fractures, lithology, or drilling methods. The term fracture used in association with the caliper-log interpretations may not necessarily indicate a bedding-plane separation, lithologic contact, or fluid-producing or fluid-receiving zones but may simply indicate an enlargement of the borehole. Caliper logs can be used to identify fractures and possible water-producing openings and correct other geophysical logs for changes in borehole diameter. They can be correlated with fluid-resistivity and fluid-temperature logs to identify fractures, water-producing zones, and water-receiving zones. Caliper logs also provide data needed to correct flowmeter measurements for changes in hole diameter.

Borehole television surveys were conducted by lowering a waterproof camera down the borehole and recording the image on standard VHS videotape. The dip direction of major fractures and bedding planes can be approximated by noting the compass bearing of the lowest point where the fracture intersects the borehole. By noting the vertical distance from the top to the bottom of the fracture as it intersects the borehole, degree of dip can be estimated by:

$$\text{Dip angle (degrees)} = \arctan (L/d) \qquad (1)$$

where L is the vertical length from top to bottom of the fracture, in inches, and
d is the diameter of the borehole, in inches.

The depth indicated on the borehole television surveys may not correspond precisely to the geophysical logs because of some minor slippage of the television cable.

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

Fluid-temperature logs provide a continuous record of the temperature of 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). A measurement of direction and rate is computed when a peak temperature is recorded by one of the thermistors. The range of flow measurement is about 0.01-1.5 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 borehole storage under pumping conditions. If the seal between the borehole and flowmeter is not complete, some water can bypass the flowmeter, resulting in measurements of flow that are less than the actual rate. Although the heatpulse flowmeter is a calibrated probe, the data are primarily used as a relative indicator to identify water-producing zones.

The 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. Geophysical logging with a gamma probe can be conducted in the fluid-filled, dry, cased, or uncased parts of a borehole. However, casing does reduce the gamma response. The gamma log is used to correlate geologic units between boreholes (Keys, 1990).

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

CH-5665 (MW-113)

The caliper log shows the total depth of the borehole is 175 ft, and it is cased with 6-in. diameter casing to 25 ft below land surface (bls) (fig. 2). The water level in the borehole at the time of logging was 24.76 ft bls. The caliper log shows major fractures at 28-31, 50-53, and 109-118 ft bls and constrictions at 60-61 and 64-65 ft bls. The fluid-resistivity log shows a change in slope at 29 ft bls that indicates a water-producing fracture. In addition, the fluid-resistivity log shows a change in slope at 65 ft bls that was due to the probe hanging on the constriction near that location. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 57, 74, 108, 121, 148, and 162 ft bls and downward flow at 38 ft bls (table 2). The borehole television survey shows that bedding planes strike northeast-southwest and dip steeply southeast. The geophysical logs and heatpulse-flowmeter measurements indicate two major water-producing fractures in the borehole—one just below casing at 24-32 ft bls and one at 111-118 ft bls. Water enters the borehole through fractures at 24-32 ft bls, moves downward, and exits the borehole through fractures at 50-53 ft bls. The greatest quantity of water enters the borehole through fractures at 111-118 ft bls, flows upward, and exits the borehole through fractures at 50-53 ft bls. A minor quantity of water is produced through a fracture below 162 ft bls (probably at 166 ft bls), flows upward, and exits the borehole through fractures at 50-53 ft bls. Screens were placed at 105-125 ft bls to include the water-producing fracture at 111-118 ft bls and at 160-170 ft bls to include the water-producing fracture at 166 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 2. *Summary of heatpulse-flowmeter measurements for borehole CH-5665 (MW-113) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
38	1.2	down
57	1.1	up
74	1.2	up
108	1.2	up
121	.15	up
148	.22	up
162	.28	up

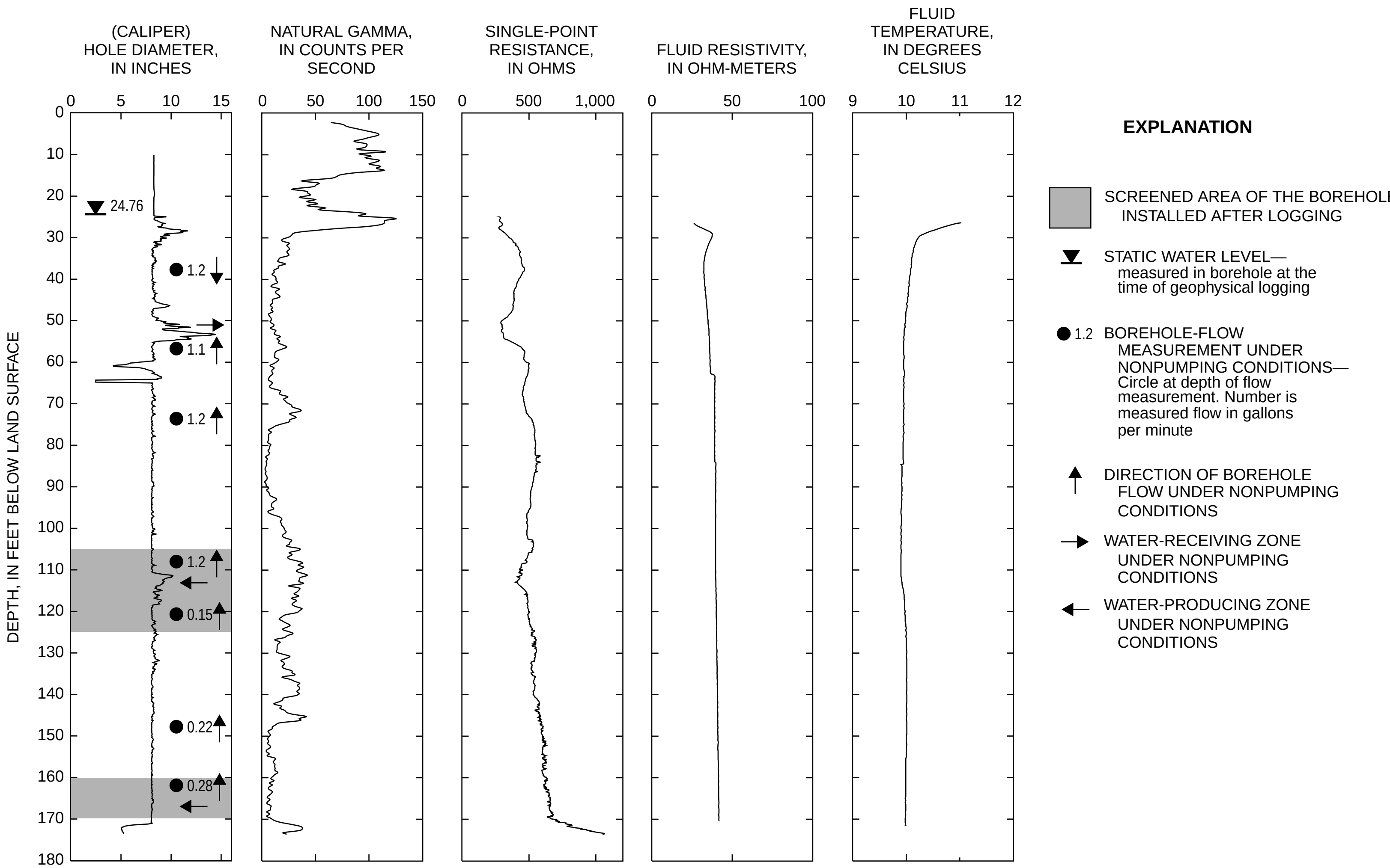

Figure 2. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5665 (MW-113), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5666 (MW-110)

The caliper log shows the total depth of the borehole is 99 ft, and it is cased with 6-in. diameter casing to 27 ft bls (fig. 3). The water level in the borehole at the time of logging was 12.03 ft bls. The caliper log shows fractures at 25, 51-53, and 95-99 ft bls. The fluid-resistivity log shows changes in slope at 28, 51, and 99 ft bls that correlate to fractures shown on the caliper log and indicate water-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 41 ft bls and downward flow at 62, 75, and 90 ft bls (table 3). The borehole television survey shows that bedding planes strike east-west and dip approximately 76° to the south-southeast. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 50-53 ft bls. A minor quantity of water moves upward and exits the borehole through fractures at the bottom of casing at 28 ft bls; the greatest quantity moves downward and exits the borehole through the fractures at 95-99 ft bls. A screen was placed at 45-55 ft bls to include the water-producing fractures at 50-53 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 3. *Summary of heatpulse-flowmeter measurements for borehole CH-5666 (MW-110) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
41	0.16	up
62	1.5	down
75	1.5	down
90	1.5	down

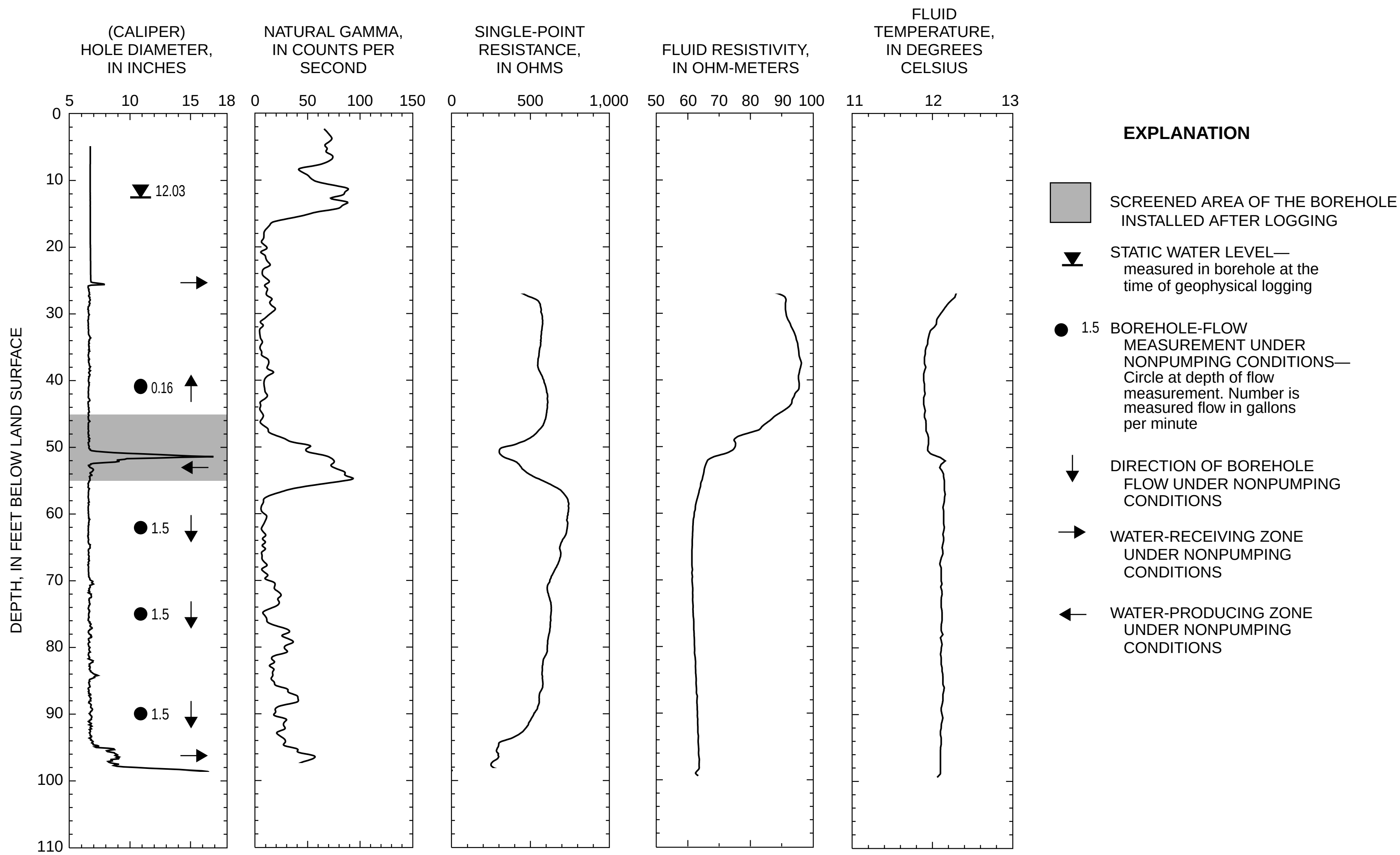

Figure 3. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5666 (MW-110), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5667 (MW-114)

The caliper log shows the total depth of the borehole is 197 ft, and it is cased with 8-in. diameter casing to 41 ft bls (fig. 4). The caliper log shows a restriction at 187 to 197 ft bls, which is mud at the bottom of the borehole. The water level in the borehole at the time of logging was 21.5 ft bls. The caliper log shows fractures at 42, 59, and 86 ft bls. The fluid-resistivity log shows changes in slope at 40 and 185 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 36, 54, 72, and 96 ft bls and no flow at 118 ft bls (table 4). The borehole television survey shows that bedding planes strike east-west and dip approximately 76° to the south. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 59, 86-87, and between 96-118 ft bls, moves upward, and exits the borehole through fractures at 42 ft bls and a break in casing above 36 ft bls. A screen was placed at 55-65 ft bls to include the water-producing fracture at 60 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 4. *Summary of heatpulse-flowmeter measurements for borehole CH-5667 (MW-114) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
36	0.13	up
54	.63	up
72	.45	up
96	.18	up
118	no flow	not determined

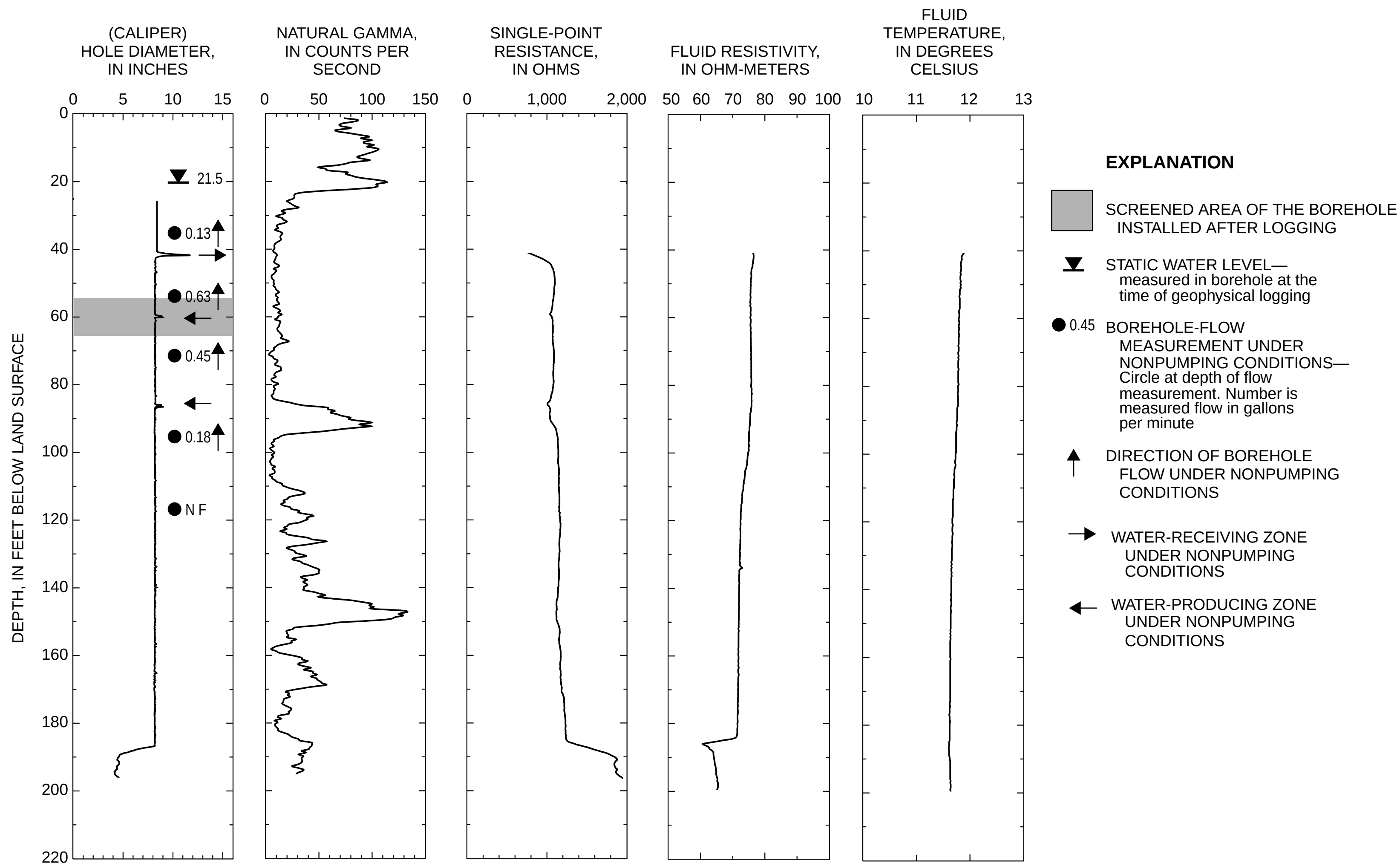

Figure 4. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5667 (MW-114), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5668 (MW-112)

The caliper log shows the total depth of the borehole is 202 ft, and it is cased with 8-in. diameter casing to 16 ft bls (fig. 5). The water level in the borehole at the time of logging was 27.12 ft bls. The caliper log shows major fractures at 21, 23-25, 32-37, and 82-84 ft bls plus other minor fractures throughout the open-hole interval. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 42, 66, 94, 126, 164, and 187 ft bls and no flow at 145 ft bls (table 5). The borehole television survey shows bedding planes strike east-west and dip approximately 76° to the south. The geophysical logs and the heatpulse-flowmeter measurements show two zones of borehole flow. Water enters the borehole through fractures at 189-196 ft bls, flows upward, and exits the borehole through fractures at 150-158 ft bls. Water also enters the borehole through fractures at 82-84, 137-140, and 192 ft bls, moves upward, and exits the borehole through the fractures at 32-37 ft bls. Screens were placed at 80-90 and 180-200 ft bls to include the water-producing fractures at 82-84 and 192 ft bls, respectively (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 5. *Summary of heatpulse-flowmeter measurements for borehole CH-5668 (MW-112) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
42	0.24	up
66	.18	up
94	.10	up
126	.10	up
145	no flow	not determined
164	.07	up
187	.08	up

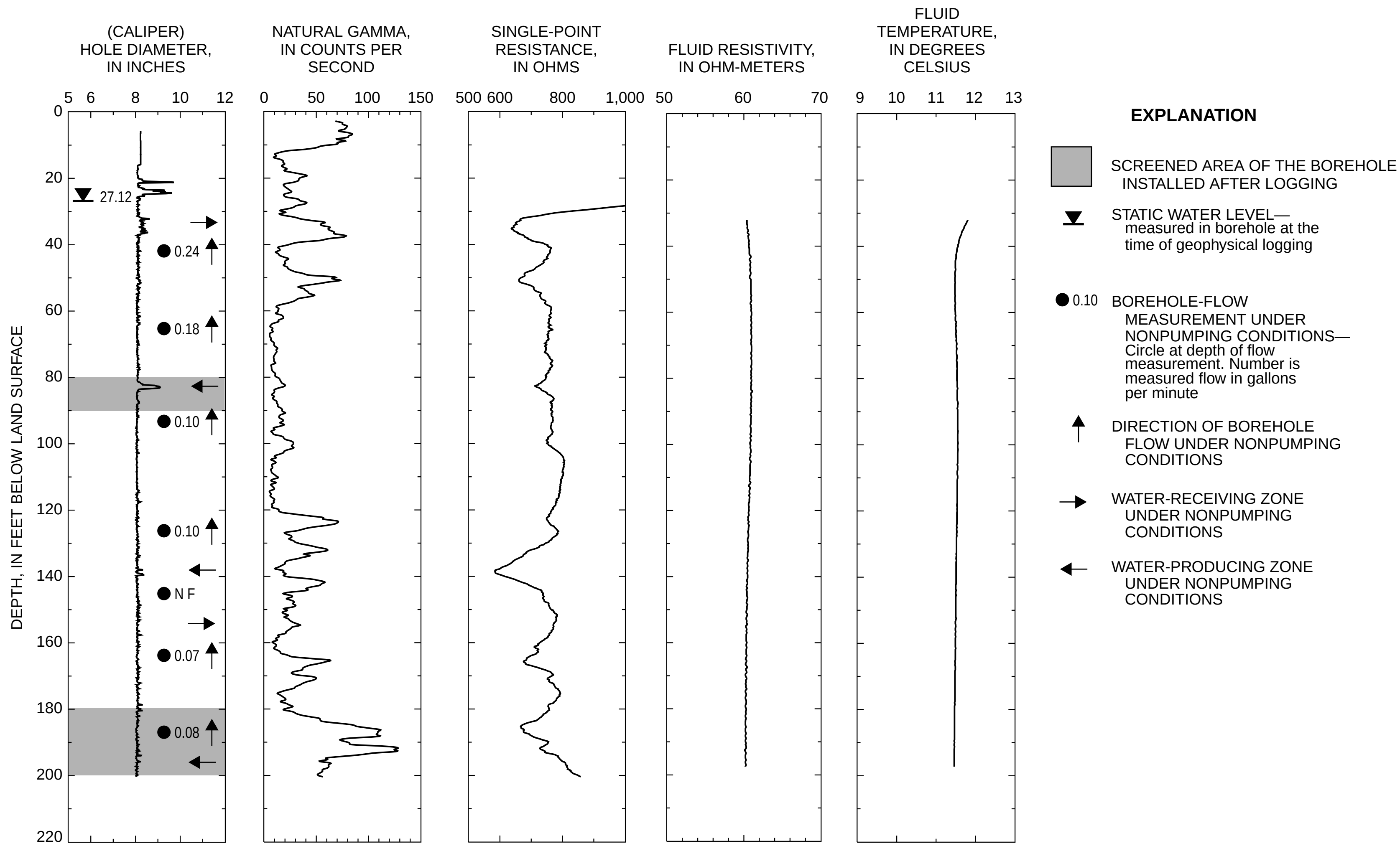

Figure 5. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5668 (MW-112), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5669 (MW-115)

The caliper log shows the total depth of the borehole is 201 ft, and it is cased with 8-in. diameter casing to 20 ft bls (fig. 6). The water level in the borehole at the time of logging was 29.85 ft bls. The caliper log shows one fracture at 59-61 ft bls plus several minor fractures from 25 to 45 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow. A submersible pump was then placed at 45 ft bls, and the borehole was pumped at less than 0.5 gal / min. The water level in the borehole declined 2.95 ft after 1 hour. Under pumping conditions, the heatpulse flowmeter measured upward borehole flow at 56 and 70 ft bls and no flow at 100, 118, 146, and 180 ft bls (table 6). The borehole television survey shows bedding planes strike east-west and dip to the south at approximately 63°. At about 100 ft bls, the strike of the Ledger Formation transitions from east-west to northeast-southwest and dips to the southeast at approximately 63°. Under pumping conditions, the geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through high fractures or bedding-plane separations between 70 and 100 ft bls. A screen was placed at 55-95 ft bls to include water-producing fractures at 60 and 79-90 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 6. *Summary of heatpulse-flowmeter measurements for borehole CH-5669 (MW-115) at the AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

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

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow rate under pumping conditions (gal/min)	Flow direction under pumping conditions
56	no flow	0.10	up
70	no flow	.08	up
100	no flow	no flow	not determined
118	no flow	no flow	not determined
146	no flow	no flow	not determined
180	no flow	no flow	not determined

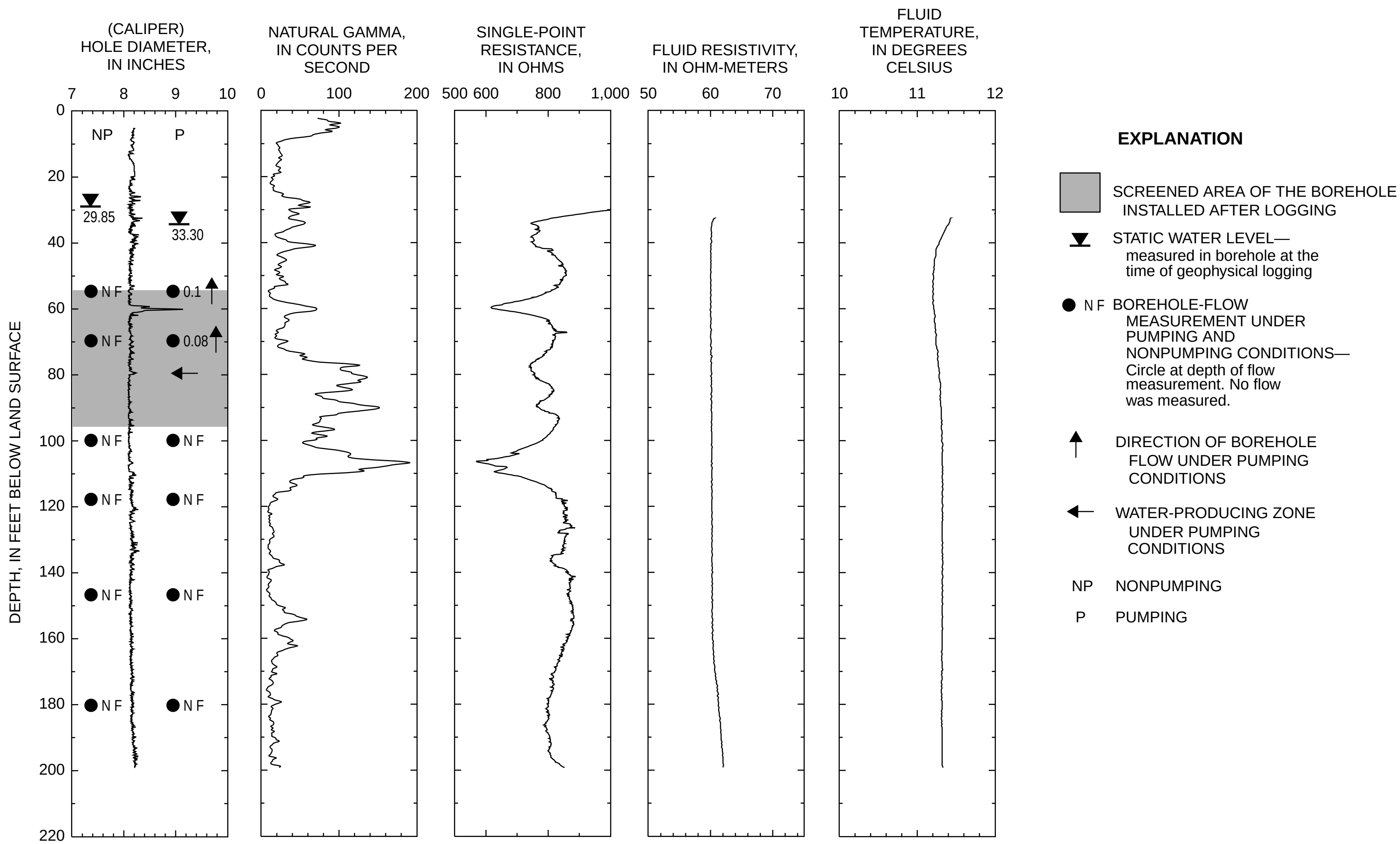

Figure 6. Borehole geophysical logs and direction of pumping and nonpumping flow within borehole CH-5669 (MW-115), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5670 (MW-111)

The caliper log shows the total depth of the borehole is 262 ft, and it is cased with 6-in. diameter casing to 73 ft bls (fig. 7). The water level in the borehole at the time of logging was 23.47 ft bls. The caliper log shows major fractures at 87 and 100 ft bls plus numerous other minor fractures throughout the open-hole interval. The fluid-temperature log shows changes in slope at 70, 136, 180, 228, and 238 ft bls that may indicate water-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 79, 91, 103, and 116 ft bls and no flow at 126, 146, 184, and 234 ft bls (table 7). The borehole television survey shows bedding planes strike east-west and dip approximately 76° to the south. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures between 120-122 and 108-110 ft bls, moves upward, and exits the borehole through the fractures at 87 and 74 ft bls. A screen was placed at 96-116 ft bls to include the water-producing fracture at 108-110 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

Table 7. *Summary of heatpulse-flowmeter measurements for borehole CH-5670 (MW-111) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
79	0.08	up
91	.14	up
103	.15	up
116	.10	up
126	no flow	not determined
146	no flow	not determined
184	no flow	not determined
234	no flow	not determined

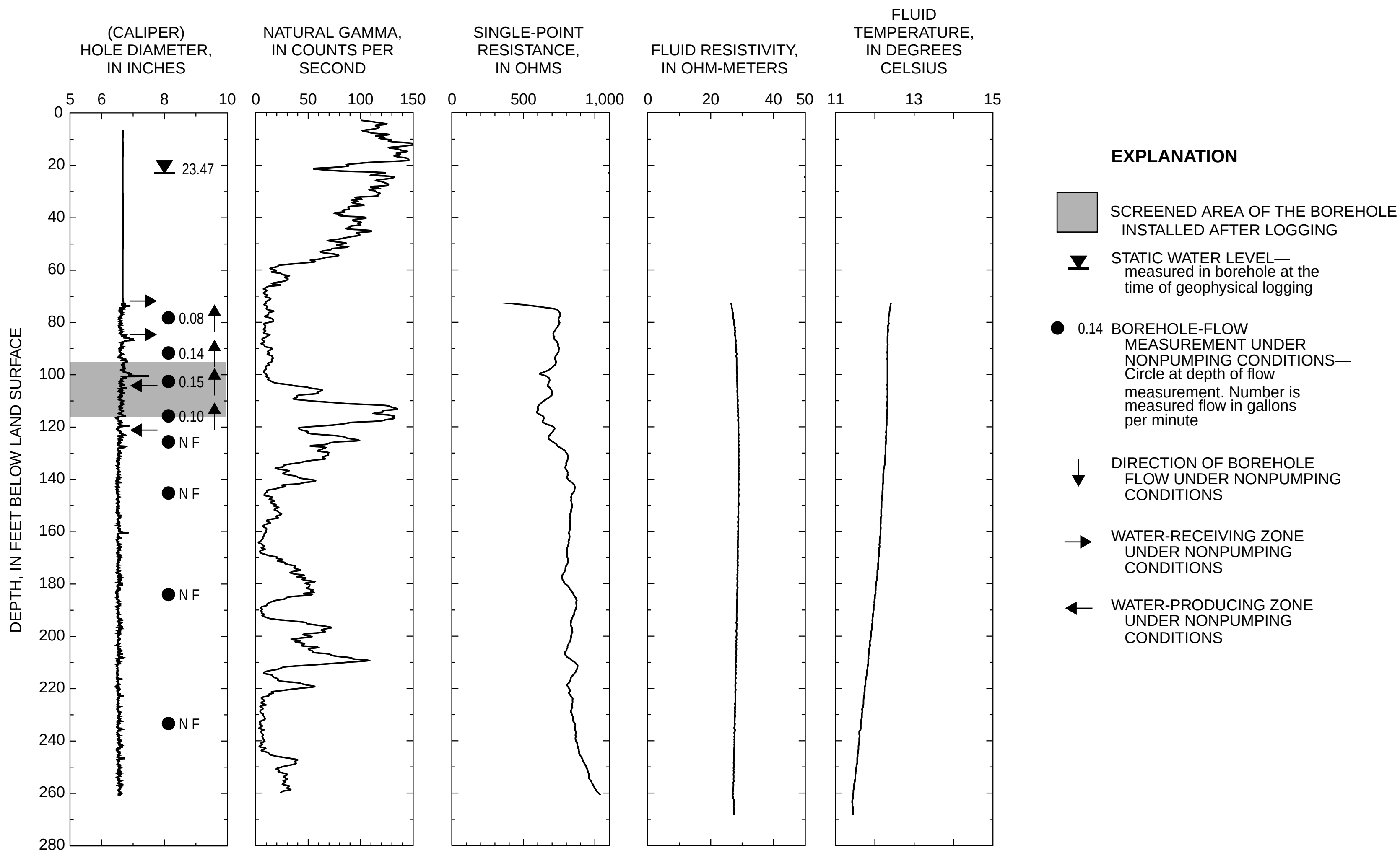

Figure 7. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5670 (MW-111), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5338 (OB-1)

The caliper log shows the total depth of the borehole is 193 ft, and it is cased with 8-in. diameter casing to 19 ft bls (fig. 8). The water level in the borehole at the time of logging was 29.21 ft bls. The caliper log shows a major fracture at 30 ft bls plus other minor fractures throughout the open-hole interval. The caliper log shows a constriction at the bottom of the borehole starting at 182 ft bls that correlates to changes shown on the single-point-resistance and fluid-resistivity logs that is identified as a drill bit by the borehole television survey. The single-point-resistance log shows numerous spikes throughout the logged interval that are probably due to poor electrical ground of the equipment. The fluid-temperature log shows a change in slope at 47 ft bls that correlates to fractures shown on the caliper log and may indicate a water-producing zone. The borehole television survey shows bedding planes strike generally northwest-southeast and dip 76° to the southwest. Below approximately 60 ft bls, bedding planes strike east-west and dip almost due south at 76°. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 36, 58, 100, and 160 ft bls. The driller’s log indicates the first damp rock cuttings at 40 ft bls and possible water production at 155 ft bls (Don Whalen, Tetra Tech NUS Inc., written commun., 1999). A screen was placed at 33-43 and 153-163 ft bls to include the potential water-producing fractures at 40 and 155 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

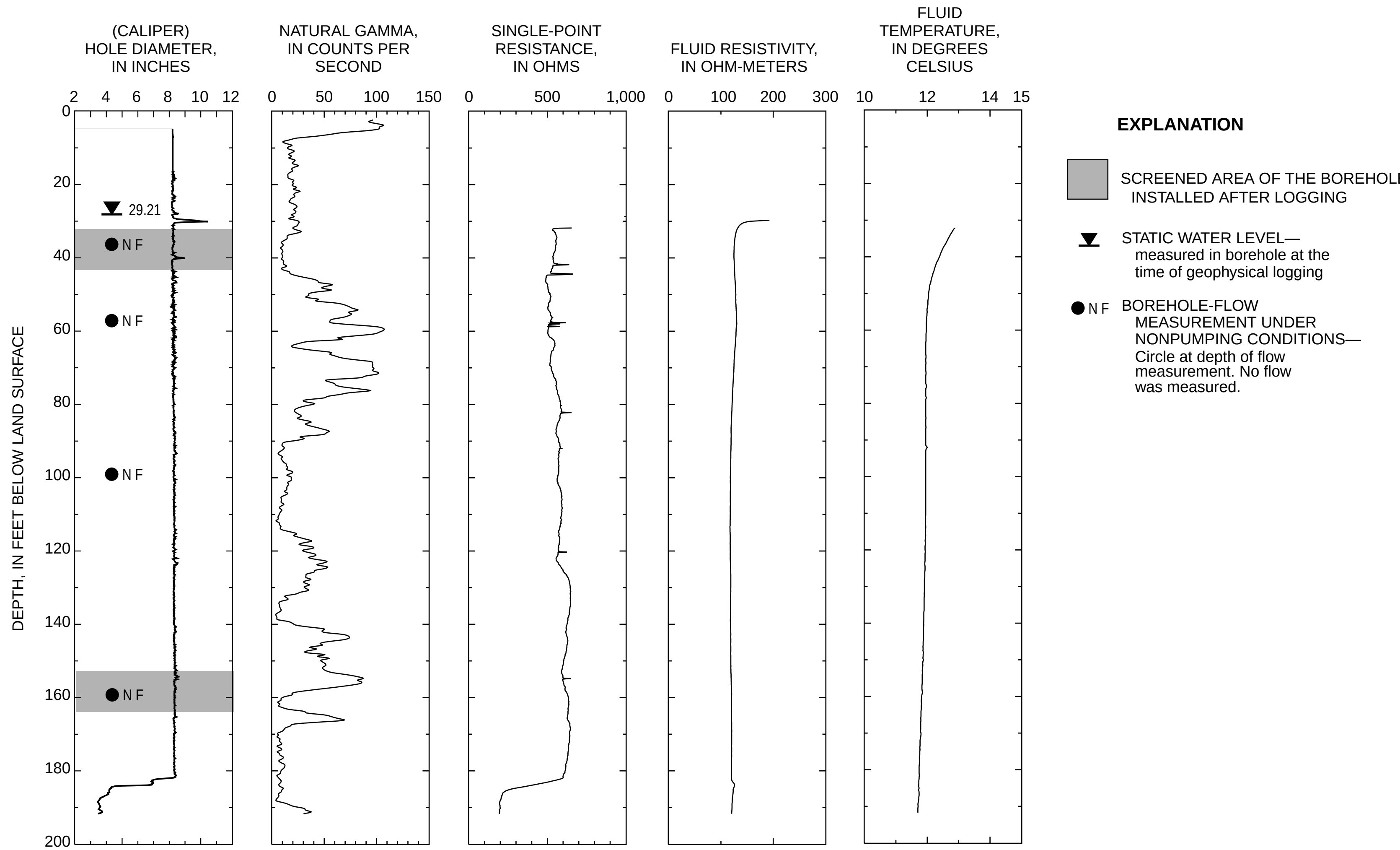

Figure 8. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5338 (OB-1), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5339 (OB-2)

The caliper log shows the total depth of the borehole is 183 ft, and it is cased with 8-in. diameter casing to 12 ft bls (fig. 9). The water level in the borehole at the time of logging was 26.35 ft bls. The caliper log shows major fractures at 14-16, 51, and 53 ft bls; minor fractures at 76, 79, and 80.5-82 ft bls; and soft sediment on the bottom of the borehole from 178 to 183 ft bls. The fluid-resistivity and fluid-temperature logs show changes in slope at 82 ft bls that correlate to fractures shown on the caliper log. Under nonpumping conditions, the heatpulse flowmeter measured downward borehole flow of 0.6 gal/min at 66 ft bls and no flow at 37 and 94 ft bls. The borehole television survey shows bedding planes strike east-west and dip approximately 63° to the south. The borehole television survey shows a shallow fracture at 20 ft bls that strikes east-west and dips approximately 63° to the north. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 51-53 ft bls, moves downward, and exits the borehole through the fractures at 76-82 ft bls. A screen was placed at 40-55 and 73-83 ft bls to include the water-producing and water-receiving fractures in these intervals (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999).

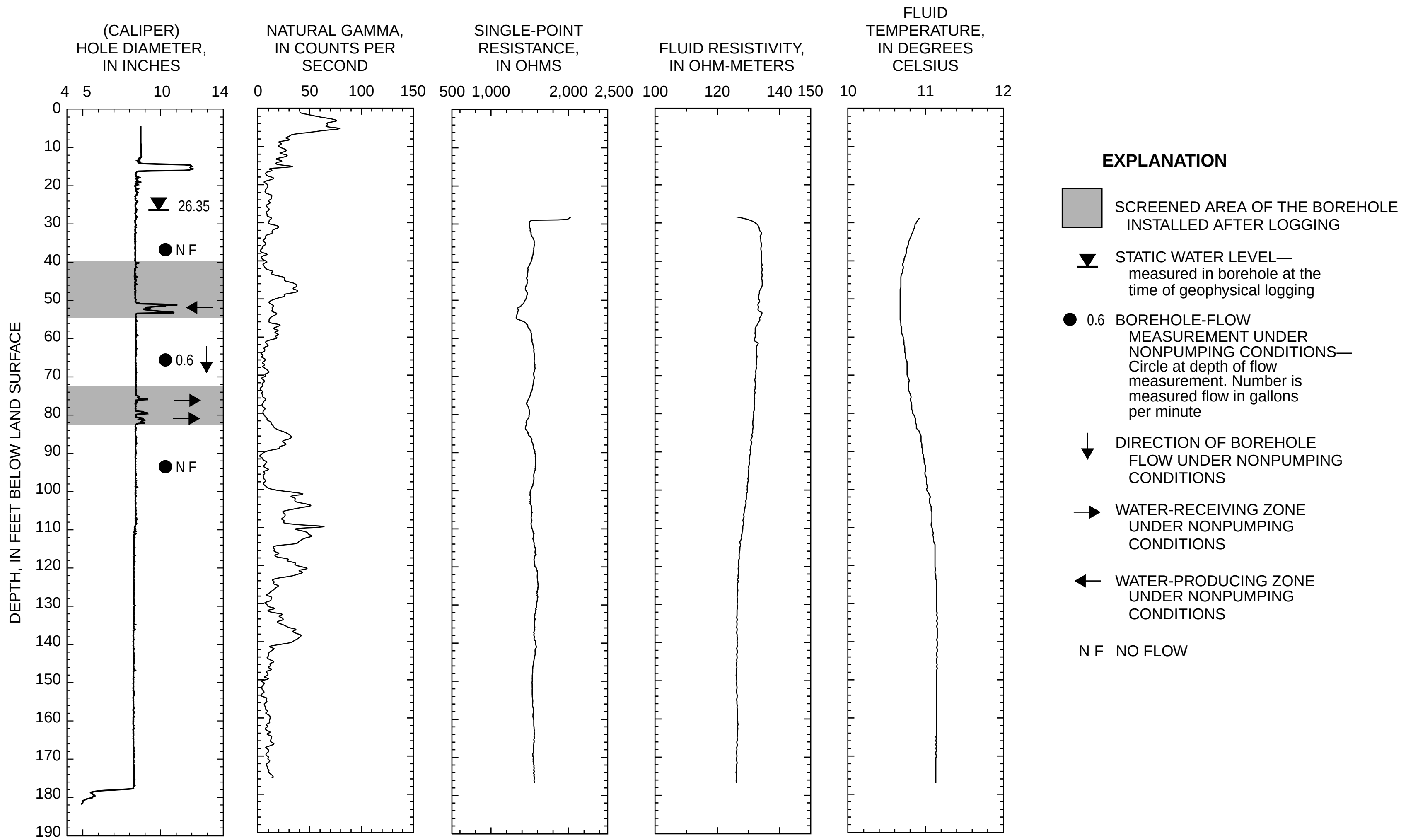

Figure 9. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5339 (OB-2), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

CH-5671 (EW-1)

Only the fluid-resistivity and fluid-temperature logs and heatpulse-flowmeter measurements were collected because this borehole had already been screened with 4-in. diameter PVC inner casing from 100-150 ft bls (Kevin Kilmartin, Tetra Tech NUS Inc., written commun., 1999). At the time of logging, the total depth had decreased to 134 ft bls (fig. 10). The water level in the borehole at the time of logging was 14.21 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward flow at 130 ft bls, turbulent but inconsistent upward flow at 115, 120, and 125 ft bls, and no flow at 90 and 104 ft bls (table 8).

Table 8. *Summary of heatpulse-flowmeter measurements for borehole CH-5671 (EW-1) at the AIW Frank/Mid-County Mustang Superfund Site, Chester 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
90	no flow	not determined
104	no flow	not determined
115	not determined	up
120	not determined	up
125	not determined	up
130	0.5	up

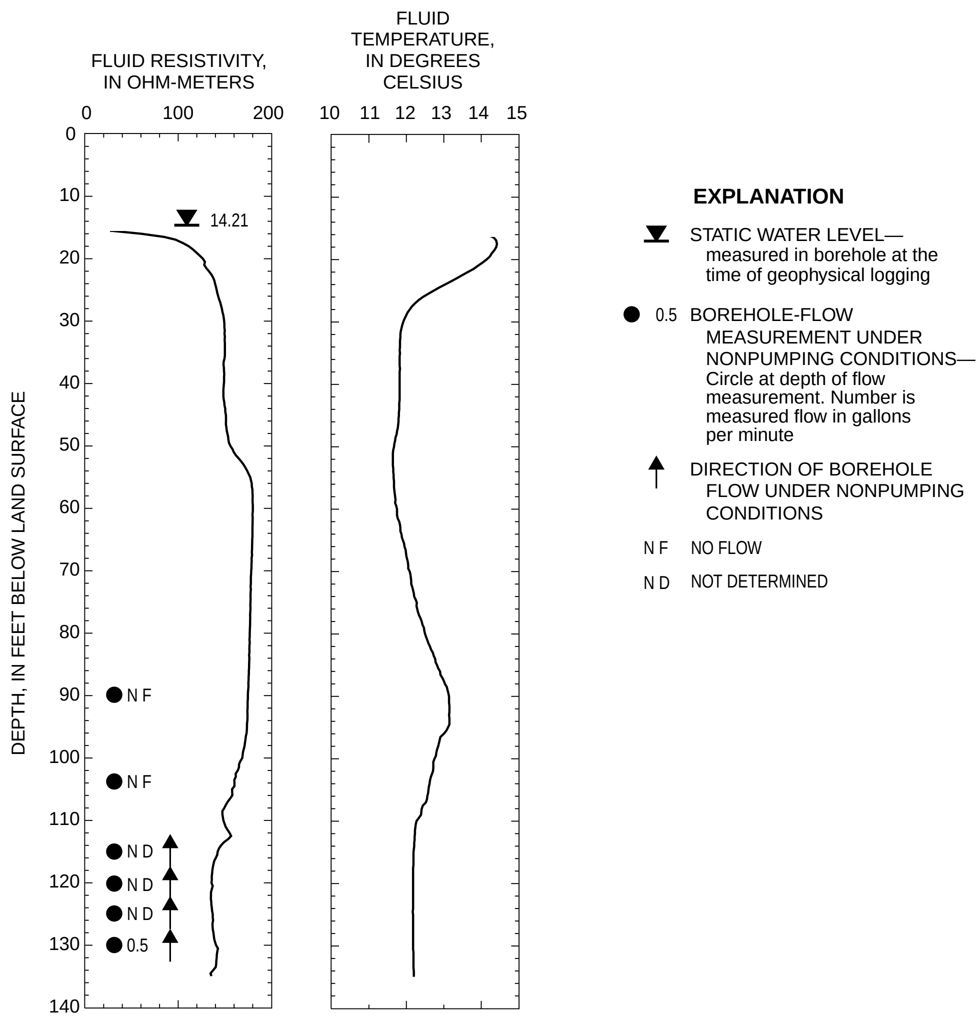

Figure 10. Borehole geophysical logs and direction of nonpumping flow within borehole CH-5671 (EW-1), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

EVALUATION OF SLUG TESTS

Slug tests are used to determine hydraulic properties of subsurface formations at a relatively small scale around individual boreholes. The duration of a slug test is relatively short, and the estimated transmissivity determined from the test is considered to be representative only of water-bearing material close to the borehole (Ferris and others, 1962). Slug tests were completed in boreholes CH-5665, CH-5666, CH-5667, CH-5668, CH-5669, and CH-5670 (fig. 1 and table 1).

Test Methods

Slug tests are conducted by measuring the rise and fall of the water level in a borehole caused by a sudden introduction of an apparatus that displaces the water. The slug apparatus was a 3.5 ft long, 4-in. diameter PVC pipe, filled with grout and capped on both ends. The slug apparatus was quickly submerged in the borehole to displace a finite volume of water. The subsequent water-level response was measured with a downhole pressure transducer. Measurements from the transducer were recorded with a data logger at the ground surface. Periodic electric-tape measurements of depth to water were made manually and used to calibrate the pressure transducer.

Data from slug tests were analyzed with the analytical solution developed by Cooper and others (1967). The solution assumes a homogeneous, isotropic, areally extensive, confined aquifer. The method involves normalizing the water-level change to the maximum change or height of the displaced water column and plotting the normalized water-level change as a function of the logarithm of time. Standard curve-matching techniques were used to match the test data to the theoretical type curve. In some cases, the displaced water column dissipated so quickly that hydraulic properties could not be reliably estimated. In these cases, however, the general interpretation is that the subsurface formations adjacent to the borehole have relatively large transmissivity.

Determination of Hydraulic Properties

Slug tests were completed in six screened boreholes to determine hydraulic properties at a relatively small scale around the boreholes. Transmissivities estimated from the slug tests are summarized in table 9. Transmissivity at three of the boreholes ranges between 21 and 60 ft^2/d; the transmissivity is estimated to be at least 12,000 ft^2/d at the other three boreholes. All the type curve matches assume an alpha value of $\alpha = 10^{-9}$, which corresponds to a very small storage coefficient.

Table 9. *Transmissivity determined by slug tests, AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[ft^2/d, feet squared per day; >, estimated greater than]

USGS borehole identification number	Tetra Tech NUS Inc. identification number	Date of test	Transmissivity estimate (ft^2/d)
CH-5665	MW-113	November 4, 1997	>12,000
CH-5666	MW-110	November 6, 1997	12,000
CH-5667	MW-114	November 12, 1997	>12,000
CH-5668	MW-112	November 6, 1997	29
CH-5669	MW-115	November 6, 1997	21
CH-5670	MW-111	November 12, 1997	60

For three boreholes, CH-5665, CH-5666, and CH-5667, the transmissivity is so large the water level in the borehole recovered within seconds of submerging the slug apparatus. Analyses of the response in borehole CH-5666 yields a rough estimate of transmissivity of approximately 12,000 ft^2/d (fig. 11). Based on the even more rapid responses of water levels in boreholes CH-5665 and CH-5667, the transmissivities at these boreholes are estimated to be greater than 12,000 ft^2/d.

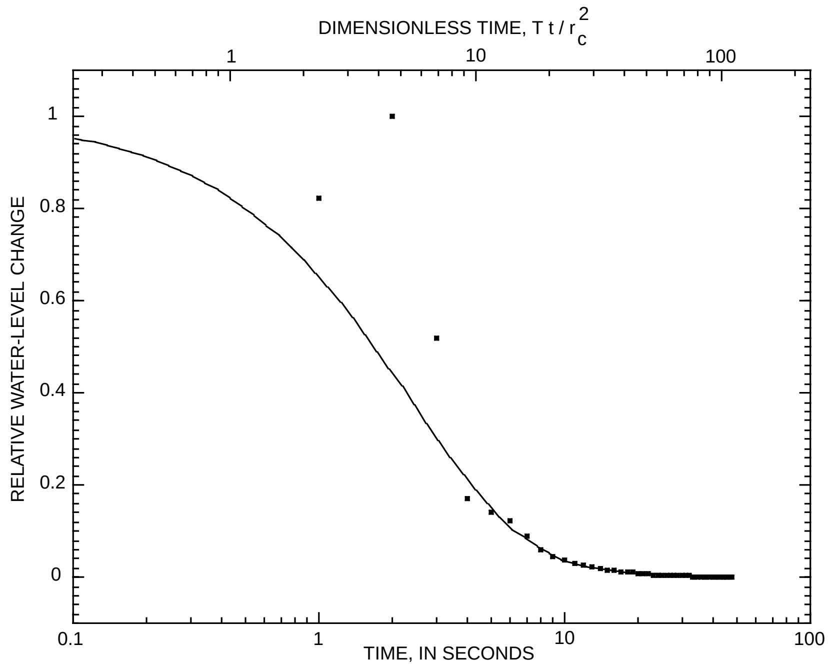

Figure 11. Relative water-level change (points) as a function of logarithm of time and type curve (lines) for slug test of borehole CH-5666 (MW-110), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania. [T, transmissivity; t, time; r_c, casing radius]

The water level in three of the boreholes—CH-5668, CH-5669, and CH-5670—did not recover to the pre-slug level after 1 hour (figs. 12-14). The water-level response in these boreholes agrees reasonably well with the theoretical response of a homogeneous, isotropic, areally extensive, confined aquifer (Cooper and others, 1967).

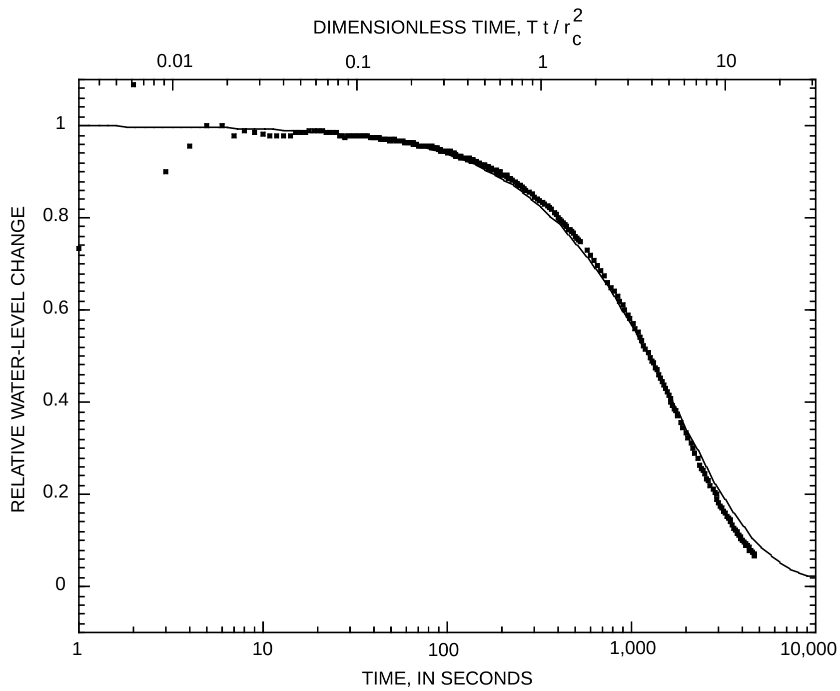

Figure 12. Relative water-level change (points) as a function of logarithm of time and corresponding type curve (line) for slug test of borehole CH-5668 (MW-112), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.
[T, transmissivity; t, time; r_c, casing radius]

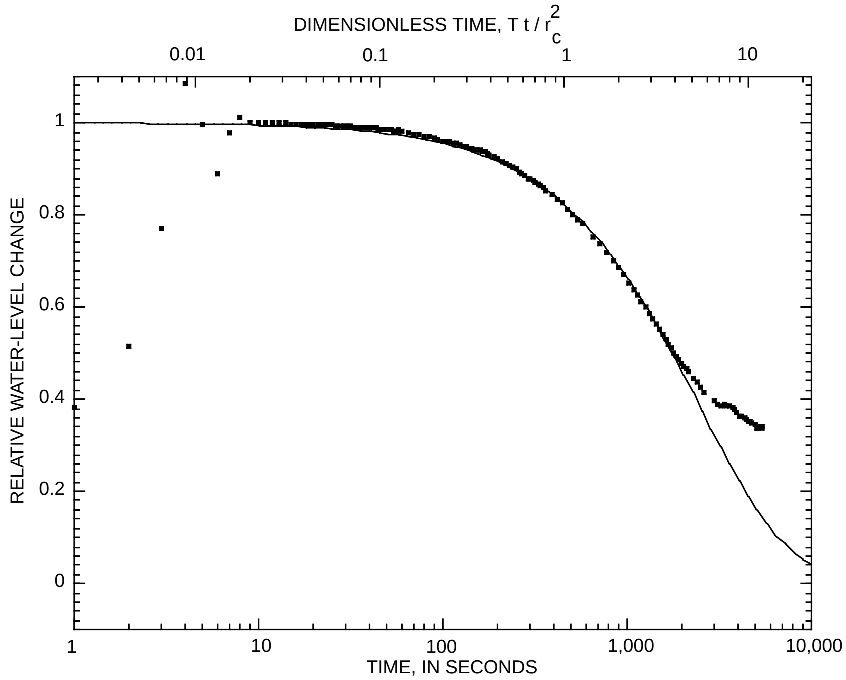

Figure 13. Relative water-level change (points) as a function of logarithm of time and corresponding type curve (line) for slug test of borehole CH-5669 (MW-115), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania. [T, transmissivity; t, time; r_c, casing radius]

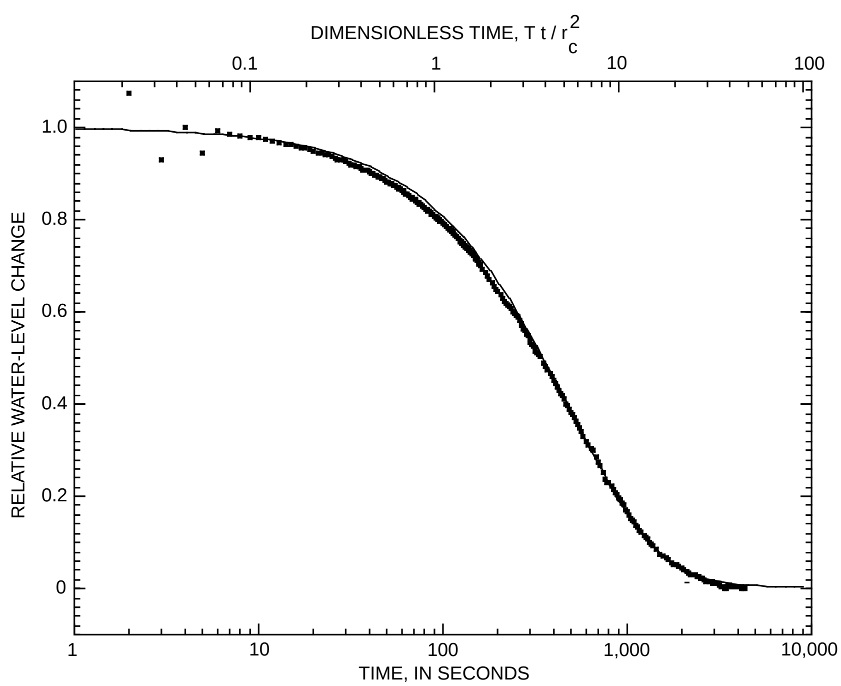

Figure 14. Relative water-level change (points) as a function of logarithm of time and corresponding type curve (line) for slug test of borehole CH-5670 (MW-111), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania. [T, transmissivity; t, time; r_c, casing radius]

SUMMARY AND CONCLUSIONS

The AIW Frank / Mid-County Mustang Superfund Site is underlain by Ordovician-age Conestoga Limestone and Cambrian-age Ledger Dolomite, which consists of silty, clay-rich soils that overlie bluish-grey limestone and dolomite. The rocks of the Conestoga and Ledger Formation generally strike from northeast-southwest to east-west and dip steeply to the southeast and south from approximately 63° to 76°. Ground water is present in bedding-plane separations and solution enlarged fractures. Driller's logs and slug tests show that water production (and transmissivity) in boreholes are greatly variable with location, and range from 3 gal / min (21 ft^2 / d) in CH-5669 to an estimated 250 gal / min (>12,000 ft^2 / d) in CH-5666.

Water flows in an open borehole under nonpumping conditions because of differences in hydraulic head; water flows in the direction of decreasing head. Heatpulse-flowmeter measurements showed borehole flow in all wells except boreholes CH-5668 and CH-5669. Upward borehole flow rates ranged from 0.07 gal / min in borehole CH-5668 to 1.2 gal / min in borehole CH-5665. Downward borehole flow rates ranged from 0.6 gal / min in borehole CH-5339 to 1.5 gal / min in borehole CH-5666.

Water-producing zones, water-receiving zones, and intervals of vertical borehole flow were identified by the use of geophysical logs, heatpulse-flowmeter measurements, borehole television surveys, and driller's logs. This enabled boreholes to be screened at selected water-producing intervals so that water from these intervals could be sampled.

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