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Evaluation of Geophysical Logs and Video Surveys in Boreholes Adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania

by Dennis J. Low and Randall W. Conger

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
	Volume	
gallon (gal)	3.785	liter
	Flow Rate	
gallon per minute (gal/min)	0.00006309	cubic meter per second
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius

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

Abbreviated water-quality unit used in this report:

µg/L, micrograms per liter

EVALUATION OF GEOPHYSICAL LOGS AND VIDEO SURVEYS IN BOREHOLES ADJACENT TO THE BERKLEY PRODUCTS SUPERFUND SITE, WEST COCALICO TOWNSHIP, LANCASTER COUNTY, PENNSYLVANIA

by Dennis J. Low and Randall W. Conger

ABSTRACT

Between February 1998 and April 1998, geophysical logs were collected in nine boreholes adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pa. Video surveys were conducted on four of the nine boreholes. The boreholes range in depth from 320 to 508 feet below land surface, are completed open holes, have ambient vertical flow of water, and penetrate a series of interbedded siltstone, sandstone, and conglomerate units. The purpose of collecting geophysical-log data was to help determine horizontal and vertical distribution of contaminated ground water migrating from known or suspected sources and to aid in the placement of permanent borehole packers. The primary contaminants were derived from paint waste that included pigment sludges and wash solvents. The chlorinated volatile organic compounds probably originated from the wash solvents.

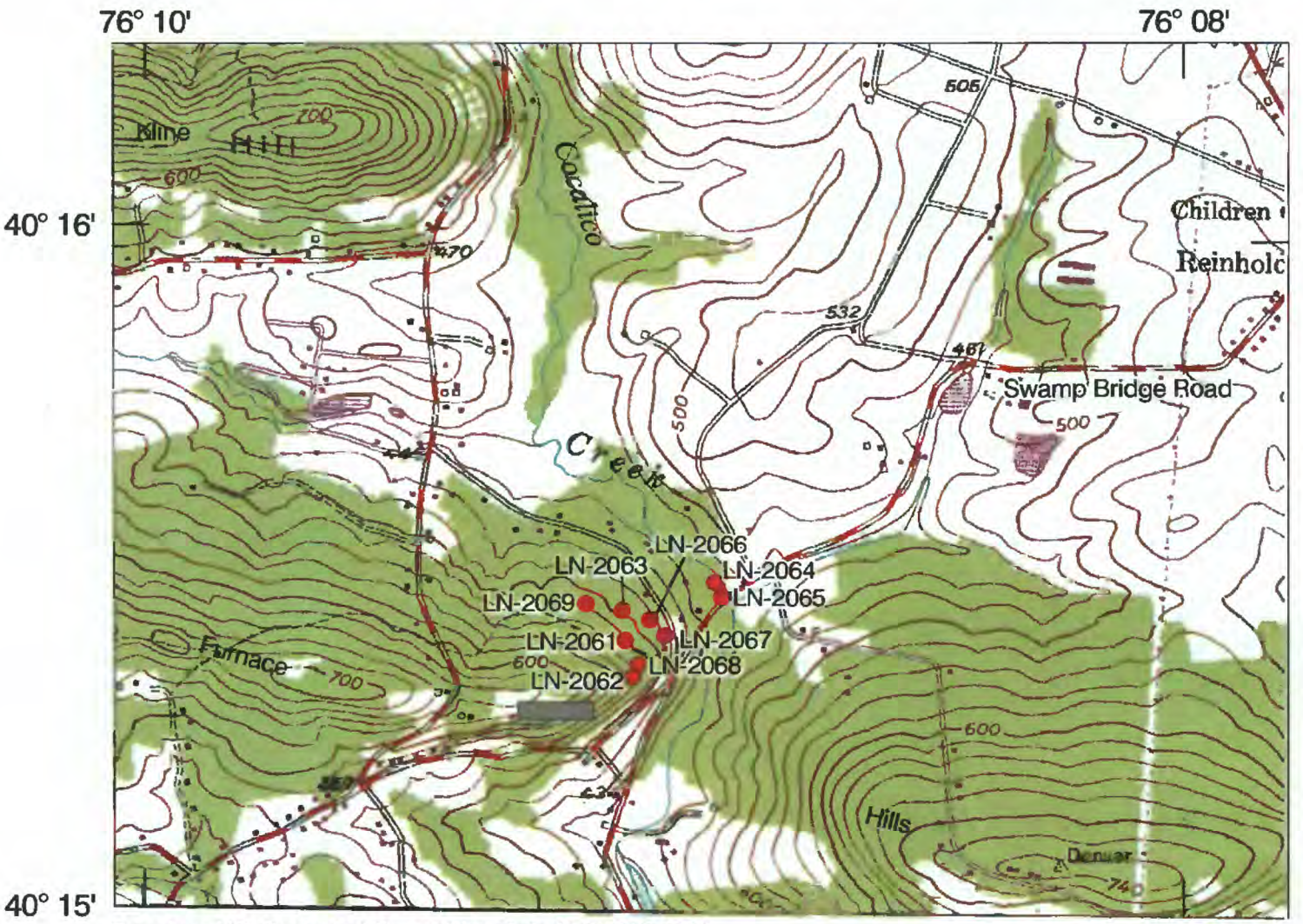
Caliper logs and video surveys were used to locate fractures; inflections on fluid-resistivity and fluid-temperature logs were used to locate possible water-bearing fractures. Heatpulse-flowmeter measurements were used to verify the locations of water-producing or water-receiving zones and to measure rates of flow between water-bearing fractures. Single-point-resistance and natural-gamma logs provided information on stratigraphy. After interpretation of geophysical logs, video surveys, and driller's logs, permanent multiple-packer systems were installed in each borehole to obtain depth specific water samples from one or more water-bearing fractures in each borehole.

INTRODUCTION

The Berkley Products Superfund Site (Berkley Site) covers approximately 21 acres; the landfill area and monitor wells are shown on the U.S. Geological Survey (USGS) Womelsdorf 7.5-minute topographic quadrangle map (fig. 1). The Berkley Site was used as a municipal waste dump from approximately 1930 until 1965. In 1965, the Lipton Paint Company, a subsidiary of Berkley Products Company, purchased the property. The operation continued to receive household trash from nearby communities but also began to receive paint wastes from Lipton. The property was purchased by its current owner in September 1970 after it was closed by Lipton.

During the period from 1965 to 1970, it is estimated that the Berkley Site may have received anywhere from 650 to about 40,000 gal of paint wastes from the Lipton Paint Company. It is believed that these wastes included pigment sludges and wash solvents (U.S. Environmental Protection Agency, 1995). Interviews with former operators and haulers indicate that the municipal trash was dumped to the south of the access road, toward the hillside; the paint wastes were deposited in the northern part of the dump.

The Berkley Site was originally investigated by the Pennsylvania Department of Environmental Resources (PaDER) and the U.S. Environmental Protection Agency (USEPA) in 1984. The Berkley Site was placed on the National Priorities List (NPL) in 1990. Results of environmental investigations by PaDER and by USEPA and its consultants indicate that the ground water beneath the Berkley Site is contaminated with volatile organic compounds (VOC's); concentrations of methylene chloride are as great as 860 mg/L in water samples from on-site monitor wells (U.S. Environmen-



Base from U.S. Geological Survey Womelsdorf 1:24,000, 1984

Figure 1. Locations of landfill and boreholes logged adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

tal Protection Agency, 1995). VOC's were generally not detected in ground-water samples from domestic wells or springs or in surface-water samples (U.S. Environmental Protection Agency, 1995). A draft Remedial Investigation (RI) was completed in January 1995, and a Feasibility Study (FS) was completed in September 1995 by the USEPA and its contractors (Halliburton-NUS, 1995).

In May 1997, the USGS was asked by USEPA to assist with hydrologic investigations for the Remedial Design (RD) study at the Berkley Site. USGS involvement was directed toward identification of water-bearing zones in the contaminated fractured-bedrock aquifer to help ensure that monitor wells were completed at appropriate depth horizons. This work is part of the support provided by the USGS to the USEPA on hydrogeologic investigations at Superfund sites in Pennsylvania.

Purpose and Scope

This report evaluates geophysical logs and video surveys collected by the USGS in boreholes adjacent to the Berkley Site, West Cocalico Township, Lancaster County, Pa., from February 9, 1998, to April 15, 1998 (table 1 and fig. 1). This report (1) identifies the location of subsurface fractures; (2) identifies, where possible, important water-bearing fractures; (3) identifies zones of potential borehole flow; and (4) describes the direction and rate of vertical borehole flow. These data provided hydrogeologic information in the vicinity of the Berkley Site and were used to select the most appropriate depth to screen and set permanent (Westbay[1]) packers in nine boreholes adjacent to the Berkley Site.

Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs and heatpulse-flowmeter measurements were collected in the nine boreholes. Video surveys were conducted in four of the nine boreholes (table 2). A cross-reference between USGS borehole-identification numbers and Berkley Products identification numbers is presented in table 1.

Location and Physiography

The Berkley Site is in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province (Fenneman, 1938; Berg and others, 1989) and is located on the tail of the east-west trending Furnace Hills ridge. The topography of the area is characterized by rolling hills and narrow ridges that are separated by broader valleys; altitudes range between 420 and 920 ft above mean sea level. Altitude on site ranges between 420 ft above sea level along Swamp Bridge Road to about 640 ft above sea level in the landfill area (fig. 1). The region is dissected by a mature, well-integrated drainage network. Landfill activities on the site have altered the original topographic surface.

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 1. *Well depth and casing length for boreholes logged by the U.S. Geological Survey adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

U.S. Geological Survey borehole-identification number	Berkley Products identification number	Depth of well below land surface (feet)	Length of casing below land surface (feet)
LN-2061	MW-6	499	21
LN-2062	MW-8	503	21
LN-2063	MW-9	498	19
LN-2064	MW-13	508	30
LN-2065	MW-14	485	30
LN-2066	MW-10	499	21
LN-2067	MW-11	445	20
LN-2068	MW-7	494	19
LN-2069	MW-12	320	20

Table 2. *Boreholes logged adjacent to the Berkley Products Superfund Site, February 9,1998, through April 15, 1998, West Cocalico Township, Lancaster County, Pennsylvania*

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

U.S. Geological Survey borehole-identification number	Berkley Products identification number	Date logged	Depth logged (feet)	Depth to water below land surface (feet)	Geophysical logs run
LN-2061	MW-6	2/16/98	499	123.42	C, G
LN-2061	MW-6	2/17/98	200	124.40	C
LN-2061	MW-6	2/25/98	181	119.60	B, C, F, G, R, T, V
LN-2061	MW-6	3/19/98	499	109.60	C, F, G, R, T
LN-2062	MW-8	2/09/98	503	81.30	C, F, G, R, T, V
LN-2063	MW-9	2/12/98	498	100.40	C
LN-2063	MW-9	2/17/98	124	96.75	C
LN-2063	MW-9	2/25/98	112	90.10	C, F, G, R, T, V
LN-2063	MW-9	3/25/98	494	123.42	C, F, G, R, T, V
LN-2064	MW-13	3/04/98	93	30.00	B, C, F, G, R, T, V
LN-2064	MW-13	3/28/98	491	2.10	C, F, G, R, T, V
LN-2065	MW-14	2/24/98	415	9.84	B, C, F, G, R, T, V
LN-2065	MW-14	3/04/98	334	3.60	B, C, F, G, R, T, V
LN-2065	MW-14	3/31/98	460	2.11	C, F, G, R, T
LN-2066	MW-10	3/30/98	382	63.01	C, F, G, R, T, V
LN-2066	MW-10	4/09/98	499	79.00	C, F, G, R, T, V
LN-2067	MW-11	3/31/98	410	63.00	C, F, G, R, T, V
LN-2067	MW-11	4/08/98	432	81.07	C, V
LN-2068	MW-7	4/06/98	494	118.20	C, F, G, R, T, V
LN-2069	MW-12	4/15/98	319	57.90	B, C, F, G, R, T, V

HYDROGEOLOGY

The Berkley Site is underlain by approximately 9,400 ft of interbedded sandstones, siltstones, and conglomerates of the Triassic age Hammer Creek Formation (fig. 2). Thickness of these individual units is highly variable, ranging from less than 1 to more than 100 ft beneath the site. A diabase dike of Triassic age is located immediately west of the site and has intruded the Hammer Creek Formation (Geyer and others, 1963; Berg and others, 1980; Wood, 1980).

Sandstone is the dominant lithology of the Hammer Creek Formation in the surrounding area but reportedly underlies less than one-third of the Berkley Site (U.S. Environmental Protection Agency, 1995). The sandstones range in color from red through brown to light gray and locally white. Most of the sandstones are composed of angular to subrounded, very-fine to coarse, colorless quartz grains in a matrix of clay-size material with hematite. The finer-grained sandstones tend to be better sorted than the coarser varieties. Bedding typically ranges from 1 or 2 in. to a foot or greater. Ripple marks, cross bedding, lensing, and channelling have been reported (Geyer and others, 1963).

The red siltstones underlie less than one-third of the site (U.S. Environmental Protection Agency, 1995) and are thin to medium bedded, usually friable, typically nonmicaceous, and interbedded with shale and sandstone. Mudcracks and ripple marks are present.

The coarse quartz conglomerates are ridge formers and underlie almost two-thirds of the site (U.S. Environmental Protection Agency, 1995). The conglomerates consist principally of angular to subangular grains of quartz, fragments of quartzite, some sandstone, and other rock fragments that are joined together by a matrix of clay-size material with hematite. Some lighter-colored conglomerates may be cemented with silica or calcite (Geyer and others, 1963). The conglomerate is typically thick to massively bedded with interbeds of sandstone.

The fine-grained, dark gray to black diabase dike forms a distinct ridge that runs northeast to southwest and underlies about 5 percent of the landfill area (U.S. Environmental Protection Agency, 1995). It consists principally of gray plagioclase feldspars (labradorite) and black or greenish-black pyroxene. Heating by the dike has produced a narrow (few yards width) alteration zone in the surrounding sedimentary rock (Geyer and others, 1963).

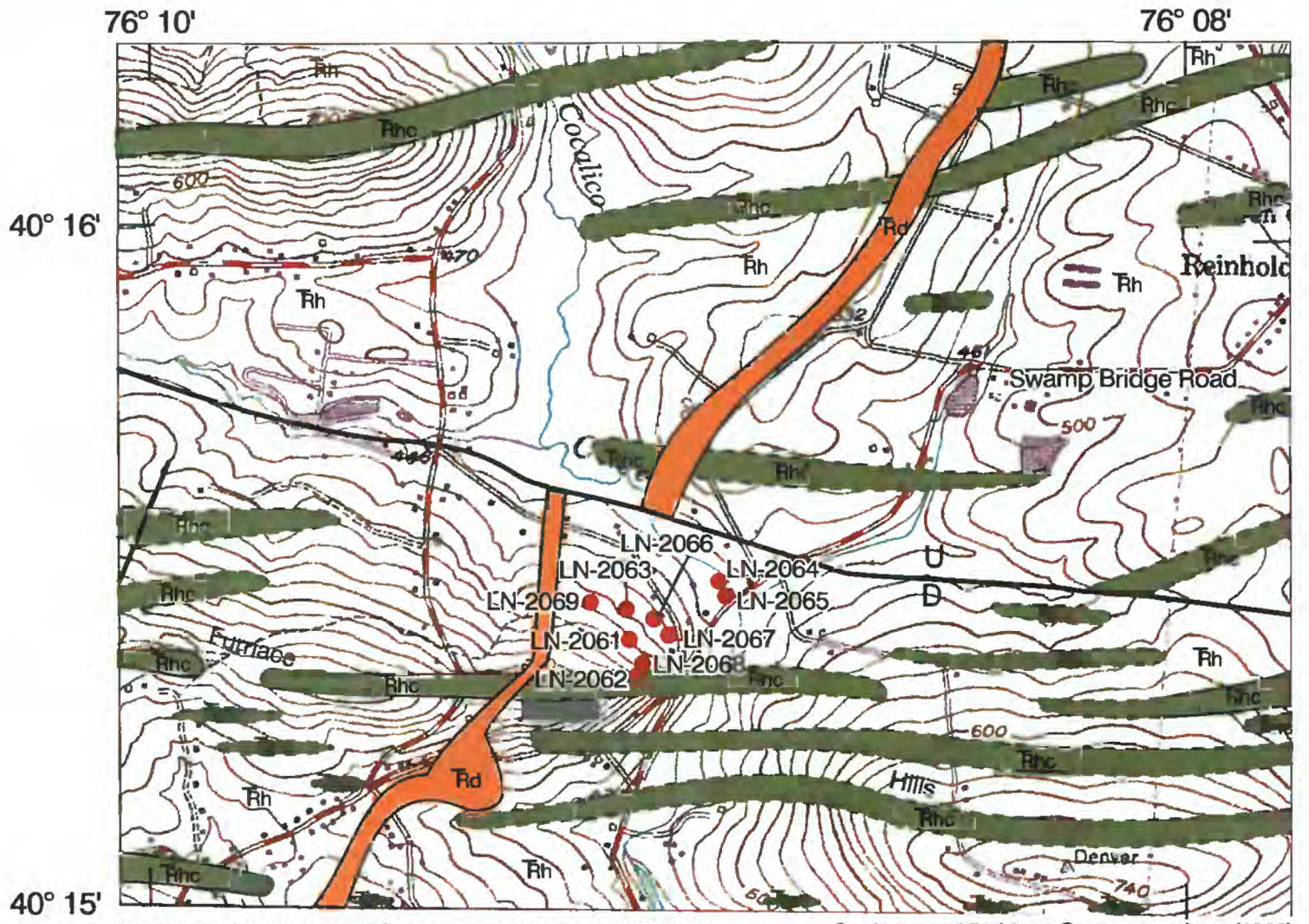
Much of the area surrounding the Berkley Site has been extensively faulted. A major, generally east-west fault is present about 0.5 mi north of the Berkley Site. Another major east-west fault, about 2.5 mi north of the Berkley Site, marks the contact between the Gettysburg-Newark Lowland Section and the Reading Prong Section of the New England Physiographic Province. In general, beds strike east-west and dip from 20° to 63° to the north; the average dip is about 36° (Geyer and others, 1963).

Ground water at the Berkley Site originates from infiltration of local precipitation and discharges to Cocalico Creek and leaks downward to deeper ground-water-flow systems. Precipitation infiltrates the soil and weathered overburden, enters the ground water, and moves through secondary openings such as joints, bedding planes, and vertical and horizontal fractures in the underlying bedrock, especially in the sandstones and conglomerates. Water-bearing fractures, detected from geophysical logging of the nine boreholes adjacent to the Berkley Site, are most common in the brittle sandstone and conglomerate beds (33 water-bearing fractures) and less common in the siltstone (18 water-bearing fractures) or at a lithologic contact (14 water-bearing fractures). Wood (1980, p. 16-18) describes the ground-water-flow system in the Hammer Creek Formation as consisting of a series of alternating, dipping, tabular aquifers that can extend hundreds to thousands of feet. The water-bearing fractures are more or less continuous along strike but can be terminated by faulting, intrusion of diabase dikes, or pinch out. Hydraulic connection between individual aquifers is poor; the greatest permeability is parallel to strike.

The diabase dike immediately west of the site is a ground-water divide. Water levels collected during the RI (U.S. Environmental Protection Agency, 1995) from monitor wells west of the diabase dike were considerably higher than in monitor wells east of the dike. Ground-water flow west of the dike is generally horizontal with little or no vertical component, whereas east of the dike there is a considerable downward vertical gradient (U.S. Environmental Protection Agency, 1995, fig. 3-13).

Ground water in the upper part of the Hammer Creek Formation generally is under unconfined (water-table) conditions. Water at an intermediate and deep part of the aquifer may be confined or semi-confined, resulting in borehole flow. Generally, wells penetrate multiple systems, and water levels measured in these wells represent composite heads. Where differences in potentiometric head are present, water in the borehole flows from zones of higher head to zones of lower head.

Water-level data indicate that the depth to water in wells at the Berkley Site generally ranges from approximately 2 to 124 ft bls (below land surface)



Base from U.S. Geological Survey Womelsdorf 1:24,000, 1984

Geology modified from Geyer and others (1963)

0 1MILE

0 1KILOMETER

EXPLANATION

GEOLOGIC UNITS

Trh HAMMER CREEK FORMATION

Trhc HAMMER CREEK FORMATION, Quartz conglomerate

Trd DIABASE

BERKLEY PRODUCTS SUPERFUND SITE, LANDFILL AREA

U / D FAULT, SHOWING DIRECTION OF MOVEMENT (U - UP, D - DOWN)

DEFINITE GEOLOGIC CONTACT

INFERRED GEOLOGIC CONTACT

LN-2065 WELL LOCATION AND IDENTIFICATION NUMBER

Figure 2. Bedrock geology of the Berkley Products Superfund Site and adjacent area, West Cocalico Township, Lancaster County, Pennsylvania.

(table 2). Ground-water levels fluctuate with precipitation events and seasonal variations in recharge. Ground water generally flows in a direction similar to the topographic gradient towards Cocalico Creek.

BOREHOLE GEOPHYSICAL LOGS AND VIDEO SURVEYS

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

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

The natural-gamma or gamma log measures the natural-gamma radiation (photons) emitted from rocks penetrated by the borehole. The most common sources 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. 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 wells or 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 increasing borehole diameter, water-bearing fractures, and increasing dissolved-solids concentration of borehole fluid. The single-point-resistance log is used to correlate geology and lithology between wells or boreholes and may help identify formation water-bearing zones (Keys, 1990).

Fluid resistivity is the inverse of fluid conductivity. The fluid-resistivity log measures the electrical resistivity of the water column in the well or borehole. The fluid-resistivity probe measures the resistivity of borehole water between electrodes in the probe. Fluid-resistivity logs reflect changes in the dissolved-solids concentration of the borehole water. Fluid-resistivity logs are used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones are usually identified by distinct changes in resistivity. Intervals of vertical borehole flow are usually identified by a low-resistivity gradient between a water-producing and a water-receiving zone. Also, zones of salt water intrusion and some types of contaminant plumes can be identified.

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

The direction and rate of borehole-fluid 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 storage within the borehole. If the seal between the borehole and flowmeter is not complete, some water can bypass the flowmeter, resulting in measurements of flow that are less than the actual rate. Although the heatpulse flowmeter is a calibrated probe, the data are primarily used as a relative indicator to identify water-producing zones.

Video surveys were conducted by lowering a waterproof camera down the borehole and recording the image on video tape. The depth indicated on the video log may not correspond exactly to the geophysical logs because of some minor slippage of the video cable.

ANALYSIS OF BOREHOLE GEOPHYSICAL LOGS AND VIDEO SURVEYS

The locations of boreholes logged are shown on figure 1. The reference measuring point for all geophysical logs and video surveys is in feet below land surface. For each borehole, the date(s) logged, depth logged, water level at the time of logging, and list of logs run in each borehole are presented in table 2.

LN-2061 (MW-6)

This monitor well was logged four times over a period of several weeks because of the unstable nature of the borehole walls (table 2). The caliper log from February 17, 1998, shows the borehole is cased with 5-in.-diameter casing to 20 ft bls (fig. 3). The caliper log shows major fractures at 30-32, 77-79, and 180-184 ft bls plus numerous minor fractures throughout the open-hole interval. At 200 ft, the borehole had collapsed. Additional geophysical logging of this borehole was halted until the borehole could be redrilled and cleaned out.

Monitor well LN-2061 was logged again on February 25, 1998. The caliper log shows the borehole walls had collapsed to a depth of 181 ft (fig. 4). The natural-gamma log shows siltstone units interbedded with sandstone and(or) conglomerate units. Major siltstone units are present at land surface to a depth of 34 ft and again from a depth of 76-155 ft. The fluid-resistivity log shows major changes in slope at 142 and 158 ft bls that correlate to minor fractures and may indicate water-producing or water-receiving zones. The video survey shows water entering the borehole through fractures at 58 and 66 ft bls, which is above the water level. At 124 ft bls there is a decrease in suspended sediment and visibility increases. The increase in visibility correlates to a minor fracture at 126 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward flow at 130 ft bls; additional flow entered through fractures at 140 and 151-162 ft bls (table 3).

Table 3. *Summary of heatpulse-flowmeter measurements for borehole LN-2061 (MW-6) on February 25, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
130	0.47	Down
145	.89	Down
164	1.4	Down
174	1.4	Down

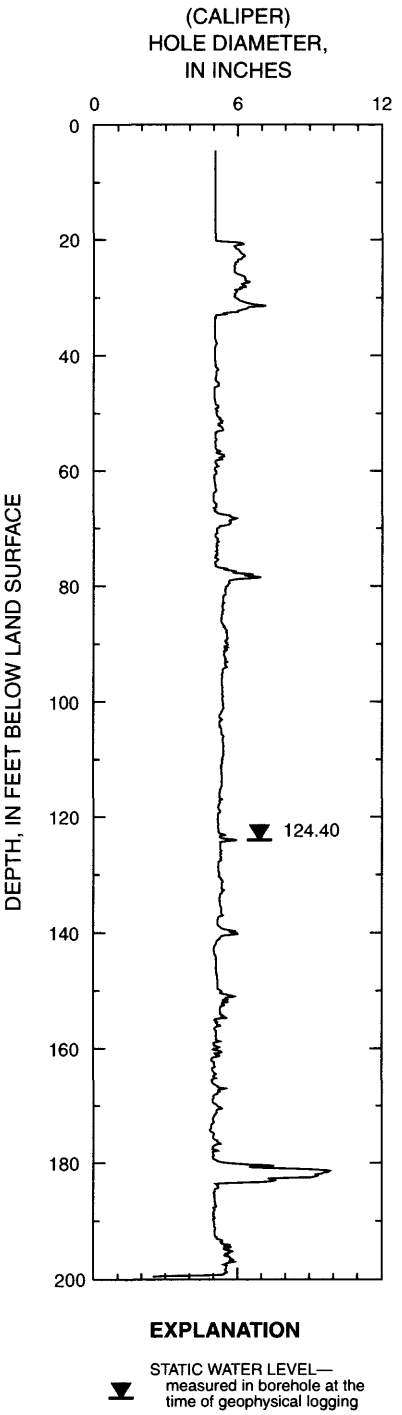


Figure 3. Caliper log for borehole LN-2061 (MW-6), collected on February 17, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

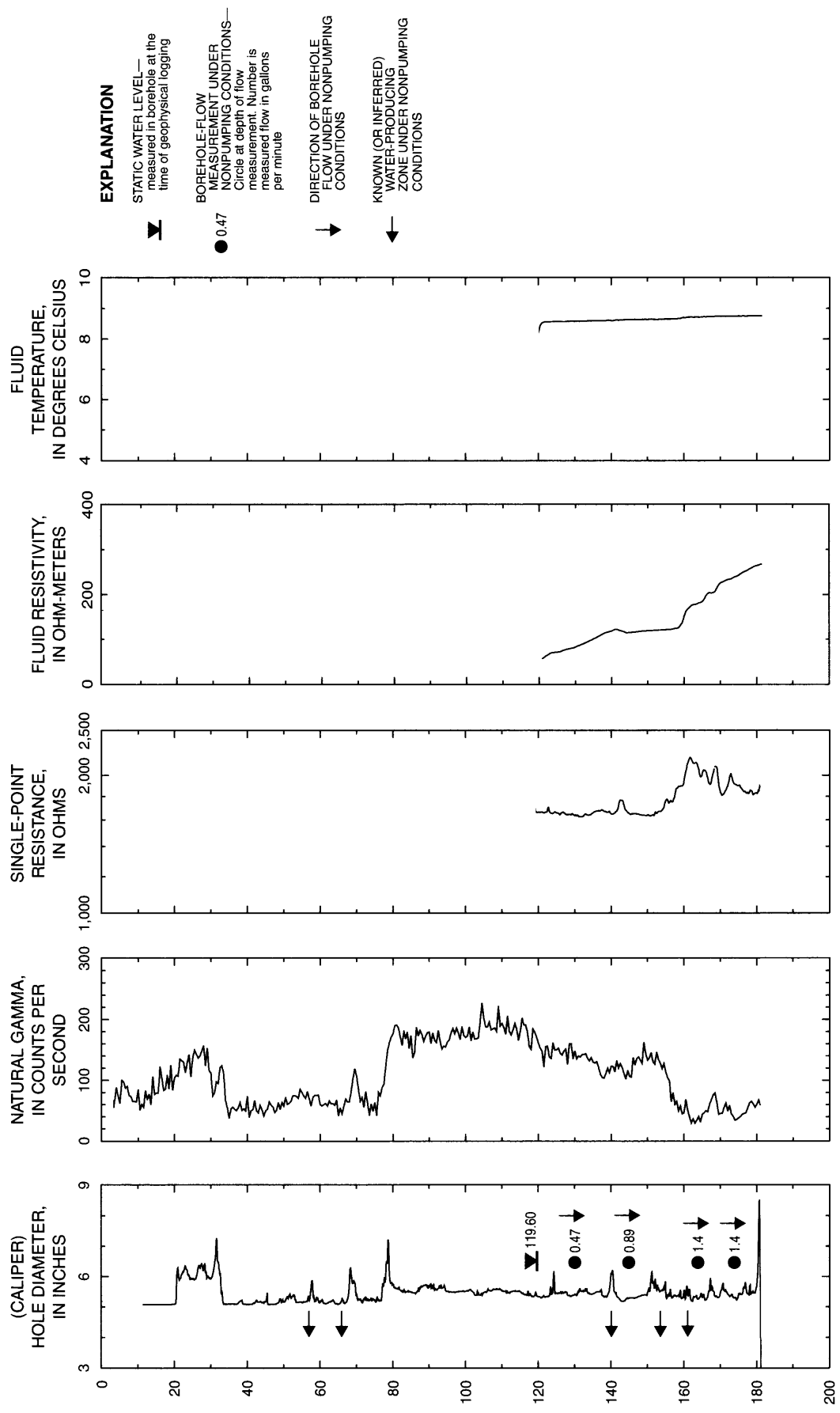


Figure 4. Geophysical logs and direction of nonpumping flow within borehole LN-2061 (MW-6), collected on February 25, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

On March 19, 1998, a 4-in.-diameter drilling rod was temporarily installed from land surface to a depth of 239 ft. The geophysical tools were then lowered through the drilling rod. Only the natural-gamma data could be obtained by logging within the drilling rod; the other logs (caliper, single-point resistance, fluid resistivity, and fluid temperature) were collected from the bottom of the drilling rod to the total depth of the borehole. The caliper log shows the total depth of the borehole is 499 ft (fig. 5). The caliper log shows numerous minor fractures throughout the open-hole interval. The natural-gamma log shows siltstone units interbedded with sandstone and(or) conglomerate units. The major siltstone units are at 180-208, 234-340, 358-370, and 442-453 ft bls. The fluid-resistivity and fluid-temperature logs show a small change in slope at 353 and 480 ft bls. The changes in slope in the fluid-resistivity logs correlate to fractures identified from the caliper log, suggesting possible water-producing or water-receiving zones. The fluid-resistivity log also shows a minor deflection at 310 ft bls. Under nonpumping conditions (February 25, 1998), the heatpulse-flowmeter measurements showed most water enters the borehole from fractures between depths of 124 to 160 ft. The water flows downward until exiting the borehole through the fracture at 475 ft bls (table 4). The driller's log and heatpulse-flowmeter measurements show the largest water-producing zone in the borehole is at approximately 158 ft bls.

A permanent borehole packer was placed at a depth of 87.5 ft bls to isolate water-producing zones at depths of 58 and 68 ft bls. Permanent borehole packers were installed at depths of 147.5 and 167.5 ft bls to isolate water-producing zones identified at depths of 124 and 140 ft bls and 151-162 ft bls. A permanent borehole packer was placed at a depth of 237.5 ft bls to include the length of borehole that did not have a complete suite of logs collected because of the repeated collapse of the borehole. Additional permanent borehole packers were placed at depths of 267.5 ft bls, to include a length of borehole that had a driller estimated yield of 1-2 gal/min; at 344.5 and 364.5 ft bls, to include two possible water-producing zones at 310 and 353 ft bls; at 439.5 ft bls, to include a length of borehole that had a driller estimated yield of 2 gal/min; and at 469.5 ft bls, to include a minor fracture at 450-452 that had a driller estimated yield of 20 gal/min and a minor fracture at 475 ft bls that is a water-receiving zone as determined from geophysical logs.

Table 4. *Summary of heatpulse-flowmeter measurements for borehole LN-2061 (MW-6) on March 19, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
244	1.4	Down
260	1.4	Down
300	1.5	Down
320	1.5	Down
346	1.3	Down
364	1.3	Down
400	1.2	Down
430	1.4	Down
458	1.4	Down
467	1.4	Down
484	No flow	Not determined

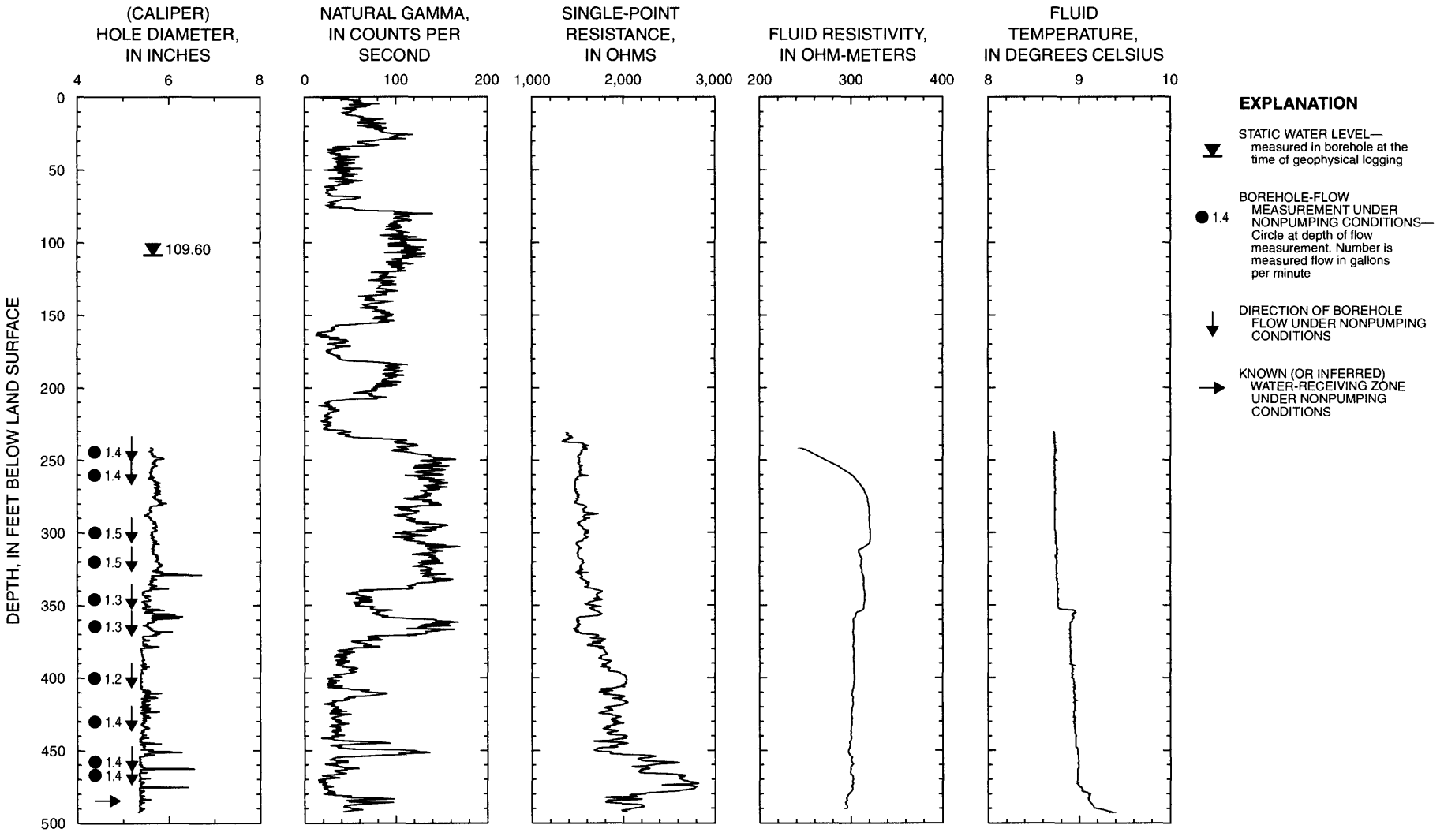


Figure 5. Geophysical logs and direction of nonpumping flow within borehole LN-2061 (MW-6), collected on March 19, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2062 (MW-8)

The caliper log shows the total depth of the borehole is 503 ft bls, and it is cased with 5-in.-diameter casing to 21 ft bls (fig. 6). The caliper log shows major fractures at 22-38, 48-52, 81, 126, 272-274, and 412-416 ft bls plus numerous smaller fractures throughout the open-hole interval. The gamma log shows siltstone units are interbedded with sandstone units. The major siltstone units are present at 14-35, 48-100, 125-228, 270-412, and 458-500 ft bls. The fluid-resistivity log shows major changes in slope at 120, 204, and 236 ft bls that correlate to minor fractures, suggesting possible water-producing and water-receiving zones. The fluid-temperature log also shows a change in slope at 204 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured downward flow at a rate of 0.4-0.5 gal/min from 103 to 182 ft bls and upward flow of 0.7-0.8 gal/min from 251 to 430 ft bls (table 5). At a depth of 216 ft bls, the upward flow had decreased to 0.3 gal/min. The geophysical logs and the heatpulse-flowmeter measurements indicate water enters the borehole through fractures at about 81 and 120 ft bls, moves downward, and exits the borehole through fractures at approximately 204 ft bls. Additional water is produced below 430 ft bls, moves upward, and exits the borehole through fractures at 236 and 204 ft bls.

Permanent borehole packers were placed at depths of 42.5, 102.5, and 112.5 ft bls to include major fractures at 22-38, 48-52, and 81 ft bls and any shallow water-producing zones. Permanent borehole packers also were placed at a depth of 132.5 ft bls to isolate the water-producing zone at 120 ft bls. Permanent borehole packers also were installed at depths of 192.5 ft bls to isolate a water-receiving zone at 186 ft bls and at 217.5 ft bls to isolate a water-receiving zone at 204 ft bls and a driller reported water-bearing zone at 210 ft bls. Permanent borehole packers installed at depths of 247.5 and 262.5 ft bls isolate water-receiving zones at 236 and 254-256 ft bls. Additional permanent borehole packers were placed at depths of 407.5 ft bls to include a major fracture at 272-274 ft bls and other possible water-producing zones near this depth. Permanent borehole packers were again installed at 427.5, 437.5, and 462.5 ft bls to include a major fracture at 412-416 ft bls and a number of water-producing zones located at depths between 430 and 457 ft bls.

Table 5. *Summary of heatpulse-flowmeter measurements for borehole LN-2062 (MW-8) on February 9, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
103	0.4	Down
136	.5	Down
182	.5	Down
216	.3	Up
251	.7	Up
264	.8	Up
280	.8	Up
320	.8	Up
368	.8	Up
406	.7	Up
430	.8	Up
457	No flow	Not determined
480	No flow	Not determined

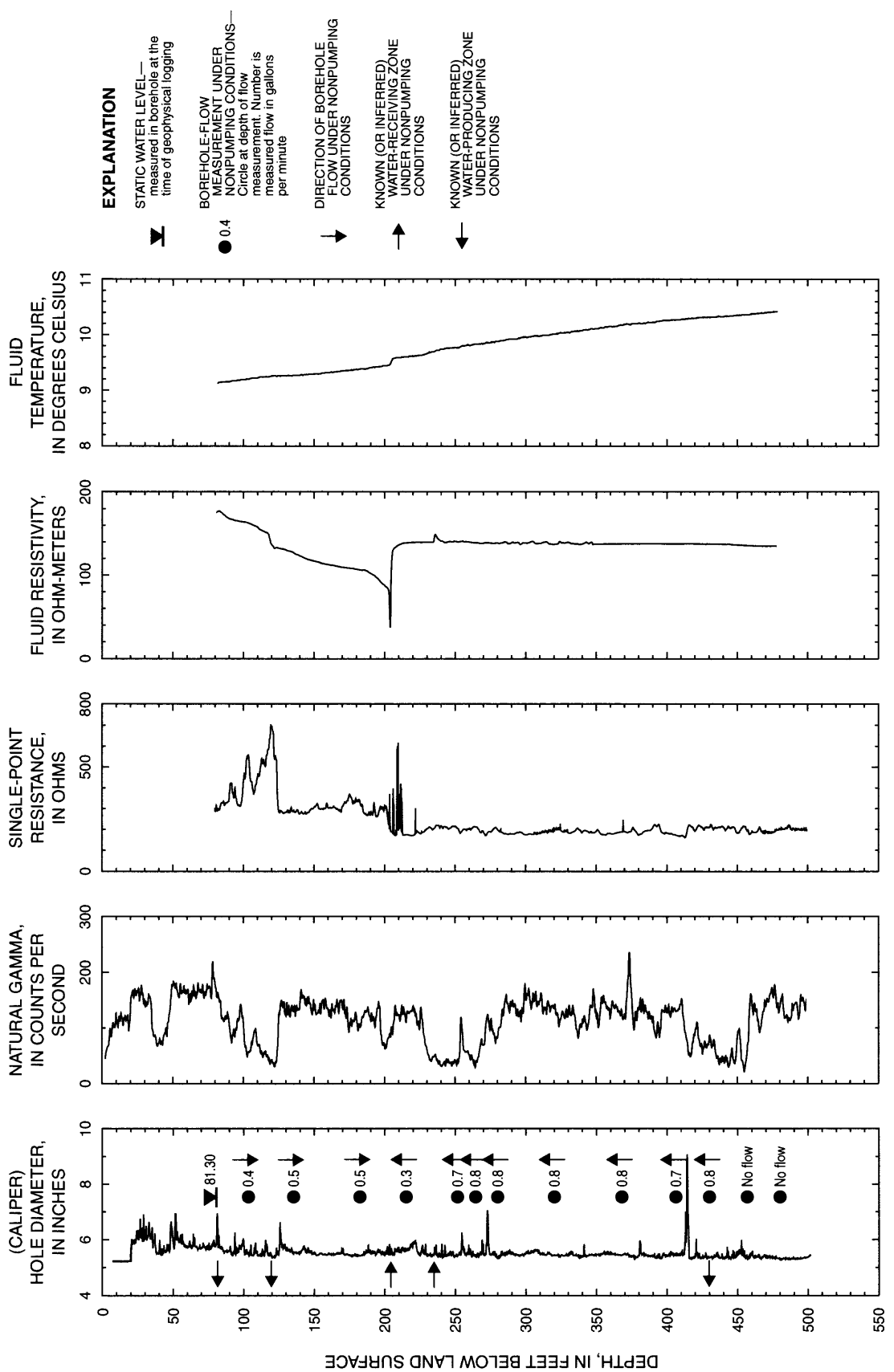


Figure 6. Geophysical logs and direction of nonpumping flow within borehole LN-2062 (MW-8), collected on February 9, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2063 (MW-9)

Monitor well LN-2063 was logged four times over a period of several weeks because of the unstable nature of the borehole walls (table 2). The caliper log from February 12, 1998, shows the borehole is cased with 5-in.-diameter casing to a depth of 19 ft, and the borehole is drilled to a depth of 498 ft bls (fig. 7). The caliper log shows major fractures at 19-34, 60-66, 80, and 106-124 ft bls; obstructions in the borehole at 48, 124-131, and 464-466 ft bls; plus numerous minor fractures throughout the open-borehole interval. Further geophysical logging of this borehole was halted until the borehole could be redrilled and cleaned out.

The caliper log from February 25, 1998, shows the borehole is cased with 5-in.-diameter casing to a depth of 21 ft bls (fig. 8). The caliper log shows major fractures at 21-34, 62-68, 82-86, and 108-112 ft bls plus numerous minor fractures throughout the open-hole interval. At 112 ft, the borehole had collapsed. The natural-gamma log shows claystone and siltstone units interbedded with sandstone and(or) conglomerate units. Claystone and(or) siltstone units are present at land surface to a depth of 34, 44-55, 61-69, and 78-86 ft bls. The fluid-resistivity log shows a major change in slope at 100 ft bls that suggests a possible fluid-producing zone. Under nonpumping conditions, the heatpulse flowmeter measured downward flow at 94 and 104 ft bls (table 6). The geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through fractures at about 92 and 96 ft bls.

On March 25, 1998, a 4-in.-diameter drilling rod was temporarily installed from land surface to a depth of 157 ft. The geophysical tools were then lowered through the drilling rod. Only the natural-gamma data could be obtained by logging within the drilling rod; the other logs (caliper, single-point resistance, fluid resistivity, and fluid temperature) were collected from the bottom of the drilling rod to the total depth of the borehole. The caliper log shows the total depth of the borehole is 494 ft (fig. 9). The caliper log shows major fractures at 420-425 and 444-446 ft bls plus numerous smaller fractures through the open-hole interval. The natural-gamma log shows claystone and(or) siltstone units interbedded with sandstone and(or) conglomerate units. Major claystone and siltstone units are present from land surface to 35 ft bls and at depths of 108-290, 355-400, 410-422, 445-467, and 479-491 ft bls. The fluid-resistivity log shows major changes in slope at 424 and 471 ft bls, the latter of which correlates to a major fracture; both deflections suggest possible fluid-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured downward flow from 165 to 419 ft bls, and no flow at 484 ft bls (table 7). The geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through fractures at about 92 and 96 ft bls. Water exits the borehole through the major fracture at 444-446 ft bls.

Permanent borehole packers were placed at depths of 40.5, 90.5, 105.5, and 172.5 ft bls to include the major fractures at 19-34, 62-68, 82-86, and 108-124 ft bls plus driller reported water-bearing zones at depths of about 87, 98, 102, and 115 ft bls. This string of packers also includes a length of borehole that did not have a complete suite of logs collected because of the repeated collapse of the borehole. Additional permanent borehole packers were placed at depths of 292.5, 312.5, 367.5, 402.5, and 437.5 ft bls to include driller reported water-bearing zones at depths of about 207, 297, 360, and 432 ft bls, a number of minor water-producing zones, and a water-receiving zone at 425 ft bls. A permanent borehole packer also was placed at 457.5 ft bls to include a major fracture from 444-446 ft bls and a number of water-producing zones between 472 and 480 ft bls.

Table 6. *Summary of heatpulse-flowmeter measurements for borehole LN-2063 (MW-9) on February 25, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
94	0.14	Down
104	.46	Down

Table 7. *Summary of heatpulse-flowmeter measurements for borehole LN-2063 (MW-9) on March 25, 1998, adjacent to the Berkley Products Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
165	1.0	Down
228	1.1	Down
294	1.2	Down
314	1.0	Down
419	1.2	Down
484	No flow	Not determined

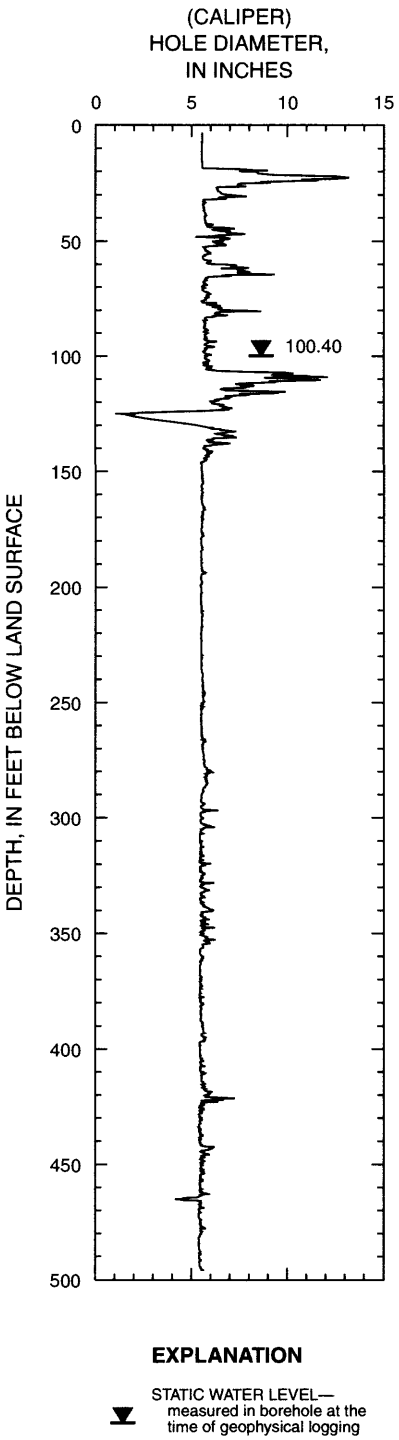


Figure 7. Caliper log for borehole LN-2063 (MW-9), collected on February 12, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

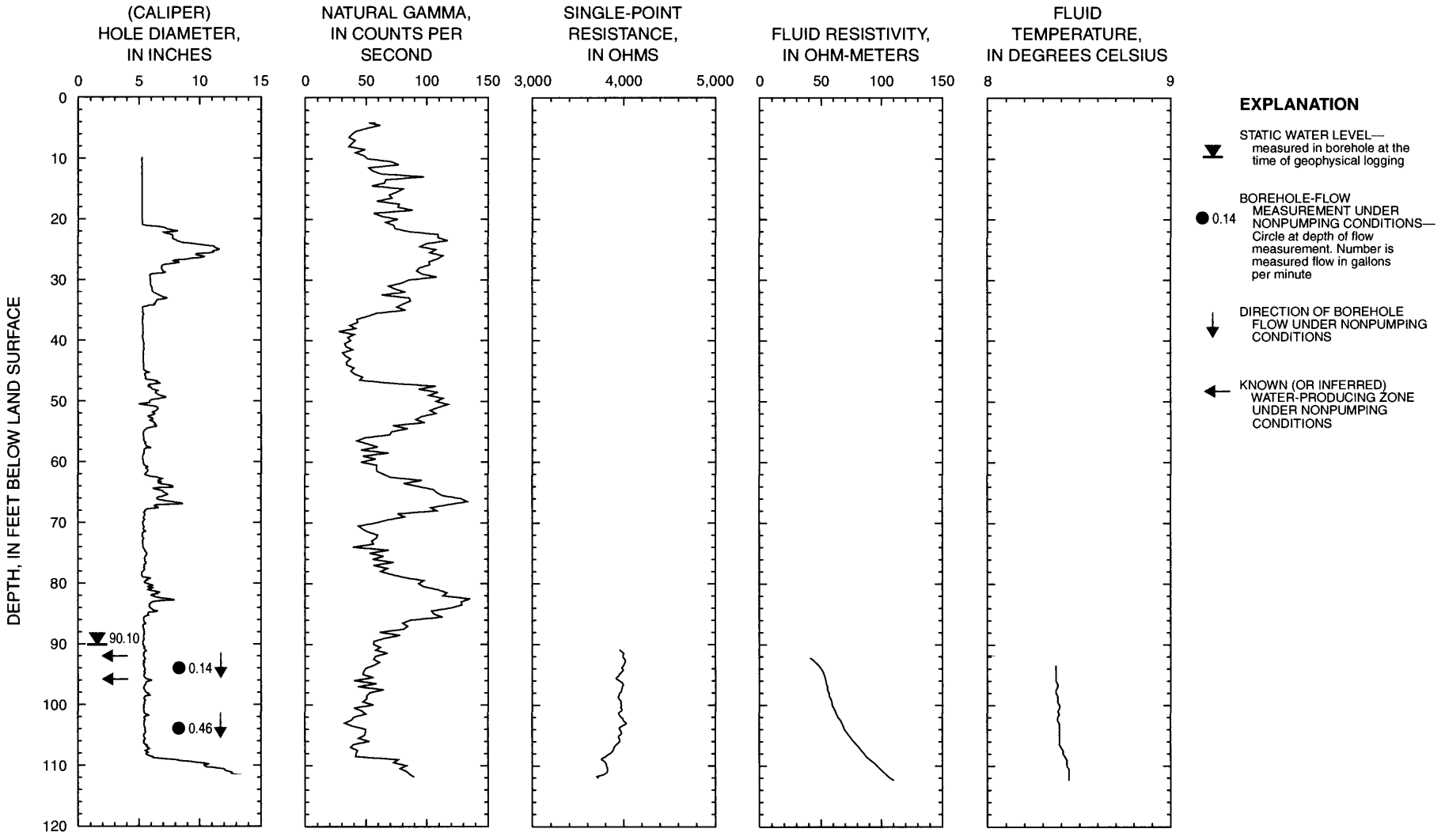


Figure 8. Geophysical logs and direction of nonpumping flow within borehole LN-2063 (MW-9), collected on February 25, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

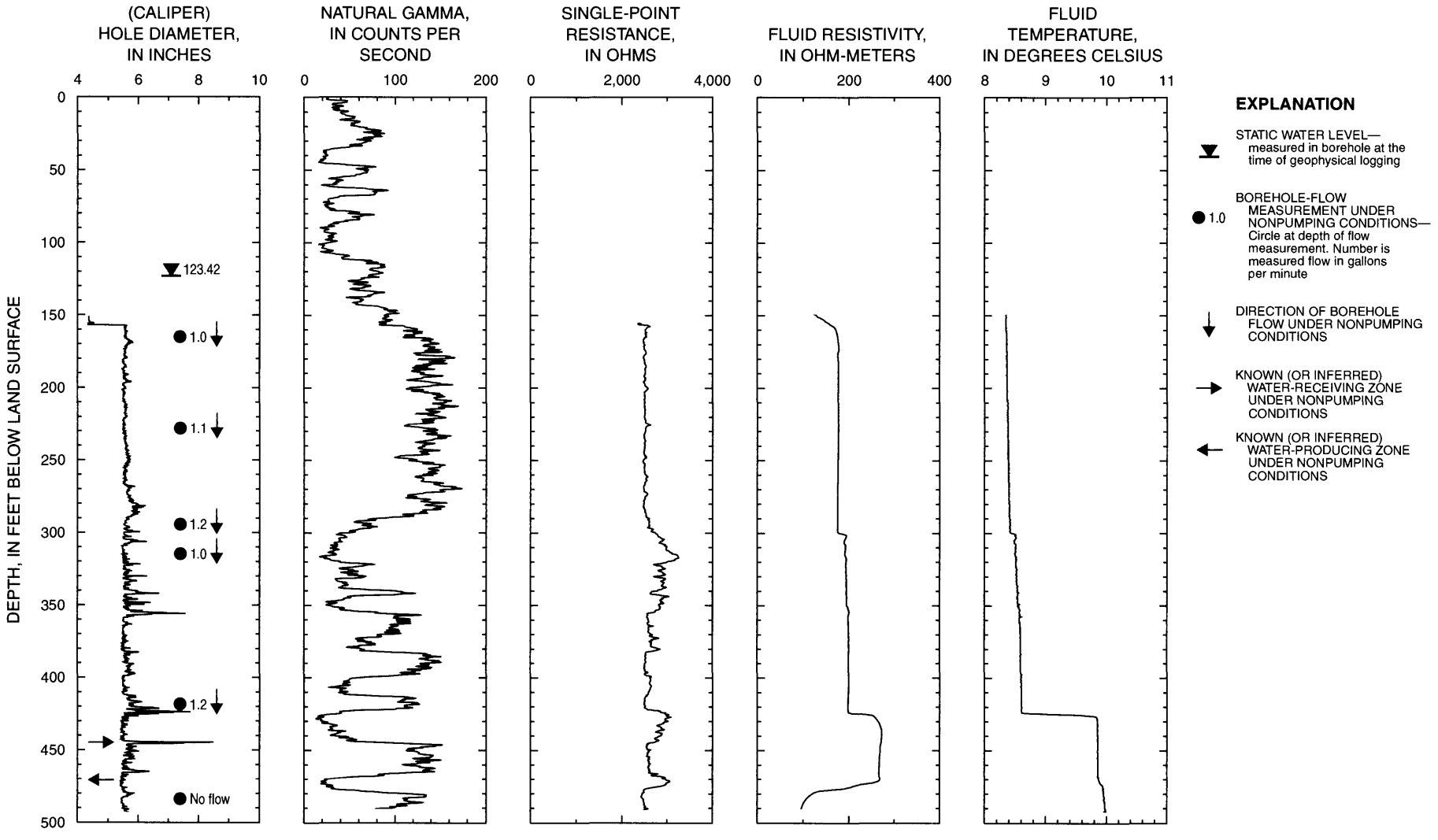


Figure 9. Geophysical logs and direction of nonpumping flow within borehole LN-2063 (MW-9), collected on March 25, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2064 (MW-13)

Monitor well LN-2064 was logged twice over a period of several weeks because of the unstable nature of the borehole walls (table 2). The caliper log from March 4, 1998, shows the borehole is cased with 5-in.-diameter casing to a depth of 30 ft bls (fig. 10). The caliper log also shows major fractures at 34-40 and 86-88 ft bls. At 93 ft, the borehole collapsed. The natural-gamma log shows the presence of sandstone and(or) conglomerate units from land surface to a depth of about 36 ft bls and a major siltstone unit from 36 ft bls to the depth of the collapsed borehole. The fluid-resistivity log shows slight deflections in slope at 32 and 37 ft bls that correspond to a major fracture. The video survey showed cloudy water from land surface to a depth of 36 ft bls and near zero visibility from 85 ft bls to the depth of the collapsed borehole. The video survey also showed a number of small horizontal fractures between the major fractures. Under nonpumping conditions, the heatpulse flowmeter measured upward flow throughout the open-hole interval (table 8). The geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through the major fracture at 34-40 ft bls, through minor fractures from 60-80 ft bls, and possibly through deeper fractures such as the major fracture at 86-88 ft bls. (Note: It is uncertain if the major fracture at 86-88 ft bls is a water-producing zone. Although the borehole collapsed at 93 ft, the borehole was probably not completely sealed. Water flowing upwards from depths greater than 93 ft may have been able to seep around the blocked segment of the borehole.)

On March 28, 1998, a 4-in.-diameter drilling rod was temporarily installed from land surface to a depth of 385 ft; it was later pulled back to a depth of 195 ft. The geophysical tools were then lowered through the drilling rod. Only the natural-gamma data could be obtained by logging within the drilling rod; the other logs (caliper, single-point resistance, fluid resistivity, and fluid temperature) were collected from the bottom of the drilling rod to the total depth of the borehole. The caliper logs show the borehole was logged to a depth of 491 ft bls (fig. 11); the driller's log indicates that the borehole was drilled to a depth of 508 ft bls. The caliper log shows a major fracture at 396 ft bls plus numerous minor fractures throughout the open-hole interval. The natural-gamma log shows siltstone units are commonly interbedded with sandstone and(or) conglomerate units. The major, and relatively clean, sandstone and conglomerate units are present from land surface to 36, 228-262, 289-322, and 356-396 ft bls. The fluid-resistivity and fluid-temperature logs show major changes in slope at 236, 298, 303, and 310 ft bls that correlate to fractures, suggesting possible water-producing zones. Under nonpumping conditions, the heatpulse flowmeter measured no flow from 315-480 ft bls; water enters the borehole through minor fractures from 294-310 ft bls and flows upward (table 9). Almost half of the water exits the borehole through the major fracture at 86-88 ft bls.

Permanent borehole packers were placed at depths of 25.5 and 30.5 ft bls to prevent flow from entering the steel casing. The permanent borehole packer at 65.5 ft bls isolated the major fracture at 34-40 ft bls and the driller reported water-bearing zone at 60 ft bls. Permanent borehole packers also were placed at depths of 120.5 and 210.5 ft bls to include the length of borehole that did not have a complete suite of logs collected because of the repeated collapse of the borehole, as well as the major fracture at 88-90 ft bls. Additional permanent borehole packers were placed at 255.5, 290.5, and 352.5 ft bls to include driller reported water-bearing zones at about 235, 280, and 374 ft bls and possible water-producing zones at 298, 303, and 310 ft bls.

Table 8. *Summary of heatpulse-flowmeter measurements for borehole LN-2064 (MW-13) on March 9, 1998, adjacent to the Berkley Products Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
33	1.0	Up
50	.6	Up
60	.8	Up
70	.7	Up
82	.5	Up

Table 9. *Summary of heatpulse-flowmeter measurements for borehole LN-2064 (MW-13) on March 28, 1998, adjacent to the Berkley Products Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
215	1.1	Up
254	.9	Up
290	.9	Up
305	.3	Up
315	No flow	Not determined
333	No flow	Not determined
390	No flow	Not determined
440	No flow	Not determined
480	No flow	Not determined

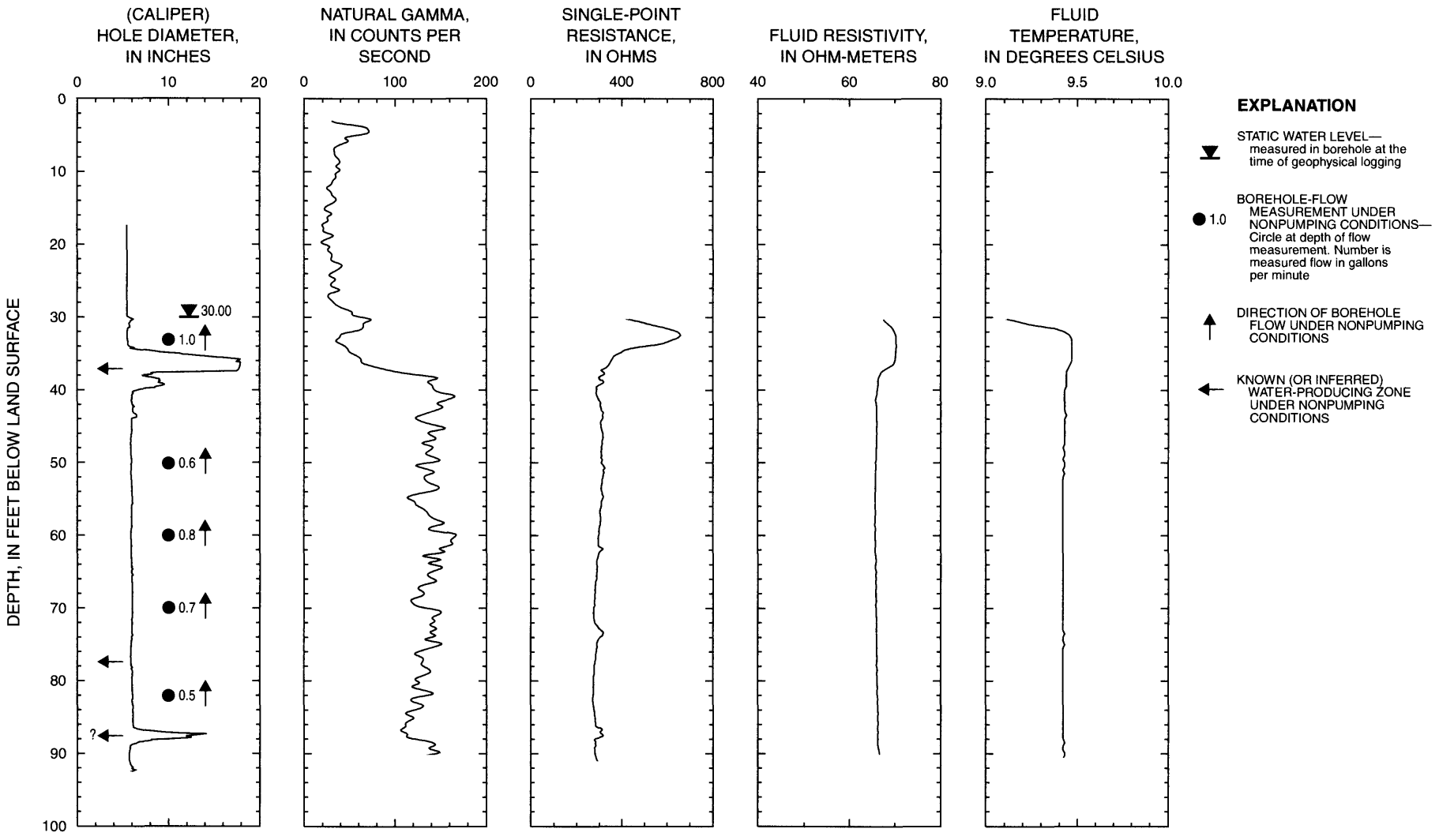


Figure 10. Geophysical logs and direction of nonpumping flow within borehole LN-2064 (MW-13), collected on March 4, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

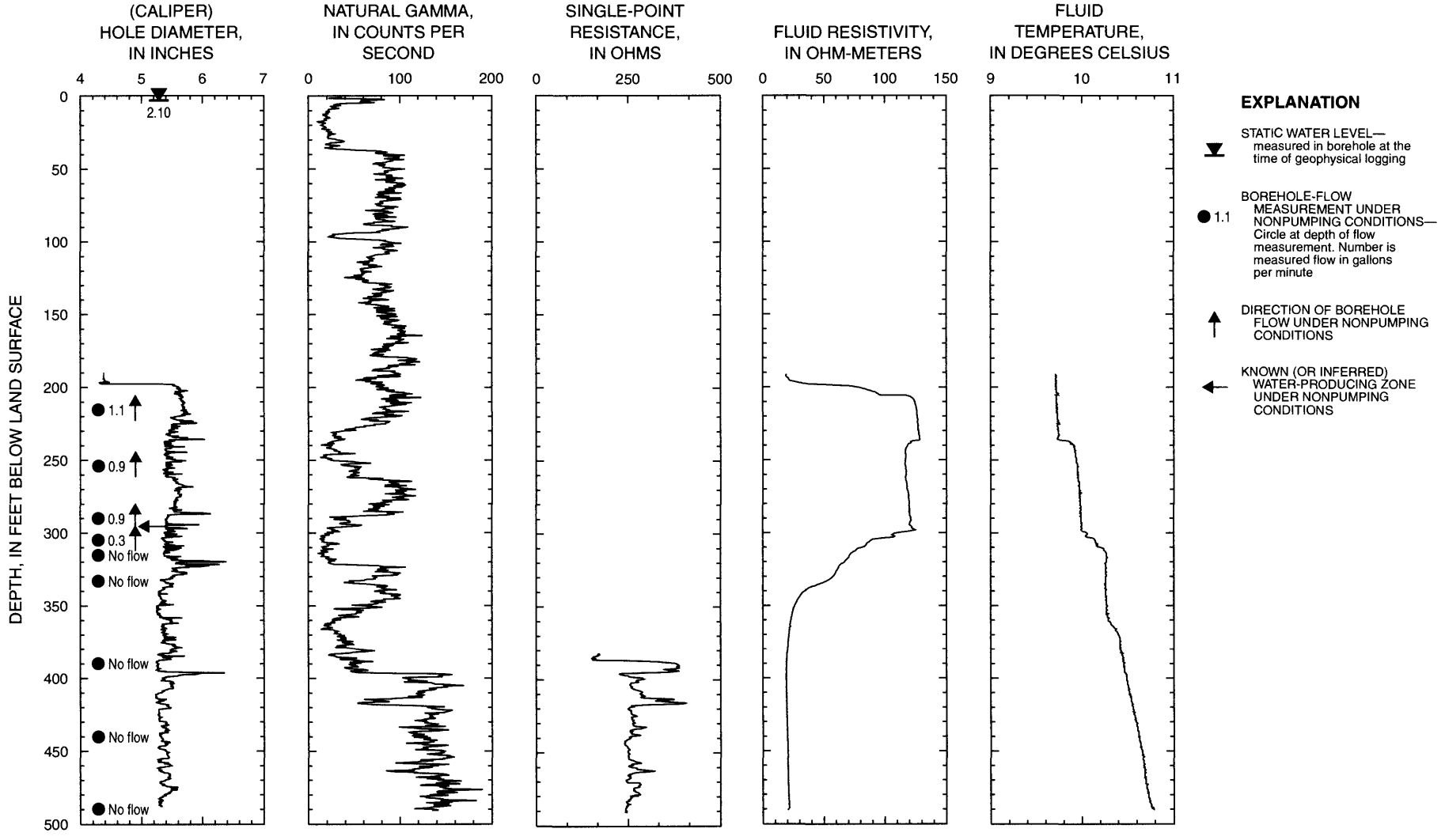


Figure 11. Geophysical logs and direction of nonpumping flow within borehole LN-2064 (MW-13), collected on March 28, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2065 (MW-14)

Monitor well LN-2065 was logged four times (twice on February 24, 1998) over a period of several weeks because of the unstable nature of the borehole walls (table 2). The first caliper log from February 24, 1998, shows the borehole is cased with 5-in.-diameter casing to a depth of 30 ft bls, and the total depth of the borehole is 415 ft bls (fig. 12). The caliper log shows major fractures at 121-122, 124-126 (fig. 12), and 379 ft bls (fig. 13) plus numerous other fractures throughout the open-hole interval. A constriction of the borehole is present at 130 ft bls. After completion of the caliper log, the borehole collapsed at 189 ft bls. Logging, however, with the natural-gamma, fluid-resistivity, fluid-temperature, and heatpulse-flowmeter tools continued above the collapsed part of the borehole. The natural-gamma log shows siltstone units are commonly interbedded with sandstone and(or) conglomerate units. The major sandstone or conglomerate units are present from land surface to a depth of 58 ft bls and from 89-172 ft bls. The fluid-resistivity log shows major changes in slope at 101 and 107 ft bls that correlate to fractures on the caliper log and may indicate water-producing or water-receiving zones.

The borehole was then cleaned out and deepened by the driller to a depth of 460 ft bls. A 4-in.-diameter drilling rod was then temporarily installed to a depth of 347 ft to prevent collapse of the borehole. The caliper log shows major fractures are present at 379, 415-418, and 451 ft bls (fig. 13). The natural-gamma log shows siltstones are the dominant rock type at depths of 55-90, 175-340, and 380-400 ft bls. The fluid-resistivity log shows minor changes in slope at 367, 401, 411, and 426 ft bls; the fluid-temperature log shows a minor change in slope at 426 ft bls. These deflections may indicate water-producing or water-receiving zones.

A full suite of logs, including the video survey, was run on March 4, 1998, to a depth of 334 ft bls where the borehole had collapsed (table 2) (fig. 14). The fluid-resistivity and fluid-temperature logs showed a possible water-producing zone at 107 ft bls but little if any deflection in slope below a depth of 110 ft, which indicates the absence of water-producing or water-receiving zones. The video survey shows numerous horizontal, vertical, and open fractures beginning at 35 ft bls and continuing to 334 ft bls where the borehole was completely bridged. Turbulence was noted at the fractures from 34-40 and 50-58 ft bls that may have been caused by drilling activity about 130 ft to the northwest. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 47, 70, 94, 118, 150, 210, and 280 ft bls (table 10).

The borehole was relogged on March 31, 1998 (table 2), after a 4-in.-diameter drill rod was again temporarily inserted into the borehole to a depth of 347 ft bls to prevent further caving of the borehole wall. There was little change in the caliper, natural-gamma, fluid-resistivity, and fluid-temperature logs (fig. 15) since February 24, 1998 (fig. 13), and the borehole remained open to 460 ft bls. The video survey was resumed at 348 ft bls. This video shows horizontal and vertical fractures at 350 ft bls, a blow out at 380 ft bls, and water entering the borehole through a minor fracture at 426 ft bls. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 360, 376, 390, 406, and 422 ft bls; no flow was measured at 444 ft bls (table 11). The suite of geophysical logs and heatpulse-flowmeter measurements indicate that, under nonpumping conditions, water enters the borehole through a minor fracture at 426 ft bls and moves upward; most water exits the borehole through the fractures at 34-40 ft bls.

Table 10. *Summary of heatpulse-flowmeter measurements for borehole LN-2065 (MW-14) on March 4, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
47	1.0	Up
70	1.1	Up
94	1.2	Up
118	1.2	Up
150	1.0	Up
210	.9	Up
280	.9	Up

Table 11. *Summary of heatpulse-flowmeter measurements for borehole LN-2065 (MW-14) on March 31, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
360	1.1	Up
376	1.2	Up
390	1.1	Up
406	1.2	Up
422	1.2	Up
444	No flow	Not determined

Permanent borehole packers were placed at depths of 25.5 and 30.5 ft bls to prevent flow from entering the casing. The packer at 65.5 ft bls was installed to isolate a driller reported water-bearing zone at 40 ft bls and to include minor fractures at 49-62 ft bls that produce turbulent flow. A permanent borehole packer was installed at 90.5 ft bls to isolate possible minor water-producing zones. Permanent borehole packers also were placed at depths of 140.5, 205.5, 315.5, 385.5, and 445.5 ft bls to include possible water-producing fractures at 107, 367, 401, and 426 ft bls plus several water-producing zones reported by the driller at depths of about 250-280, 359, and 440 ft bls.

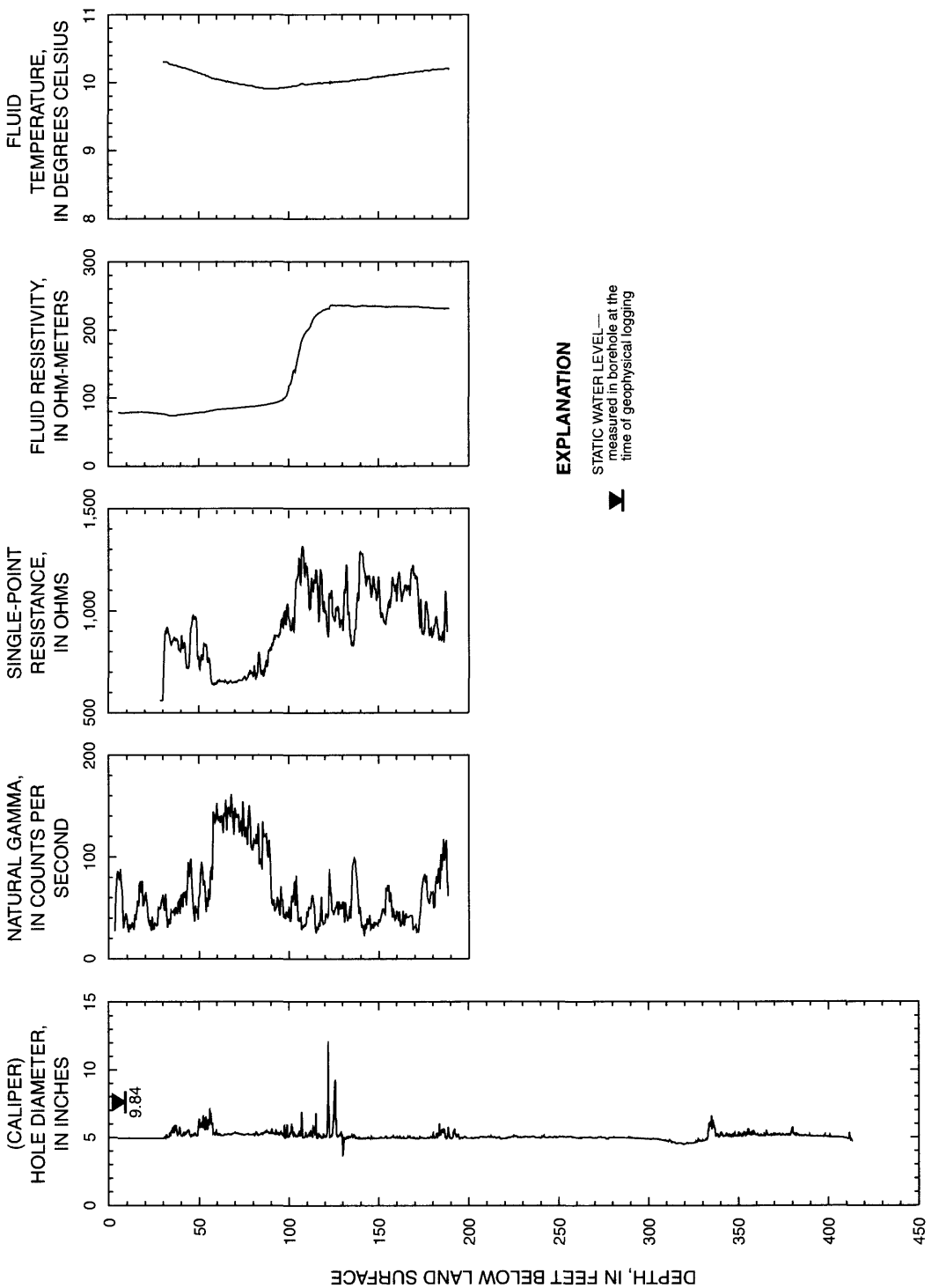


Figure 12. Geophysical logs for LN-2065 (MW-14), collected on February 24, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

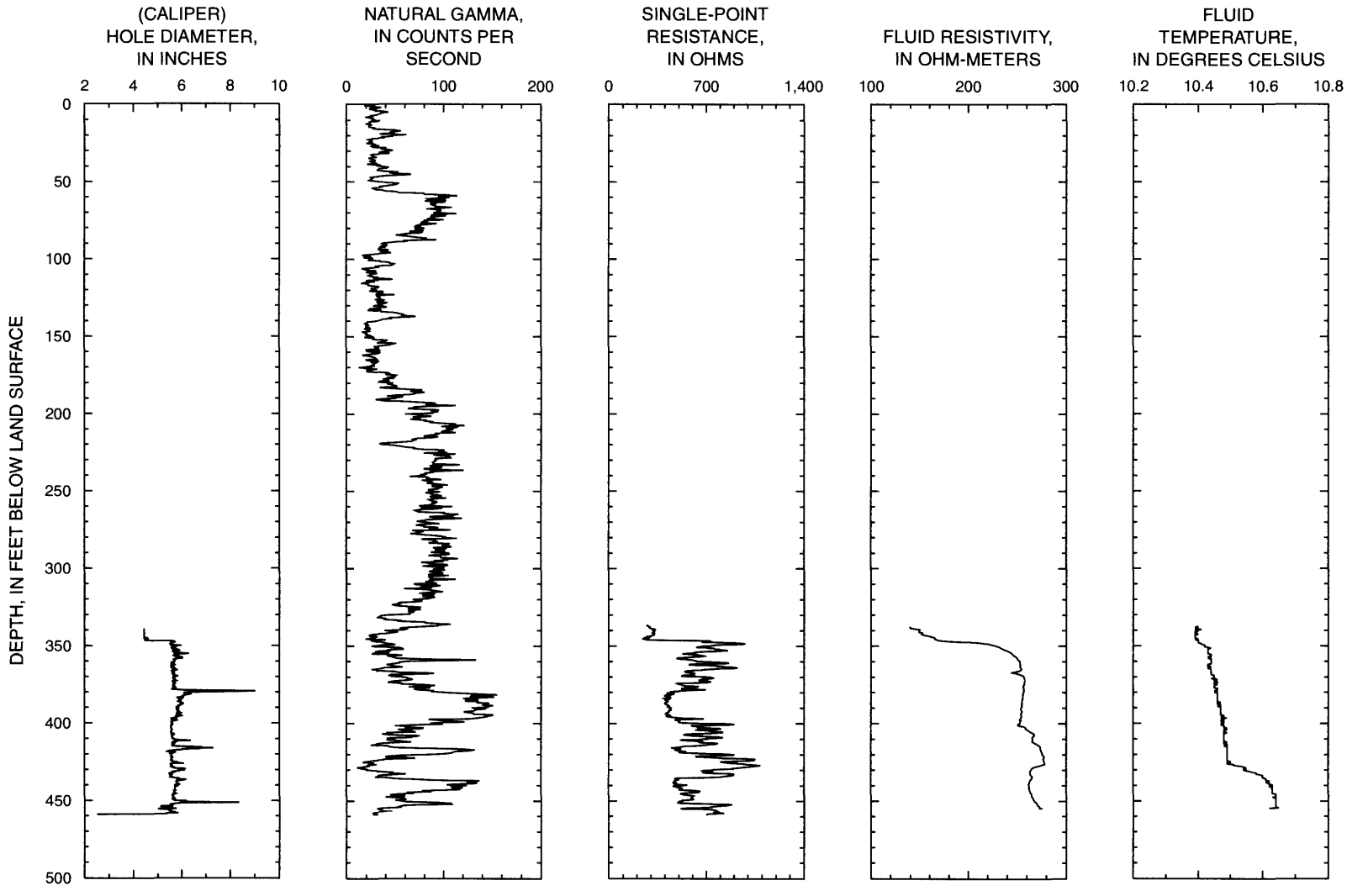


Figure 13. Geophysical logs for LN-2065 (MW-14), collected on February 24, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania, after well was deepened to 460 ft.

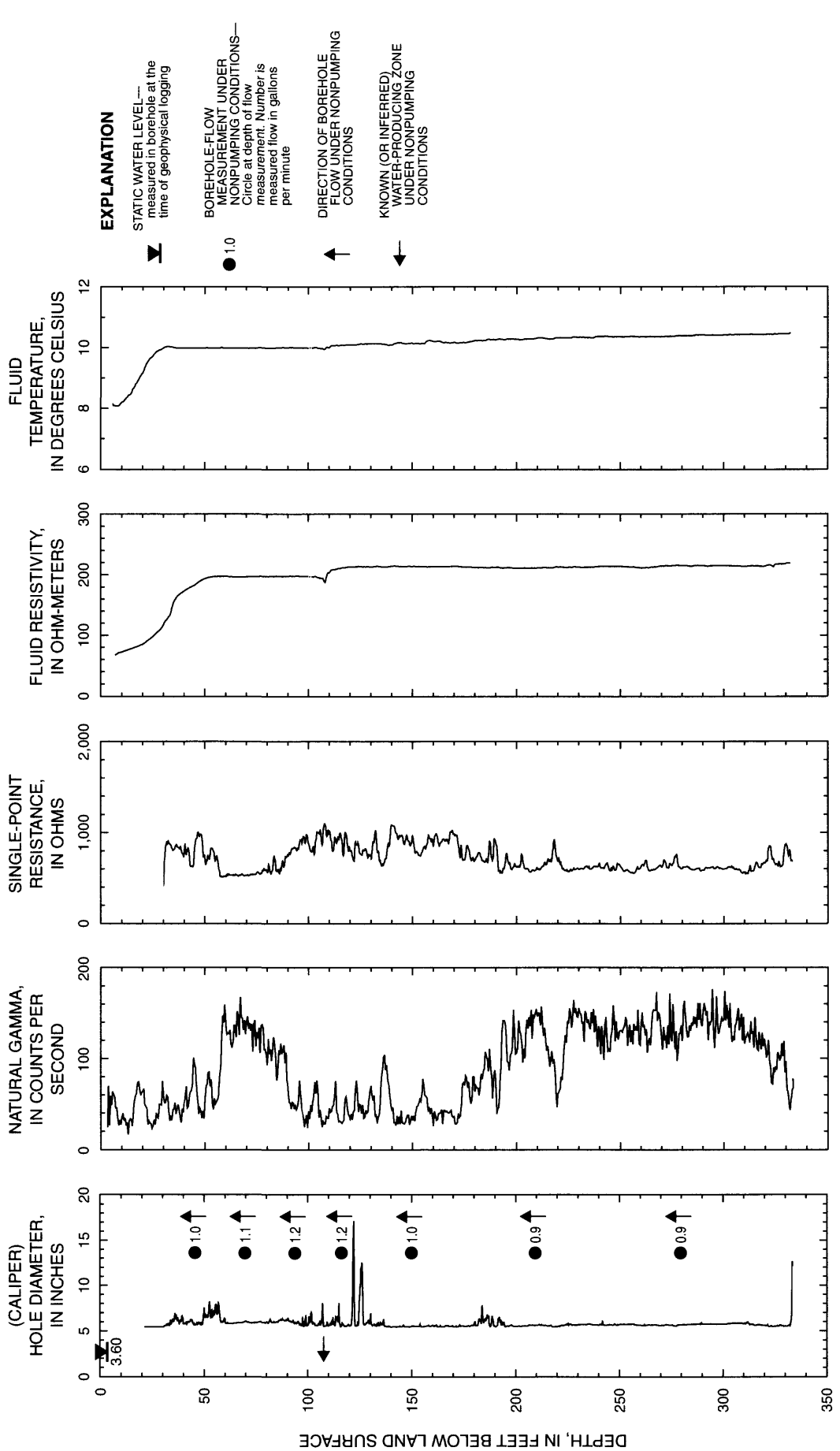


Figure 14. Geophysical logs for LN-2065 (MW-14), collected on March 4, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

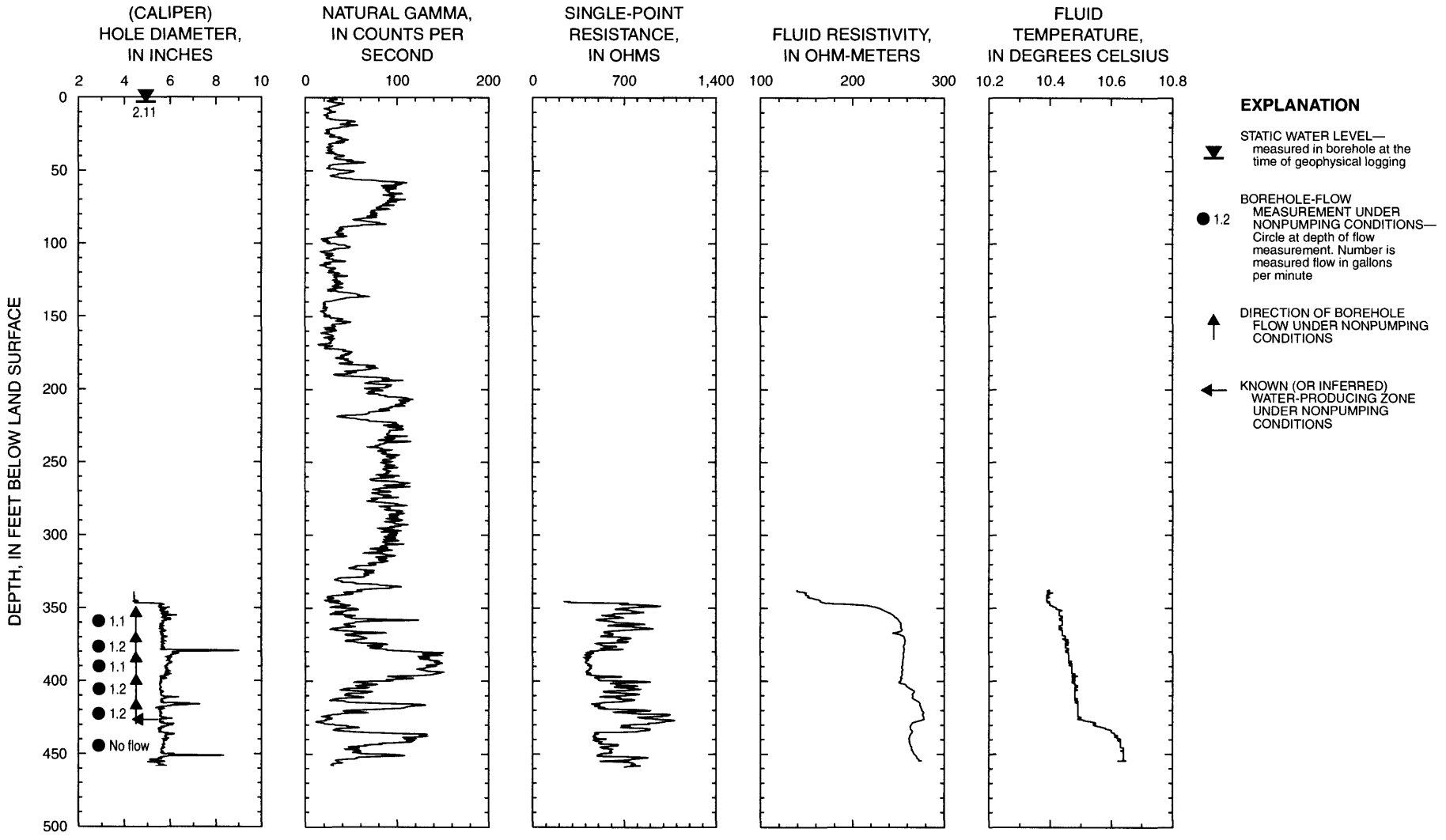


Figure 15. Geophysical logs and direction of nonpumping flow within borehole LN-2065 (MW-14), collected on March 31, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2066 (MW-10)

Monitor well LN-2066 was logged twice over a period of several weeks because of the unstable nature of the borehole walls (table 2). The caliper log from March 30, 1998, shows the borehole is cased with 5-in.-diameter casing to 21 ft bls; the total depth of the borehole is 382 ft bls (fig. 16). The caliper log shows major fractures at 21-31, 99-102, and 304-310 ft bls plus numerous smaller fractures throughout the open-hole interval. The natural-gamma log shows siltstone units interbedded with sandstone and(or) conglomerate units. Major siltstone units are present at 20-63, 73-204, 266-278, and 325-346 ft bls. The fluid-resistivity log shows major changes in slope at 96, 98, 112, 318, 351, and 358 ft bls and a minor deflection at 227 ft bls. The fluid-temperature log shows a change in slope at 318 and a minor deflection at 227 ft bls. The deflections in slope from the fluid-resistivity and fluid-temperature logs correlate to fractures at 99-102, 111, 225, 320, 350, and 357 ft bls on the caliper log. Under nonpumping conditions, the heatpulse flowmeter measured downward flow at 78, 92, 106, 120, 150, 219, and 292 ft bls and upward flow at 334 ft bls (table 12). The driller reported a water-producing zone (less than 1 gal/min) at a depth of 60 ft bls.

The caliper log from April 9, 1998, shows the total depth of the borehole is 499 ft bls (fig. 17). The caliper log shows major fractures at 21-31, 99-102, and 304-310 ft bls plus numerous smaller fractures throughout the open-hole interval. The natural-gamma log shows siltstone units interbedded with sandstone and(or) conglomerate units. Major siltstone units are present at 20-63, 73-204, 266-278, 325-346, 406-433, and 447-480 ft bls. The fluid-resistivity log shows major changes in slope at 96, 98, 112, 318, 445, 448, 454, and 485 ft bls and minor deflections at 138, 166, and 390 ft bls. The fluid-temperature log shows a major change in slope at 317 ft bls and a minor change in slope at 446 ft bls. The deflections in slope correlate to fractures at 99-102, 111, 225, 320, 350, 357, 445, and 453 ft bls on the caliper log. Under nonpumping conditions, the heatpulse flowmeter measured downward flow at 92, 106, 120, 150, 219, and 292 ft bls, upward flow at 323, 334, 354, 364, and 438 ft bls; and no flow at 450, 460, and 492 ft bls (table 13). The suite of geophysical logs and heatpulse-flowmeter measurements indicate that water enters the borehole through fractures at 87, 96, and 111 ft bls and moves downward. Additional water enters the borehole at 445 and possibly 489 ft bls and moves upward. Water exits the borehole through fractures at approximately 320 ft bls.

Permanent borehole packers were installed at depths of 51.5 and 106.5 ft bls to isolate the major fractures at 21-31 and 99-102 ft bls, water-producing zones at 86, 96, and 98 ft bls, and a driller reported water-producing zone at about 60 ft bls. Permanent borehole packers installed at depths of 126.5, 202.5, 247.5, and 292.5 ft bls isolate possible water-producing zones at 111 and 225 ft bls and driller reported water-producing zones at 120, 198, 225, and 240 ft bls. A permanent borehole packer was placed at 327.5 ft bls to include the water-receiving zone at 320 ft bls. Additional permanent borehole packers were placed at depths of 377.5, 427.5, and 447.5 ft bls to include the water-producing fracture at 445 ft bls plus a number of minor fractures.

Table 12. *Summary of heatpulse-flowmeter measurements for borehole LN-2066 (MW-10) on March 30, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
78	1.0	Down
92	1.2	Down
106	1.4	Down
120	1.5	Down
150	1.5	Down
219	1.5	Down
292	1.5	Down
334	1.1	Up

Table 13. *Summary of heatpulse-flowmeter measurements for borehole LN-2066 (MW-10) on April 9, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
92	0.4	Down
106	.7	Down
120	1.3	Down
150	1.4	Down
219	1.5	Down
292	1.5	Down
323	1.3	Up
334	1.2	Up
354	1.2	Up
364	1.3	Up
438	1.2	Up
450	No flow	Not determined
460	No flow	Not determined
492	No flow	Not determined

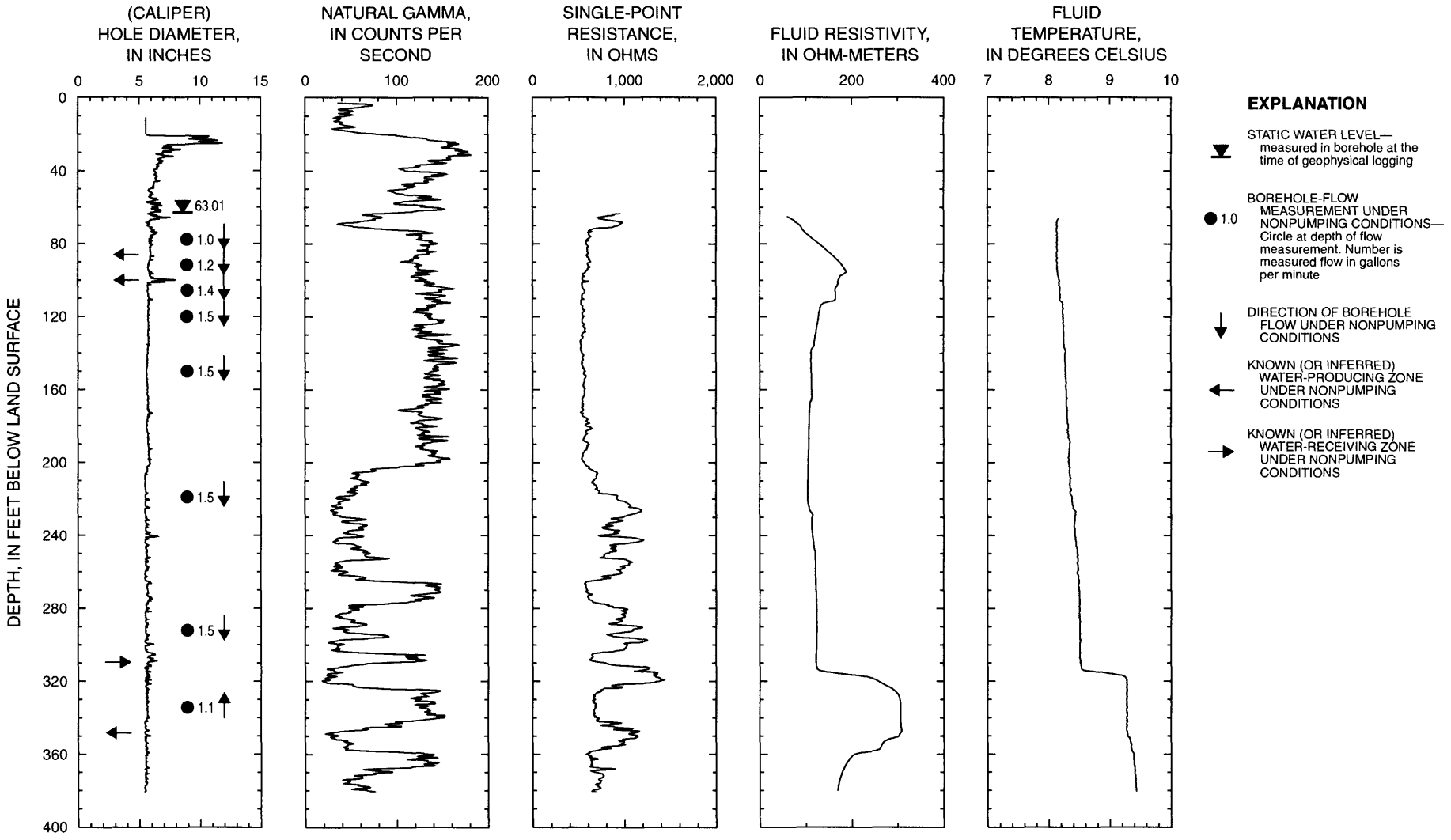


Figure 16. Geophysical logs and direction of nonpumping flow within borehole LN-2066 (MW-14), collected on March 30, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

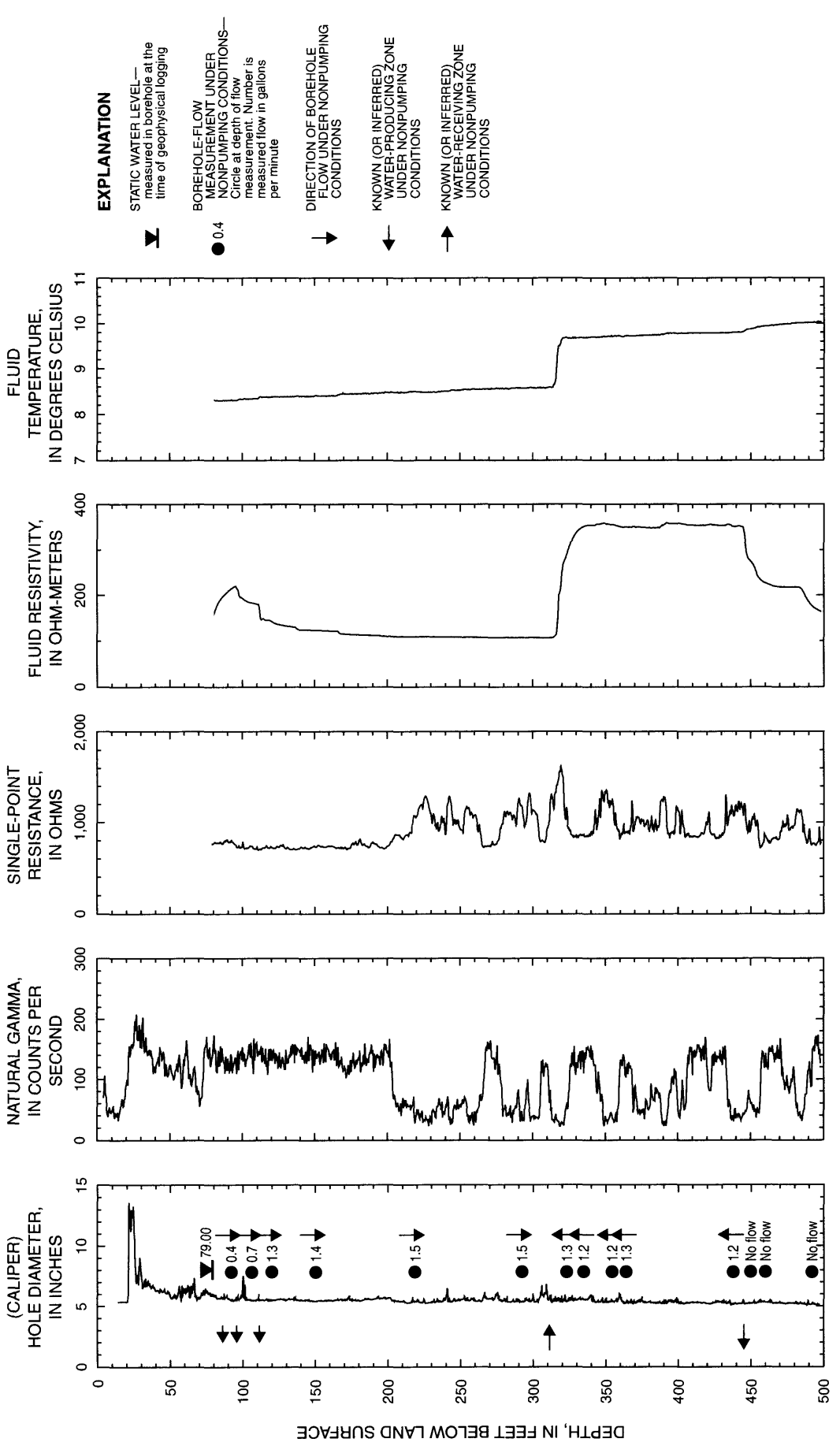


Figure 17. Geophysical logs and direction of nonpumping flow within LN-2066 (MW-10), collected on April 9, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2067 (MW-11)

Monitor well LN-2067 was logged twice over a period of 2 weeks because of the unstable nature of the borehole walls (table 2). The caliper log from March 31, 1998, shows the borehole is cased with 5-in.-diameter casing to 20 ft bls (fig. 18), and it is 410 ft deep. The caliper log shows major fractures at 27-30, 40-47, 67-72, 77-79, and 171-172 ft bls plus numerous smaller fractures throughout the open-hole interval. The caliper log indicates a constriction in borehole diameter at 303 ft bls; however, this was caused by the probe being caught on a fracture. The natural-gamma log shows siltstone units interbedded with sandstone units. The major siltstone units are present from land surface to a depth of 42, 69-143, 159-182, 204-251, and 261-295 ft bls. A major sandstone unit is present from 361-408 ft bls. The fluid-resistivity log shows major changes in slope at 87, 142, 152, and 260 ft bls and minor slope changes at 272, 297, and 330 ft bls. The fluid-temperature log shows a slight change in slope at 142 and 260 ft bls. Deflections in slope in the fluid-resistivity and fluid-temperature logs approximately correlate to fractures shown on the caliper log and could indicate water-producing and water-receiving zones. Heatpulse-flowmeter measurements were attempted, but the borehole collapsed at a depth of 44 ft bls.

Because of borehole collapse, the borehole was drilled deeper to a reported depth of 445 ft. After drilling, a 4-in.-diameter temporary drilling rod was inserted to a depth of 88 ft to prevent further borehole collapse. The caliper log from April 8, 1998, shows the total depth of the borehole is 432 ft, and major fractures are located at 159-162, 169-172, 302-304, 335-340, 352-361, 403, and 411-414 ft bls plus numerous smaller fractures throughout the open-hole interval (fig. 19). Under nonpumping conditions, the heatpulse flowmeter measured downward flow at 92 and 110 ft bls and upward flow at 146, 157, 244, 268, 286, 330, 348, 374, 392, 402, and 412 ft bls (table 14). The suite of geophysical logs and heatpulse-flowmeter measurements indicate under nonpumping conditions water may enter the borehole through fractures at 88, 101, 152, 260, 272, 297, and 411-414 ft bls and exit the borehole through the fracture at 130 or 142 ft bls.

Permanent borehole packers were placed at depths of 53.5 and 111.5 ft bls to include major fractures at 27-30, 40-47, 67-72, 77-79 ft bls and water-producing zones at 88 and 101 ft bls. Additional permanent borehole packers were placed at 135.5 and 185.5 ft bls to include major fractures at 159-162 and 169-172 ft bls and water-receiving zones at 143 and 152 ft bls. The remaining borehole packers were placed at 245.5, 265.5, 325.5, and 390.5 ft bls to include major fractures at 302-304, 335-340, 352-361, 403, and 411-414 ft bls; water-producing zones at 260, 272, 297, and below 400 ft bls; plus several water-producing zones reported by the driller at about 210, 255, 315, and 365 ft bls.

Table 14. *Summary of heatpulse-flowmeter measurements for borehole LN-2067 (MW-11) on April 8, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

[>, greater than]

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
92	0.6	Down
110	1.0	Down
146	>1.5	Up
157	>1.5	Up
244	>1.5	Up
268	>1.5	Up
286	>1.5	Up
330	>1.5	Up
348	>1.5	Up
374	>1.5	Up
392	>1.5	Up
402	>1.5	Up
412	.8	Up

LN-2068 (MW-7)

The borehole of monitor well LN-2068 was very unstable and constantly collapsed just below the bottom of the 5-in.-diameter casing. A 4-in.-diameter drilling rod was inserted in the borehole to a depth of 197 ft to prevent collapse of the borehole wall. The caliper log shows the total depth of the borehole is 494 ft bls, and the driller's log reports the borehole is cased with 5-in.-diameter casing to 19 ft bls (fig. 20). The caliper log shows a major fracture at 240-242 ft bls, a constriction in borehole diameter at 270-272 ft bls, and numerous minor fractures throughout the open-hole interval. The natural-gamma log shows siltstone units interbedded with sandstone and(or) conglomerate units. The major siltstone units are at land surface to a depth of 47 ft bls, 74-86, 135-151, 281-360, 382-421, and 470-494 ft bls. A major sandstone and(or) conglomerate unit, with minor siltstone, is present from 151-281 and again at 421-470 ft bls. The fluid-resistivity and fluid-temperature logs show changes in slope at 206, 239, and 252 ft bls; the fluid-temperature log also shows a change in slope at 270 ft bls. The deflections in slope in the two logs correlate to fractures on the caliper log and indicate possible water-producing and water-receiving zones. Under nonpumping conditions, the heatpulse flowmeter measured no flow at 203 ft bls, upward flow from 210-444 ft bls, and turbulent flow

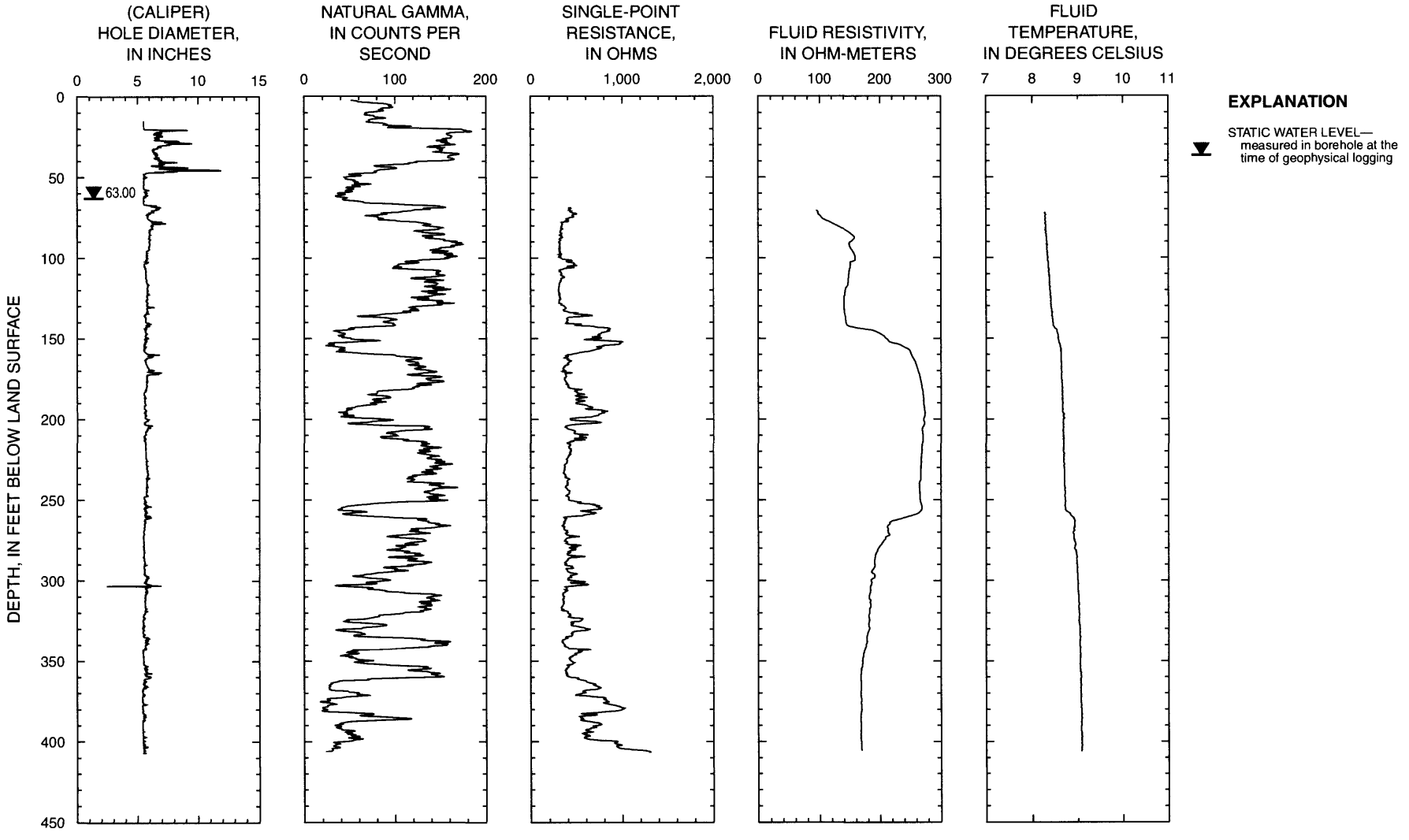


Figure 18. Geophysical logs for borehole LN-2067 (MW-11), collected on March 31, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

from 464-490 ft bls (table 15). The suite of geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through minor fractures at 270, 312, 380, and 470 ft bls and moves upward. Water exits the borehole through fractures at 205-207, 230, 240-242, and 252 ft bls.

Permanent borehole packers were placed at depths of 40.5, 140.5, 190.5, and 210.5 ft bls to include the length of borehole that did not have a complete suite of logs collected because of the repeated collapse of the borehole and the water-receiving zone at 205-207 ft bls. Additional permanent borehole packers were placed at 247.5, 267.5, 322.5, and 392.5 ft bls to include the major fracture at 240-242 ft bls and water-producing and water-receiving zones at 239, 252, 271 and 380 ft bls.

Table 15. *Summary of heatpulse-flowmeter measurements for borehole LN-2068 (MW-7) on April 6, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania*

[>, greater than]

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
203	No flow	Not determined
210	0.7	Up
226	.8	Up
238	1.0	Up
247	1.2	Up
256	>1.5	Up
279	>1.5	Up
300	>1.5	Up
320	>1.5	Up
360	>1.5	Up
374	>1.5	Up
390	>1.5	Up
444	>1.5	Up
464	Turbulent	Not determined
480	Turbulent	Not determined
490	Turbulent	Not determined

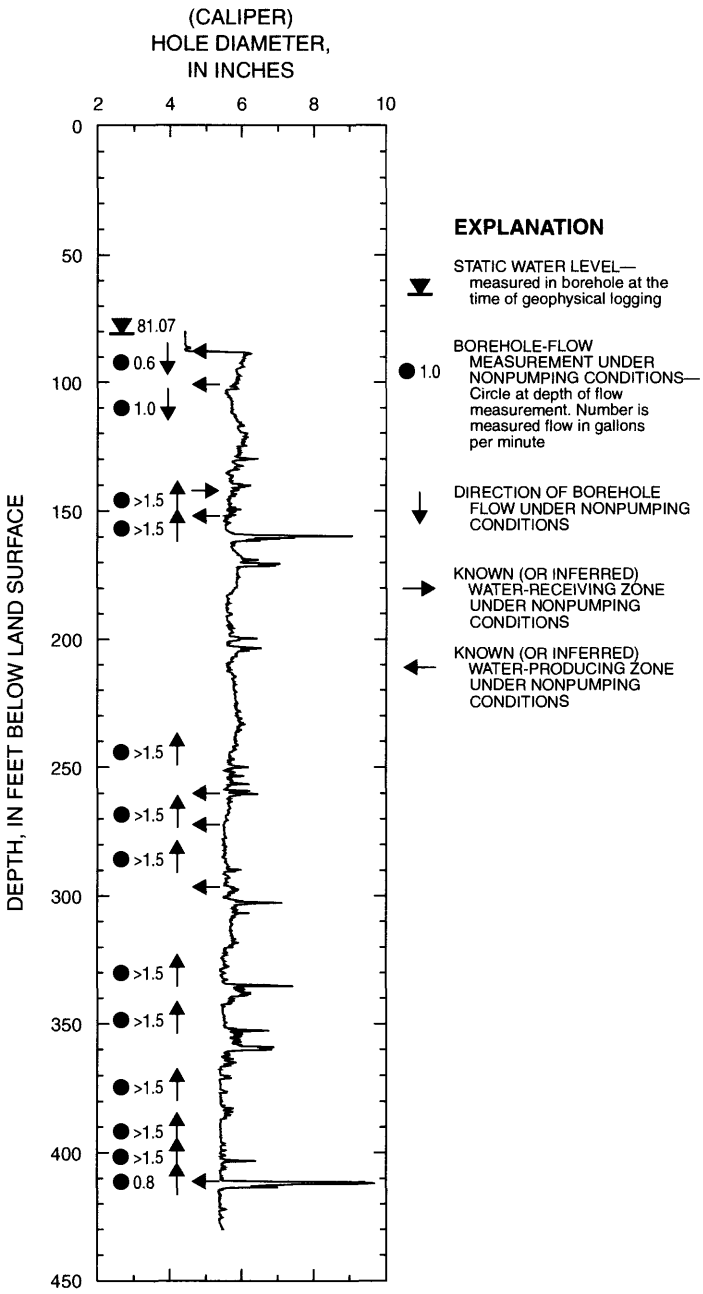


Figure 19. Caliper log and direction of nonpumping flow within borehole LN-2067 (MW-11), collected on April 8, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

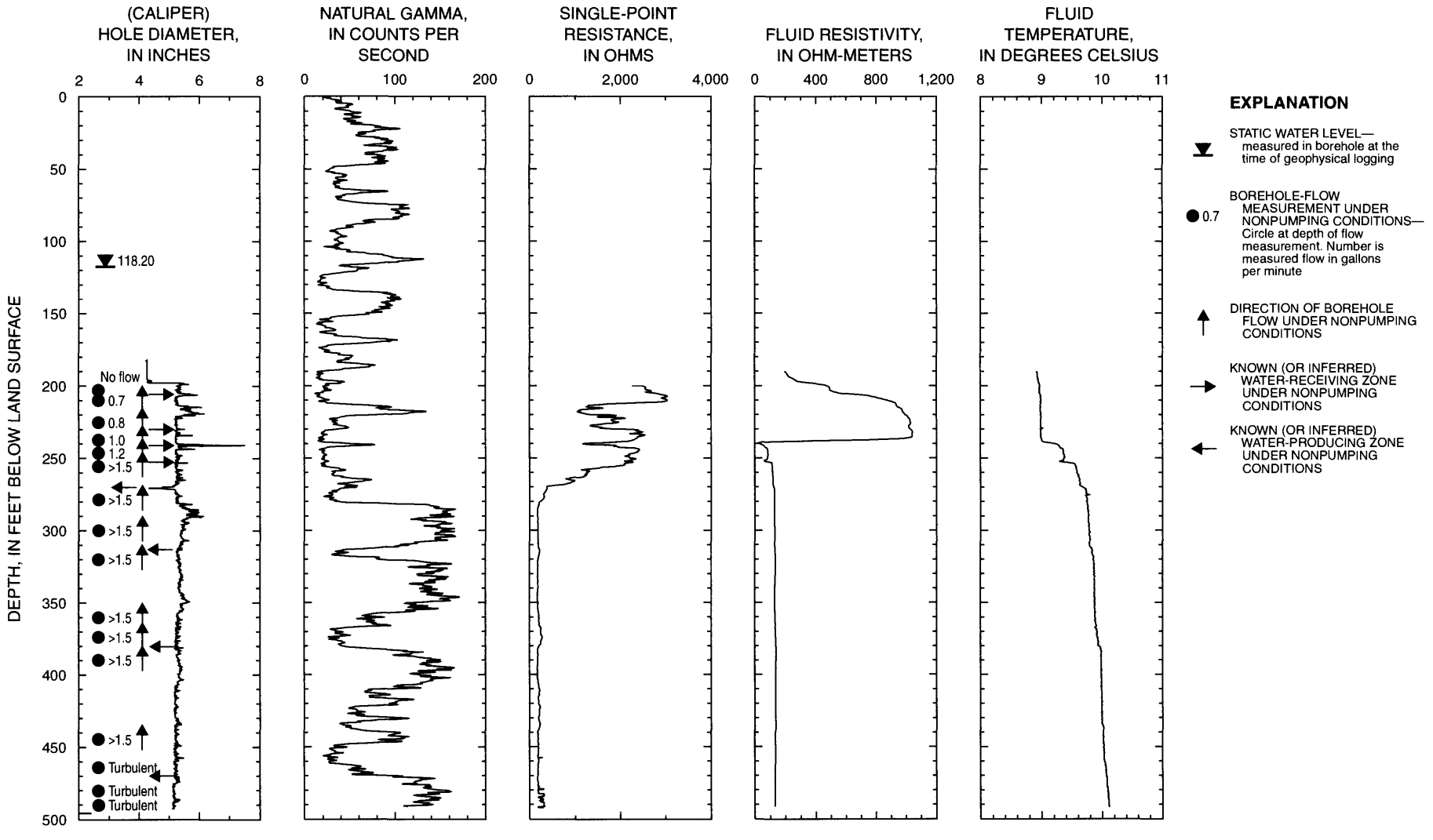


Figure 20. Geophysical logs and direction of nonpumping flow within borehole LN-2068 (MW-7), collected on April 6, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

LN-2069 (MW-12)

The caliper log shows this borehole is drilled to a depth of 319 ft bls, and it is cased with 5-in.-diameter casing to 20 ft bls (fig. 21). The caliper log shows major fracture zones at 20-25, 30-34, 40-44, 46-50, 55-62, 68-70, 82-85, 90-94, 140-142, and 308-311 ft bls plus numerous minor fractures throughout the open-hole interval. The natural-gamma log shows siltstone interbedded with sandstone and(or) conglomerate. The major siltstone units are at 12-34, 92-122, 162-201, 221-250, and 279-305 ft bls. The driller's log reports diabase at 285 ft bls. A rock sample from 285 ft bls was analyzed using x-ray defraction, and diabase was confirmed (Philip Bird, U.S. Geological Survey, oral commun., 1998). The fluid-resistivity log shows a change in slope at 274 ft bls; the fluid-temperature log shows changes in slope at 156 and 274 ft bls. The video survey showed a few horizontal fractures but a relatively large number of vertical fractures throughout the open-hole interval. The visibility was zero from 49-97 ft bls and again at a depth of about 140 ft bls. From 97 to about 140 ft bls and again from 148 to 262 ft bls, the water cleared. Under nonpumping conditions, the heatpulse flowmeter measured no flow at 64 ft bls, upward flow at 87, 108, 148, 184, 234, 244, and 265 ft bls, and no flow at 286 ft bls (table 16). The suite of geophysical logs, video survey, and heatpulse-flowmeter measurements indicate that water enters the borehole through fractures at 275, 268, and 262-264 ft bls and moves upward. Water exits the borehole through fractures at 68-100, 141, and 156 ft bls.

Table 16. *Summary of heatpulse-flowmeter measurements for borehole LN-2069 (MW-12) on April 15, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster, Pennsylvania*

[>, greater than]

Depth (feet below land surface)	Flow rate under nonpumping conditions (gallons per minute)	Flow direction under nonpumping conditions
64	No flow	Not determined
87	0.4	Up
108	.6	Up
148	.7	Up
184	>1.5	Up
234	>1.5	Up
244	>1.5	Up
265	.4	Up
286	No flow	Not determined

Permanent borehole packers were placed at depths of 27.5, 107.5, and 147.5 ft bls to include major fractures zones at 20-25, 30-34, 40-44, 46-50, 55-62, 68-70, 82-85, 90-94, and 140-142 ft bls and a number of water-receiving zones. Additional permanent borehole packers were placed at 172.5, 237.5, 272.5, and 302.5 ft bls to include a major fracture at 308-311 ft bls, a water-receiving zone at about 160 ft bls, a number of water-producing zones, plus water-producing zones at about 180 and 220-240 ft bls where the driller reported increases in yield.

SUMMARY

Between February and April 1998, the USGS, in cooperation with the USEPA, collected geophysical logs in nine open-borehole wells adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pa. Video surveys also were conducted in four of the nine open-borehole wells. The wells range in depth from 320 to 508 ft bls and penetrate the Hammer Creek Formation, which consists of a series of interbedded siltstone, sandstone, and conglomerate units. Water-bearing fractures were most common in the brittle sandstone and conglomerate beds and less common in the siltstone or at lithologic contacts. Water-producing and water-receiving zones were penetrated as shallow as 34 ft bls and as deep as 475 ft bls. Vertical borehole flow was measured in all nine boreholes. Permanent packers were installed in each borehole to obtain depth specific water samples from one or more water-bearing fractures.

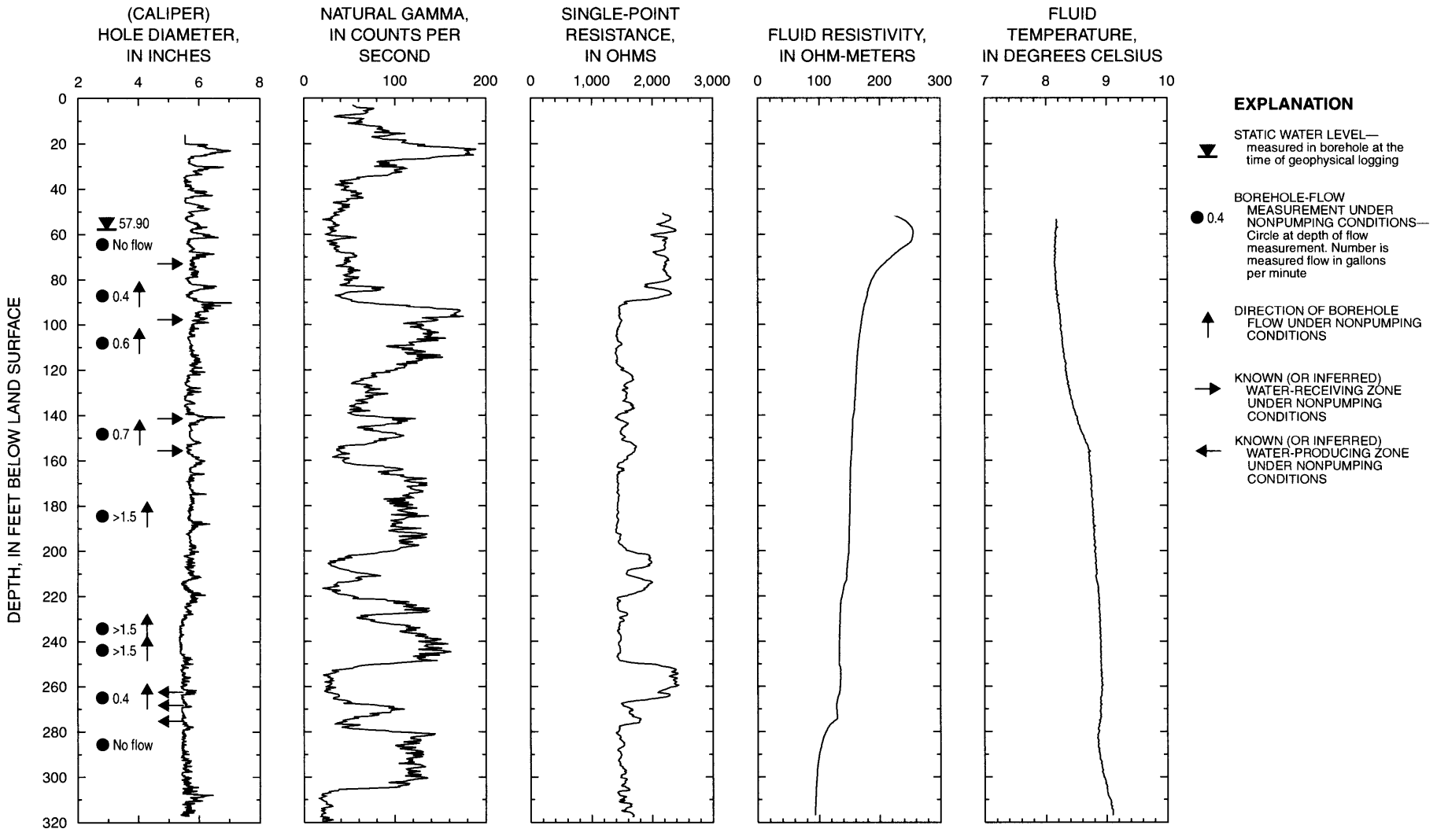


Figure 21. Geophysical logs and direction of nonpumping flow within borehole LN-2069 (MW-12), collected on April 15, 1998, adjacent to the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pennsylvania.

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