

**In cooperation with the U.S. Navy**

# **Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, Warminster Township, Bucks County, Pennsylvania, 2007**

Open-File Report 2008-1207



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By Ronald A. Sloto

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Open-File Report 2008-1207

**U.S. Department of the Interior  
U.S. Geological Survey**

**U.S. Department of the Interior**  
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**  
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## Conversion Factors

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Volume		
gallon (gal)	3.785	liter (L)
Flow rate		
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

Concentrations of chemical constituents in water are given in micrograms per liter ( $\mu\text{g/L}$ ).





# Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, Warminster Township, Bucks County, Pennsylvania, 2007

By Ronald A. Sloto

## Abstract

This study was done by the U.S. Geological Survey in cooperation with the U.S. Navy at Area C of the former Naval Air Warfare Center in Warminster Township, Bucks County, Pa., in support of hydrogeological investigations conducted by the Navy to address ground-water contamination in the Stockton Formation. Borehole geophysical logs were collected, heatpulse-flowmeter measurements were made, and borehole television surveys were run in seven boreholes ranging from 31 to 75 feet deep. Caliper logs and borehole television surveys were used to identify fractures and the location of possible water-bearing zones. Heatpulse-flowmeter measurements were used to identify fractures that were water-bearing zones. Natural-gamma and single-point-resistance logs were used to correlate lithology across the area. Elevated concentrations of tetrachloroethylene (PCE) were measured in water samples from wells with water-bearing zones in the interval of the aquifer where monitor well HN-23A is screened. Water samples from wells with water-bearing zones above or below this interval had substantially lower concentrations of PCE. Wells screened in this interval yielded less than 0.5 gallon per minute, indicating that the interval has low permeability; this may account for the small areal extent and slow migration of PCE.

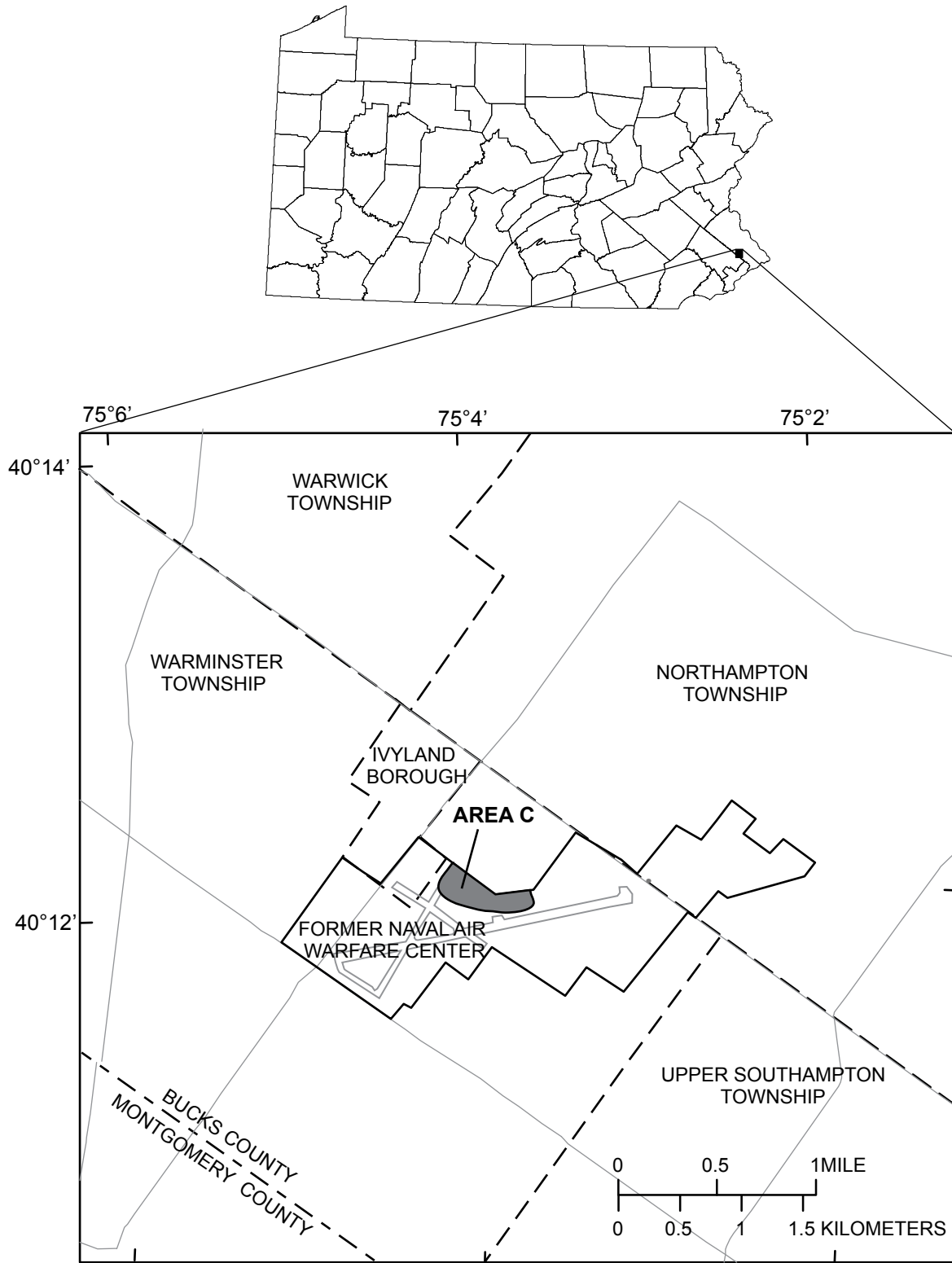
## Introduction

The former U.S. Naval Air Warfare Center (NAWC) in Warminster Township, Bucks County, Pa. (fig. 1), was acquired by the U.S. Navy in 1944 to convert and modify newly produced aircraft prior to delivery to the Naval Fleet. After World War II, the NAWC served as a research, development, testing, and evaluation center. In 1979, volatile organic compounds were detected in water from the NAWC supply wells. The following year, the Navy implemented a program to identify and evaluate past disposal sites and to control the migration of hazardous material from such sites. Area C is a part of the former NAWC that contained a known disposal site. The NAWC was closed on September 30, 1997, as part of the Base Realignment and Closure Act. Anne's Choice, a residential retirement community, has been constructed over much of Area C.

To investigate possible ground-water contamination in Area C, the Navy installed a number of monitor wells and conducted a hydrogeological investigation. Tetrachloroethylene (PCE) concentrations as high as 29  $\mu\text{g/L}$  were measured in water samples from the monitor wells (Halliburton NUS Corporation, 1994). To address ground-water contamination in Area C, the Navy installed a remediation system using six extraction wells, which began operation in 1996. PCE concentrations in two of the wells dropped below the U.S. Environmental Protection Agency Maximum Contaminant Level of 5  $\mu\text{g/L}$ , and the wells were taken out of service. Concentrations of PCE in water from the remaining four active extraction wells ranged from 3.1 to 25  $\mu\text{g/L}$  during 2006-07.

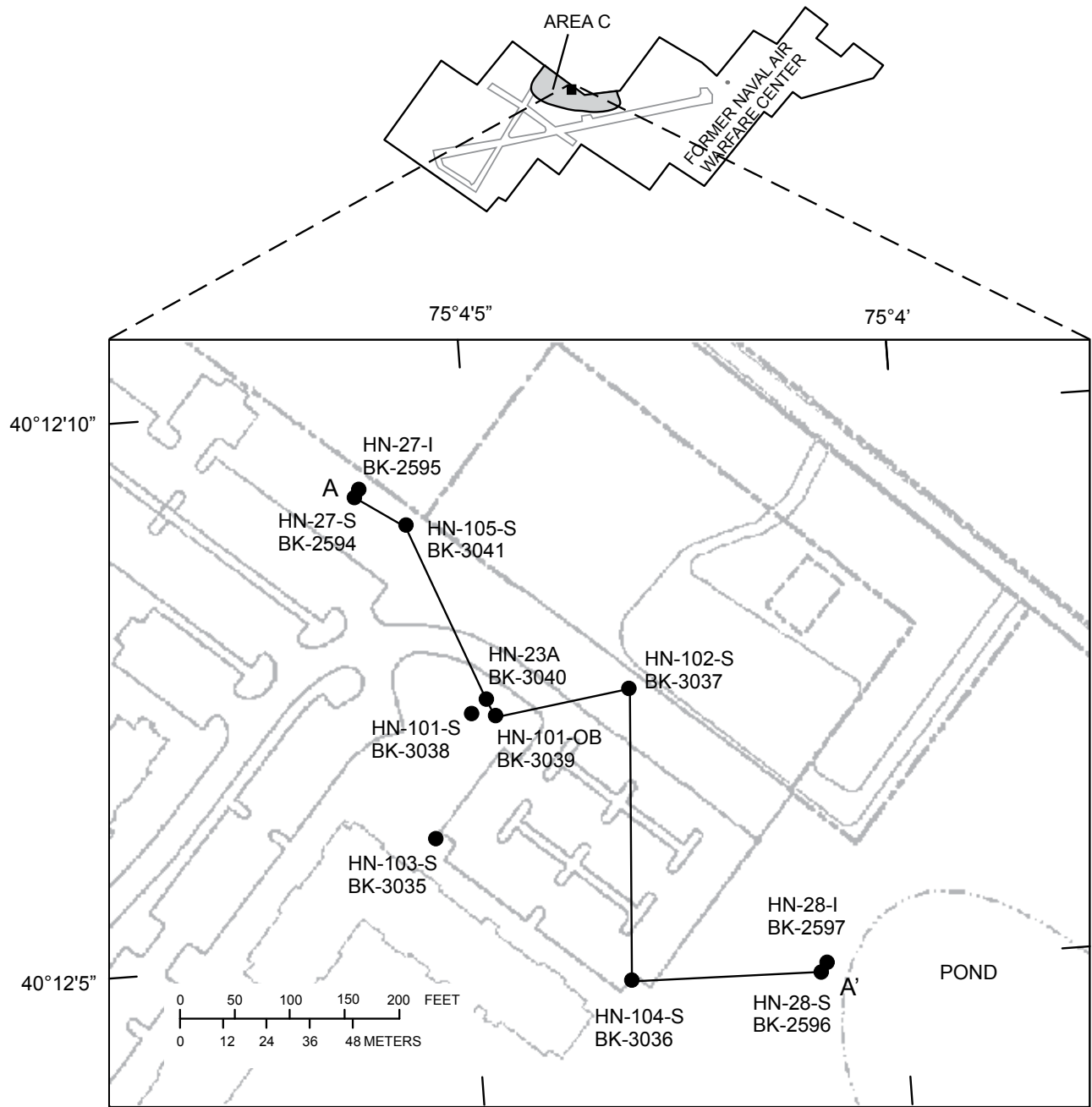
During construction of the retirement community in 2003, monitor well HN-23 was abandoned (with Navy approval), and replacement monitor well HN-23A (fig. 2) was drilled. PCE concentrations in water samples from well HN-23A were as high as 300  $\mu\text{g/L}$ , which was an order of magnitude greater than concentrations from other Area C wells. As a result, the Navy initiated an Area C source investigation. In support of this investigation, the U.S. Geological Survey (USGS) conducted borehole geophysical logging, made heatpulse-flowmeter measurements, and ran borehole television surveys in seven boreholes to assist in characterization of the aquifer hydrogeological framework.

2 Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, 2007



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection. Standard parallels 29°30'N, central meridian 75°00'W.

Figure 1. Location of the former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.



Base modified from ECOR Solutions, Inc. (2006)

EXPLANATION

- HN-104-S  
BK-3036 ●

MONITOR WELL AND IDENTIFICATION NUMBER –  
Upper number is Navy well-identification number. Lower number is U.S. Geological Survey well-identification number.
- A ——— A'

LINE OF GEOLOGIC SECTION – Used for correlation of natural-gamma and single-point-resistance borehole geophysical logs

**Figure 2.** Location of selected monitor wells in Area C at the former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

### Purpose and Scope

This report describes the results of a hydrogeological investigation conducted in 2007 by the USGS in cooperation with the U.S. Navy in Area C at the former NAWC. The USGS collected the geophysical data presented here as part of the environmental hydrogeological investigations conducted at the former NAWC. This report provides an interpretation of borehole geophysical logs, borehole television surveys, and heatpulse-flowmeter measurements made in seven boreholes ranging from 31 to 75 ft deep. It describes the location of water-bearing-fracture zones, presents a lithologic model for the area, and describes the distribution of PCE with respect to the lithology.

### Hydrogeologic Setting

The former NAWC is in the Triassic Lowlands Section of the Piedmont Physiographic Province and is underlain by sedimentary rocks of the Stockton Formation of Late Triassic age. The rocks are chiefly arkosic sandstone and siltstone. In Area C, the Stockton Formation strikes approximately N. 54° E. and dips approximately 7° NW. (Tetra Tech NUS, 2007, p. 3-1). Vertical fractures are common.

The rocks of the Stockton Formation form a complex, heterogeneous aquifer with partially connected zones of high permeability. The aquifer is composed of a series of gently dipping lithologic units with different hydraulic properties. Permeability commonly differs from one lithologic unit to another. Ground water in the unweathered part of the Stockton Formation primarily flows through a network of interconnecting secondary openings—bedding-plane fractures and joints. Primary porosity has been almost entirely eliminated by compaction and cementation (Sloto and others, 1996, p. 14).

Ground water at the former NAWC originates from local infiltration of precipitation and inflow of ground water from upgradient areas. Ground-water levels fluctuate with seasonal variations in recharge and are affected by pumping of wells. Water in the shallow part of the aquifer generally is under unconfined (water-table) conditions; ground water in the deeper part of the aquifer may be confined or partially confined (Sloto and others, 1996, p. 12-13).

### Well-Identification System

Two well-identification numbering systems are used in this report to maintain consistency with previous studies. USGS well-identification numbers consist of a county-abbreviation prefix followed by a sequentially assigned number. The prefix “BK” denotes a well in Bucks County. Navy well-identification numbers begin with the prefix “HN.” A cross-reference between Navy and USGS well-identification numbers and data for each well are given in table 1. The locations of the wells are shown on figure 2. All wells were drilled by Navy contractors with an air-rotary drilling rig.

### Methods of Investigation

This study included collection of borehole geophysical logs, heatpulse-flowmeter measurements, and borehole television surveys. They are described in the following sections.

#### Borehole Geophysical Logs

Caliper, natural-gamma, and single-point-resistance geophysical logs were collected in the boreholes listed in table 1. The logs were used to locate water-producing fractures and to correlate lithology across the site.

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. Caliper logs were used to identify fractures and possible water-producing openings. The term fracture used in association with the caliper-log interpretations might identify a change in borehole diameter that may not necessarily indicate a bedding-plane separation, lithologic contact, or water-producing or water-receiving zone but may simply indicate an enlargement of the borehole.

Natural-gamma logs record the natural-gamma radiation emitted from rocks penetrated by the borehole. Uranium-238, thorium-232, the progeny of their decay series, and potassium-40 are the most common emitters of natural-gamma radiation. These radioactive elements are concentrated in clays by adsorption, precipitation, and ion exchange. Fine-grained sediments, such as mudstone or siltstone, usually emit more gamma radiation than sandstone. Geophysical logging with a gamma probe can be conducted in the water-filled or dry, cased or uncased parts of the borehole (Keys, 1990). However, casing reduces the gamma response. The natural-gamma logs were used to correlate lithologic units between boreholes.

**Table 1.** Record of selected wells, Area C, former Naval Air Warfare Center, Warminster Township, Bucks County, Pa. Reported yield taken from driller or geologist logs.

[--, no data; <, less than]

Navy well-identification number	U.S. Geological Survey well-identification number	Depth drilled (feet)	Borehole diameter (inches)	Reported yield (gallons per minute)	Screened or open interval at time of logging (feet below land surface)
HN-23A	BK-3040	60	<sup>1</sup> 6	--	37–57
HN-27-S	BK-2594	102	6	1	18–52
HN-27-I	BK-2595	157.5	6	8	abandoned
HN-28-S	BK-2596	80	6	4	53–68
HN-28-I	BK-2597	171	6	20	abandoned
HN-101-OB	BK-3039	60	6	< .1	15–60
HN-101-S	BK-3038	25	6	< .1	14–25
HN-102-S	BK-3037	60	6	0	20–60
HN-103-S	BK-3035	51	6	< .1	22–51
HN-104-S	BK-3036	31	6	< .1	20–31
HN-105-S	BK-3041	75	6	--	18–75

<sup>1</sup>Inner casing 4 in. in diameter.

Single-point-resistance logs, also called single-point electric logs, record the electrical resistance between the borehole and an electrical ground at land surface. In general, resistance increases with grain size and decreases with borehole diameter, density of water-producing fractures, and increasing dissolved-solids concentration of borehole water (Keys, 1990). A water-filled borehole is required for single-point-resistance logs, and they are run only for the saturated part of the formation below the casing. Single-point-resistance logs were used to correlate lithologic units between boreholes.

## Heatpulse-Flowmeter Measurements

The direction and rate of vertical borehole-fluid movement were measured with a high-resolution heatpulse flowmeter. The heatpulse flowmeter operates by diverting nearly all flow to the center of the tool where a heating grid slightly heats a thin zone of water. If vertical borehole flow is occurring, the water moves up or down the borehole to one of two sensitive thermistors (heat sensors). When a peak temperature is recorded by one of the thermistors, a measurement of direction and rate is calculated by the computer collecting the logging data. The range of flow measured by the heatpulse flowmeter is about 0.01 to 1.5 gal/min in a 2- to 10-in. diameter borehole.

Heatpulse-flowmeter measurements may be affected by poor seal integrity between the borehole and the flowmeter. If the seal between the borehole and the heatpulse flowmeter is not complete, some water can bypass the flowmeter, resulting in flow measurements that are less than the actual rate. The quantity of water bypassing the tool is a function of borehole size and shape and degree of fracturing. Although the heatpulse flowmeter is a calibrated tool, the data primarily are used as a relative indicator of water-producing zones. For the wells logged in Area C, the seal integrity was considered as very good. No problems were noted concerning seal integrity.

Two types of heatpulse-flowmeter measurements were made—nonpumping and pumping. Nonpumping measurements, sometimes called ambient-condition measurements, measure the natural flow in the borehole. Pumping measurements are made while the borehole is pumped at a low rate, generally 2 gal/min or less, and the drawdown is kept constant. Under pumping conditions, hydraulically active fractures that may not produce water under nonpumping conditions are induced by the pumping to produce a measurable quantity of water. When the pumping rate is known, the relative contribution of each hydraulically active fracture can be determined. Pumping rates for wells in this report were 0.2 to 2.2 gal/min. Measurements under pumping conditions were not made in boreholes with less than 12 ft of open hole.

## Borehole Television Surveys

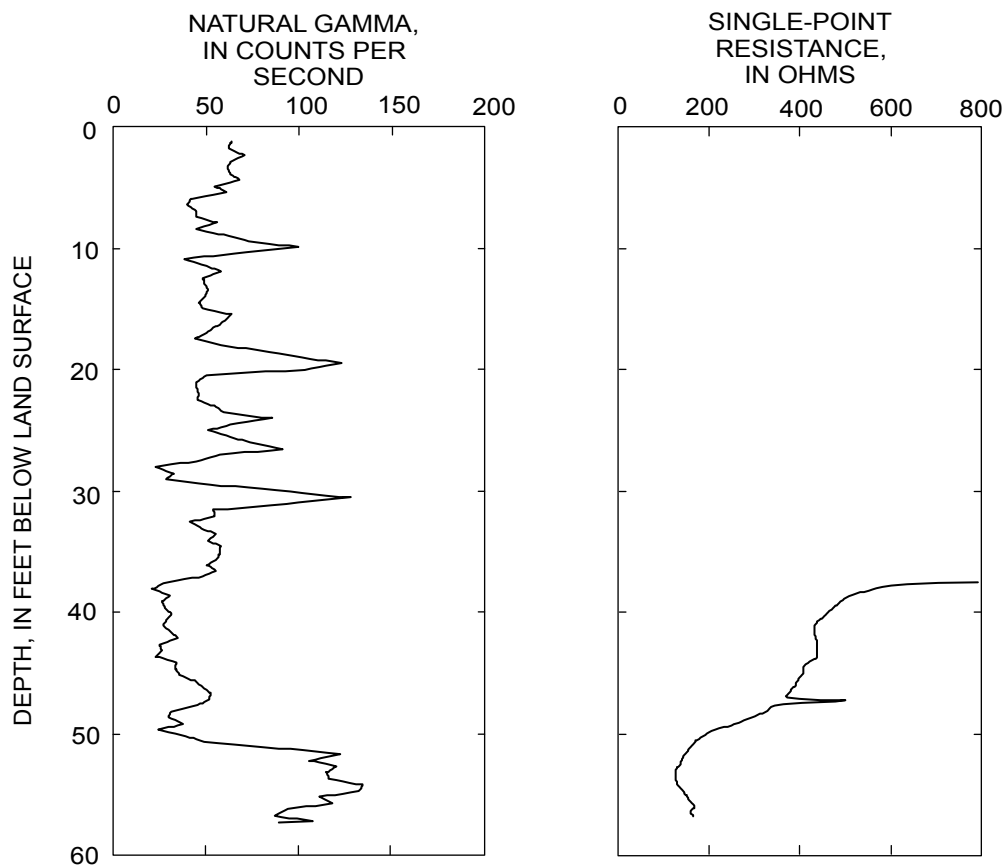
Borehole television surveys were conducted by lowering a waterproof video camera down the borehole and recording the image on video tape. The depth indicated on the video image may not correspond exactly to the geophysical logs because of slippage of the video cable. The borehole television surveys were used to visually characterize water-producing fractures identified by interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements.

## Interpretation of Borehole Geophysical Logs at Area C

Borehole geophysical logs were collected in six newly drilled wells (HN-101-OB, HN-101-S, HN-102-S, HN-103-S, HN-104-S, and HN-105-S) and one existing monitor well (HN-23A), and heatpulse-flowmeter measurements were made in the six newly drilled wells. Well locations are shown on figure 2. Interpretations of geophysical logs are provided in the following sections.

### Well HN-23A (BK-3040)

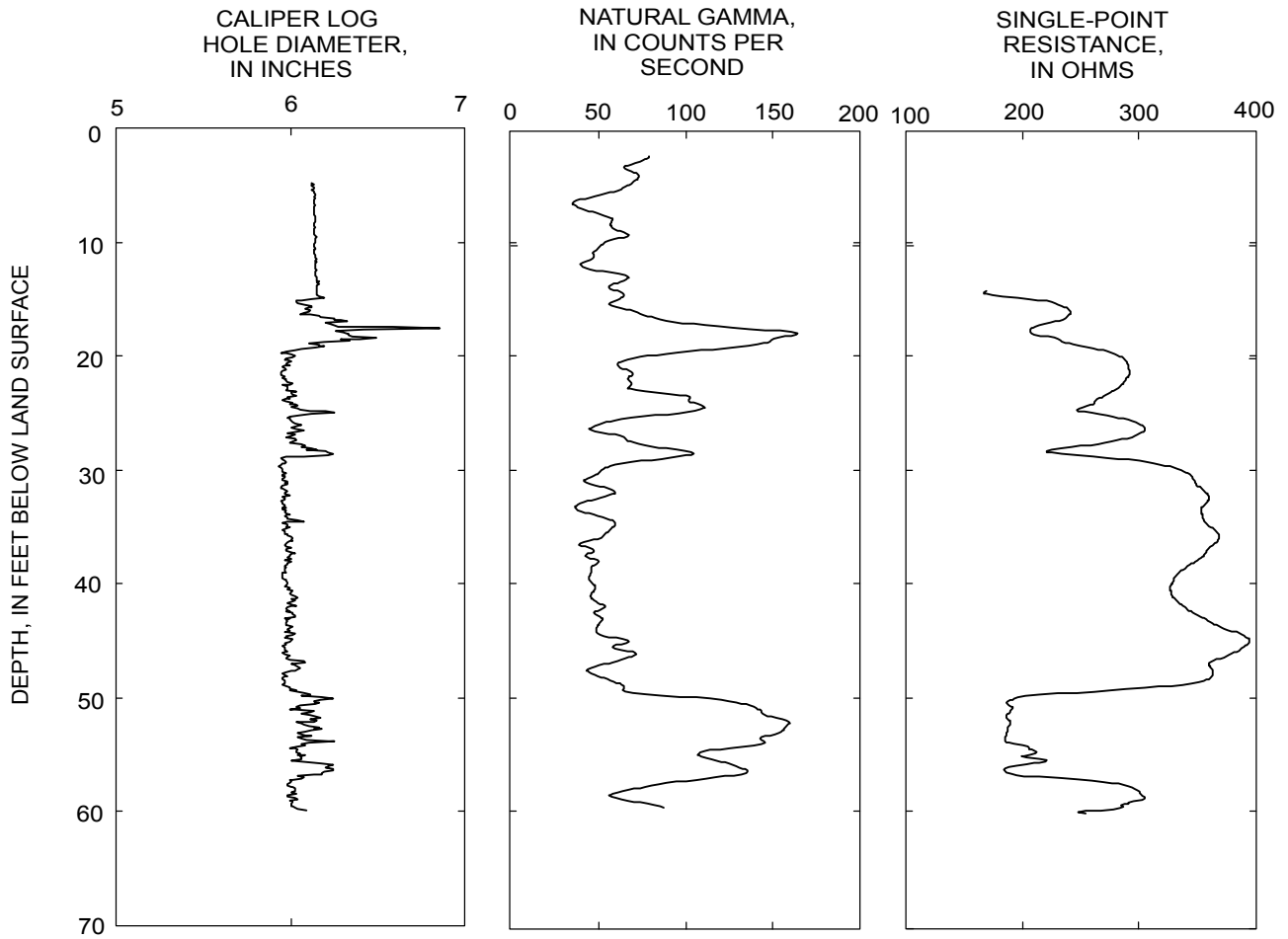
Well HN-23A is a screened monitor well; therefore, only natural-gamma and single-point-resistance logs (fig. 3) were collected by the USGS on June 12, 2007. The logs show the depth to the bottom of the screen is 57 ft. The single-point-resistance log shows the well is screened from 37 to 57 ft below land surface (bls). The spike in the single-point-resistance log shows a possible water-bearing fracture at 47 ft bls. Well HN-23A was pumped for about 5 minutes; the yield was approximately 0.5 gal/min.



**Figure 3.** Borehole geophysical logs for well HN-23A (BK-3040), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

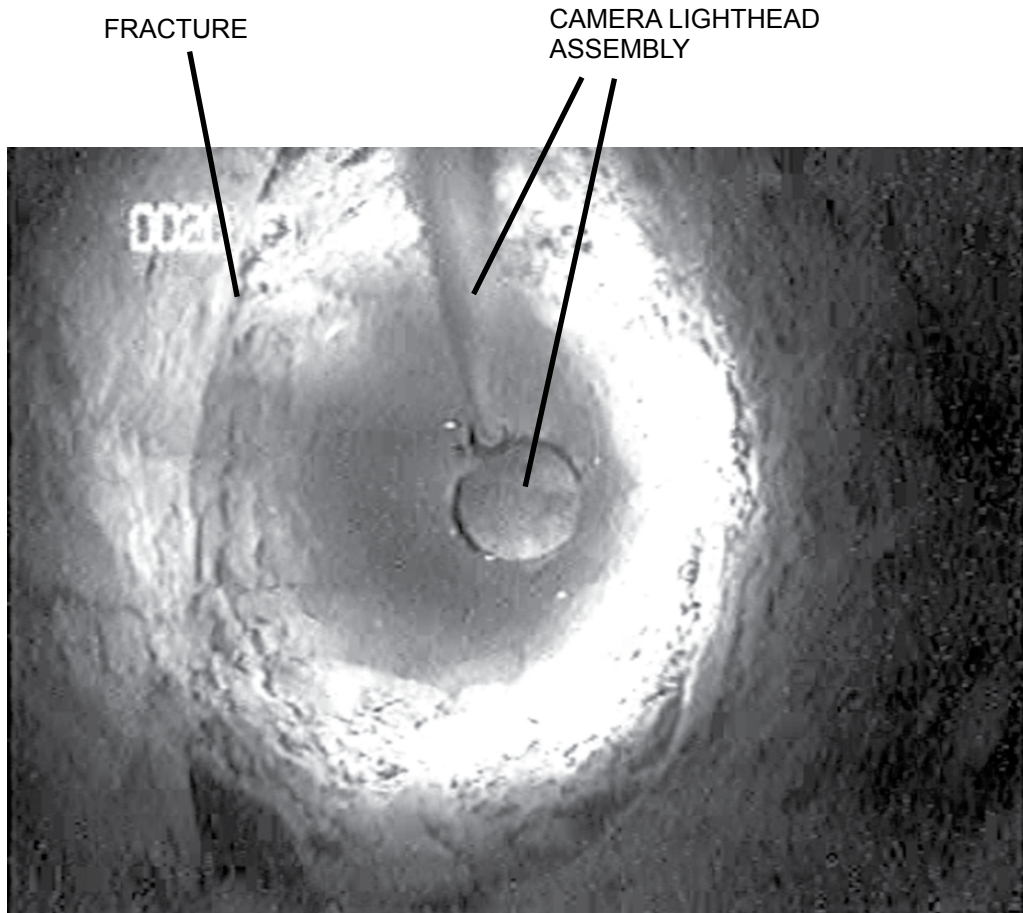
**Well HN-101-OB (BK-3039)**

Caliper, natural-gamma, and single-point-resistance logs (fig. 4) were collected in well HN-101-OB by the USGS on June 12, 2007. The caliper log shows the well is 60 ft deep and is cased to 15 ft bls, and fractures are at 17-20, 25, 28, and 50-56 ft bls. Heatpulse-flowmeter measurements were made at 22, 40, and 53 ft bls under nonpumping and pumping conditions. No vertical borehole flow was measurable under nonpumping conditions. The borehole television survey showed a high-angle fracture zone from the bottom of the casing to 24 ft bls. In this zone, the water was clear, indicating borehole flow. Below 24 ft bls, the water was very cloudy, indicating no borehole flow. When the well was pumped at 2.2 gal/min, the fracture zone at 17-20 ft bls (fig. 5) produced all the water.



**Figure 4.** Borehole geophysical logs for well HN-101-OB (BK-3039), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

8 Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, 2007

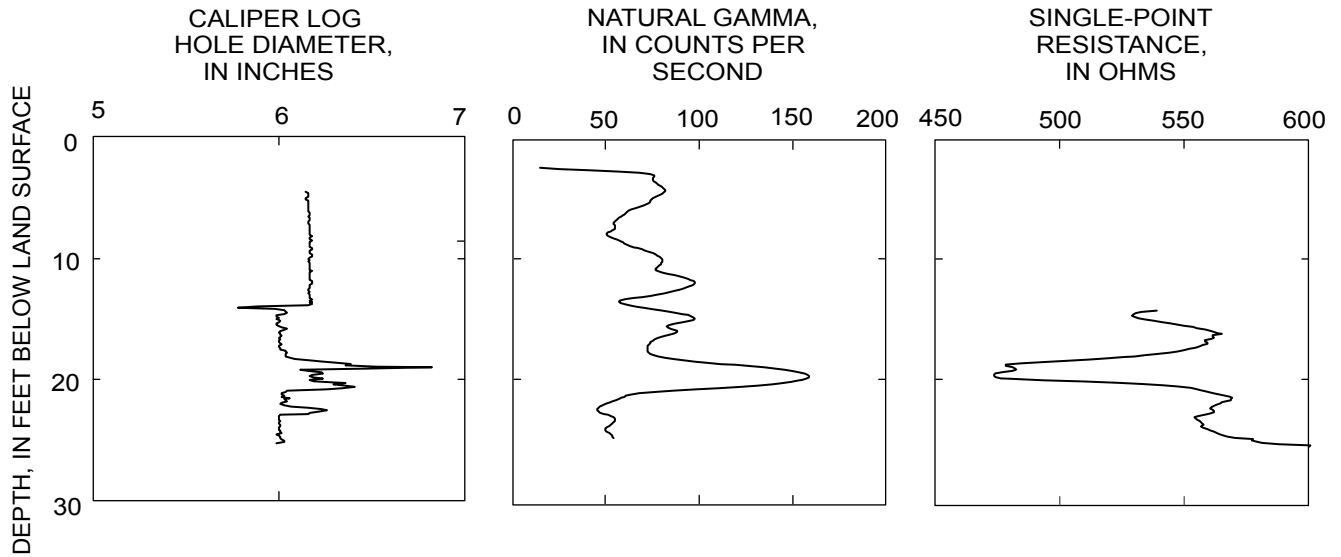


**Figure 5.** Image from borehole television survey showing fracture zone at 20 feet below land surface in well HN-101-OB (BK-3039), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.



**Well HN-101-S (BK-3038)**

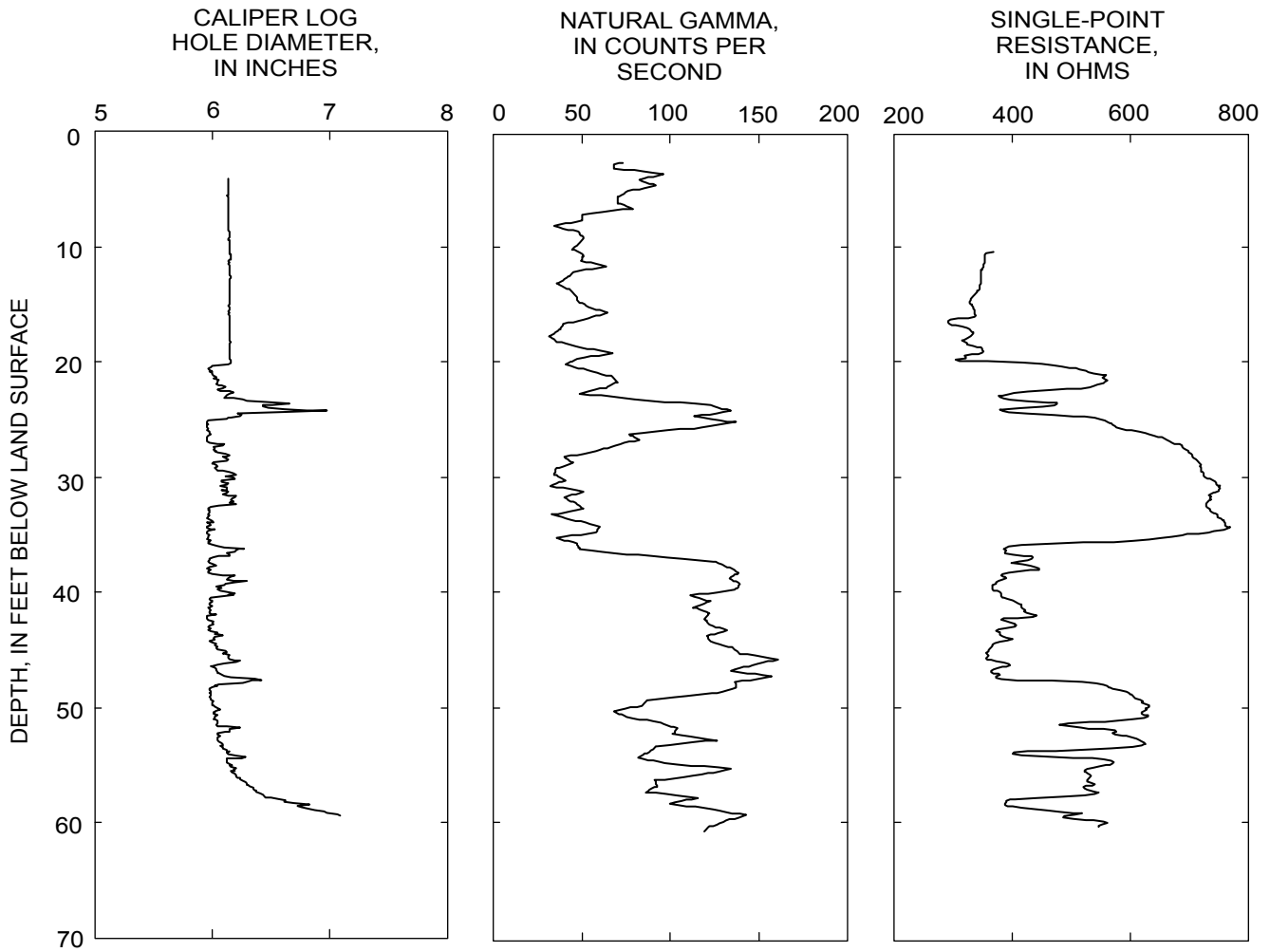
Caliper, natural-gamma, and single-point-resistance logs (fig. 6) were collected in well HN-101-S by the USGS on June 8, 2007. The caliper log shows the well is 25 ft deep and is cased to 14 ft bls, and fractures are at 19, 21, and 23 ft bls. Heatpulse-flowmeter measurements were made at 17 and 21 ft bls under nonpumping conditions. No vertical borehole flow was measurable.



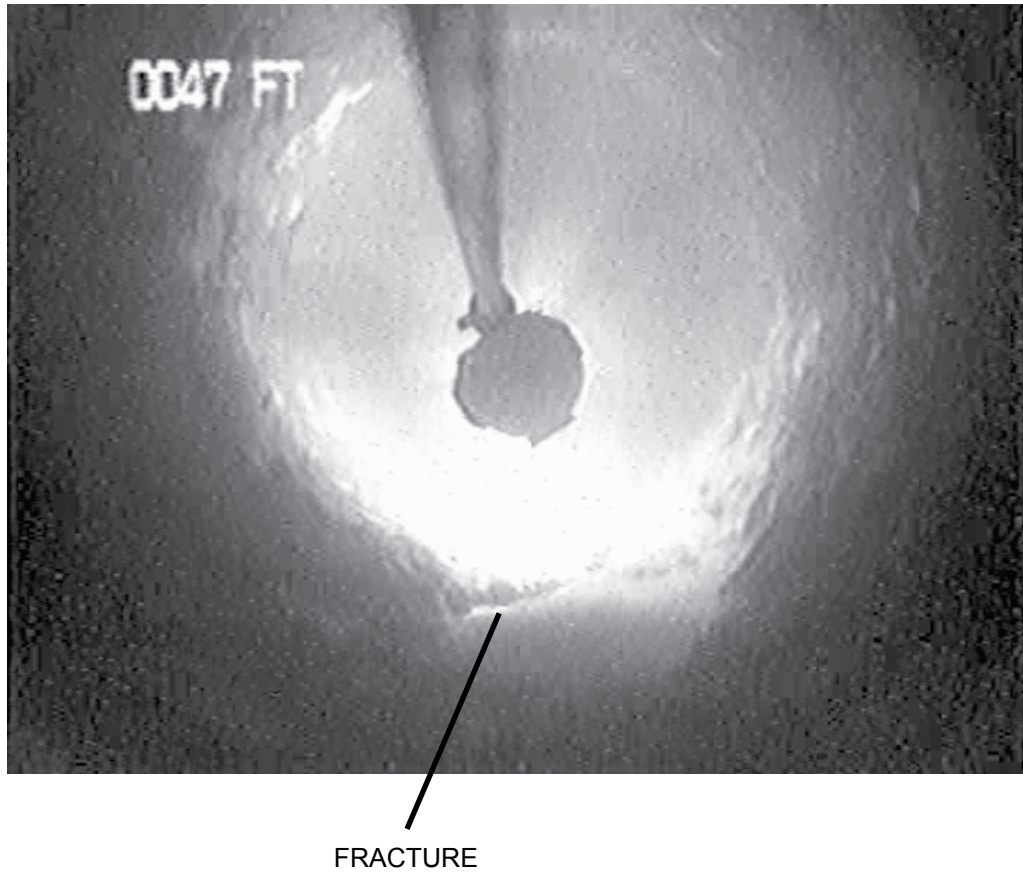
**Figure 6.** Borehole geophysical logs for well HN-101-S (BK-3038), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

**Well HN-102-S (BK-3037)**

Caliper, natural-gamma, and single-point-resistance logs (fig. 7) were collected in well HN-102-S by the USGS on June 8, 2007. The caliper log shows the well is 60 ft deep and is cased to 20 ft bls, and fractures are at 24, 36, and 48 ft bls. Heatpulse-flowmeter measurements were made at 26, 34, 43, and 49 ft bls under nonpumping and pumping conditions. No vertical borehole flow was measurable under nonpumping conditions. When the well was pumped at 0.3 gal/min, a bedding-plane fracture at 48 ft bls (fig. 8) produced all the water.



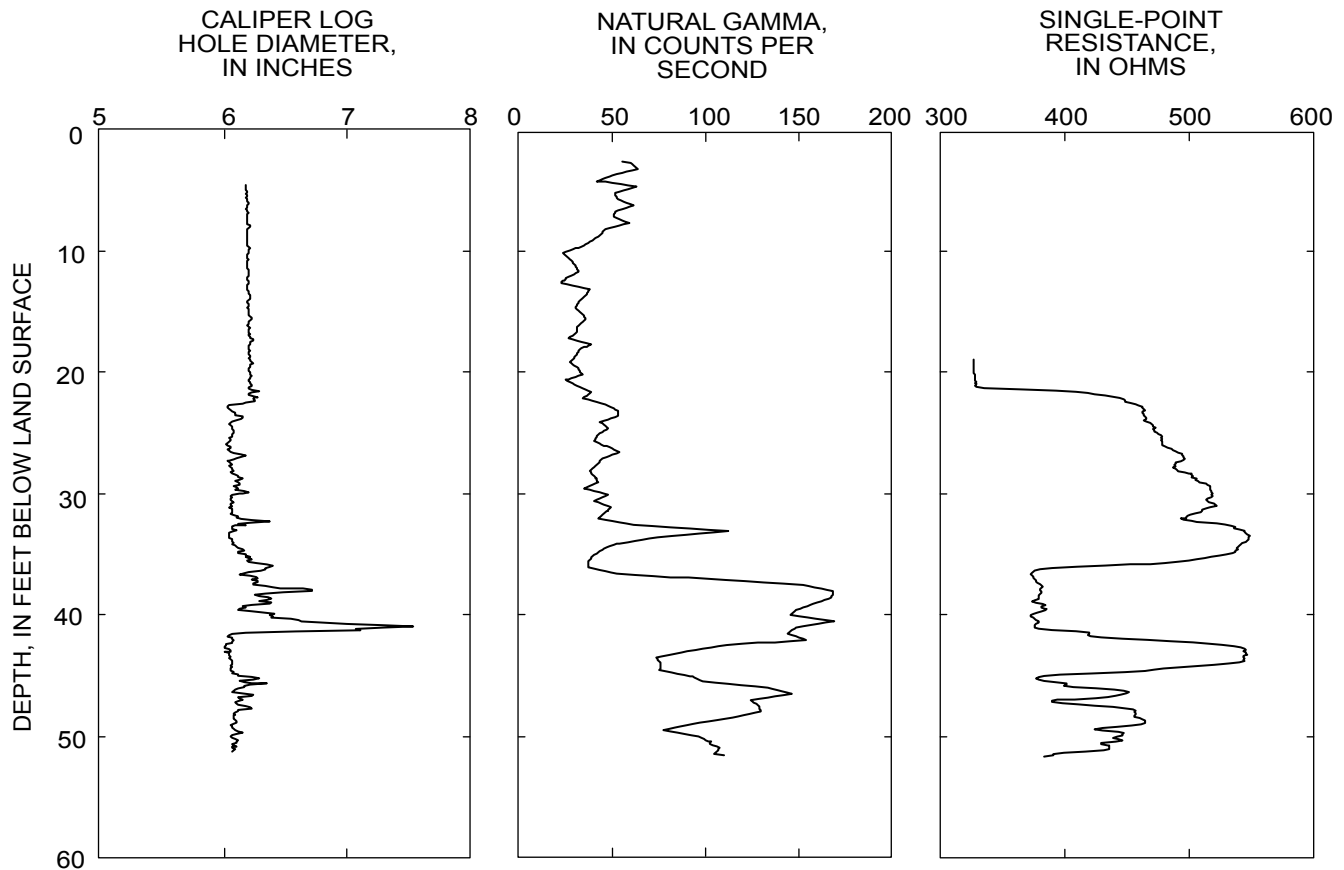
**Figure 7.** Borehole geophysical logs for well HN-102-S (BK-3037), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.



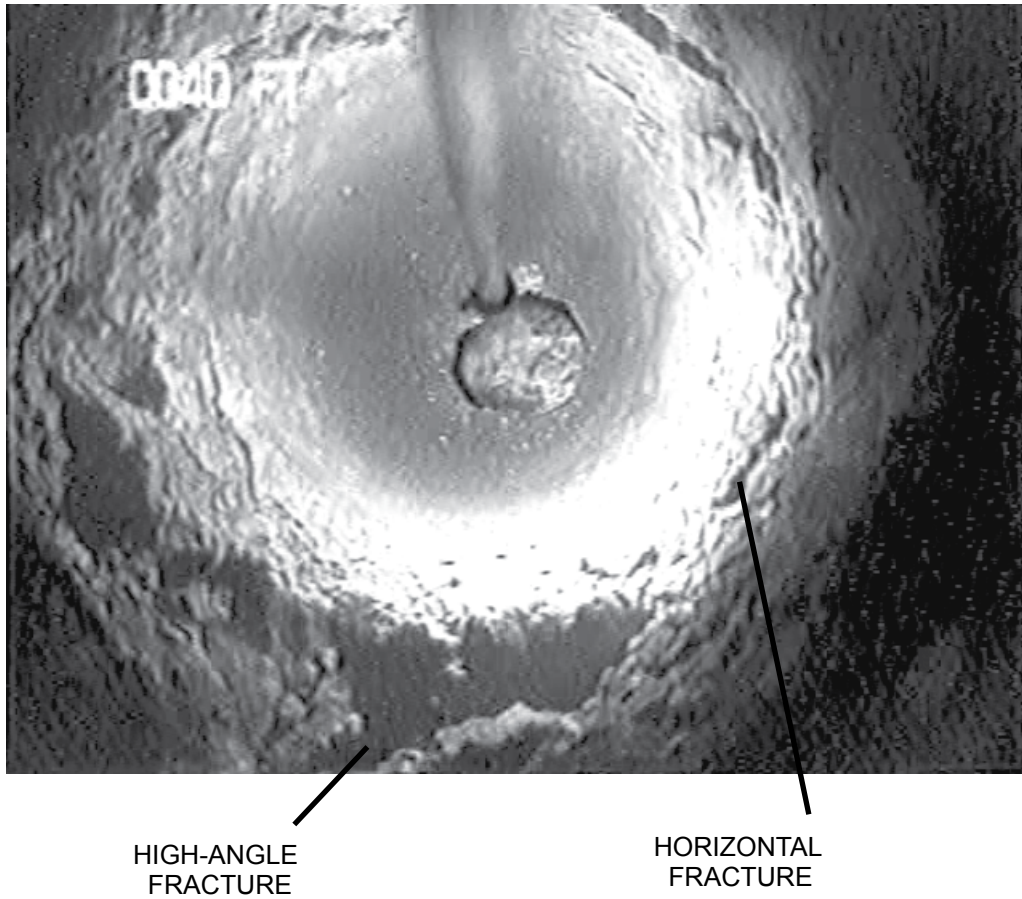
**Figure 8.** Image from borehole television survey showing horizontal fracture at 48 feet below land surface in well HN-102-S (BK-3037), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

**Well HN-103-S (BK-3035)**

Caliper, natural-gamma, and single-point-resistance logs (fig. 9) were collected in well HN-103-S by the USGS on June 8, 2007. The caliper log shows the well is 51 ft deep and is cased to 22 ft bls, and fractures are at 32, 36, 38, and 41 ft bls. Heatpulse-flowmeter measurements were made at 25, 34, and 43 ft bls under nonpumping and pumping conditions. No vertical borehole flow was measurable under nonpumping conditions. When the well was pumped at 0.3 gal/min, the fracture at 41 ft bls produced all the water. The water-bearing zone at 41 ft bls is at the intersection of a high-angle and bedding-plane (horizontal) fracture (fig. 10).



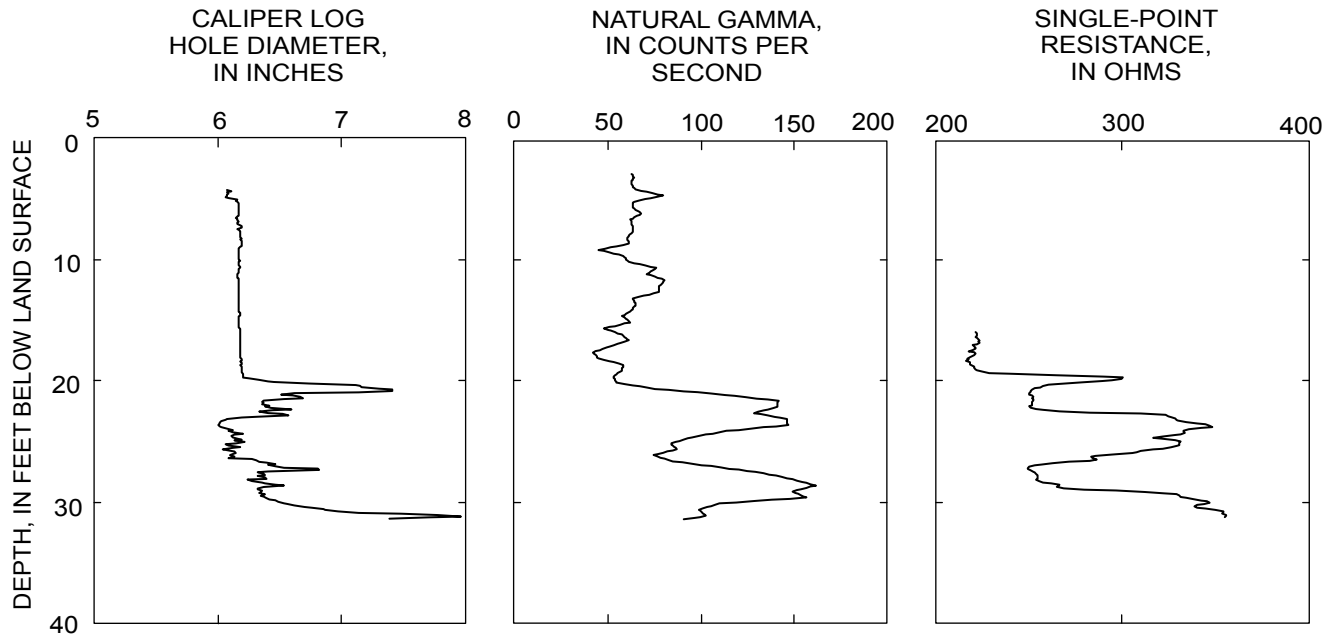
**Figure 9.** Borehole geophysical logs for well HN-103-S (BK-3035), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.



**Figure 10.** Image from borehole television survey showing a high-angle and horizontal fracture at 41 feet below land surface in well HN-103-S (BK-3035), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

**Well HN-104-S (BK-3036)**

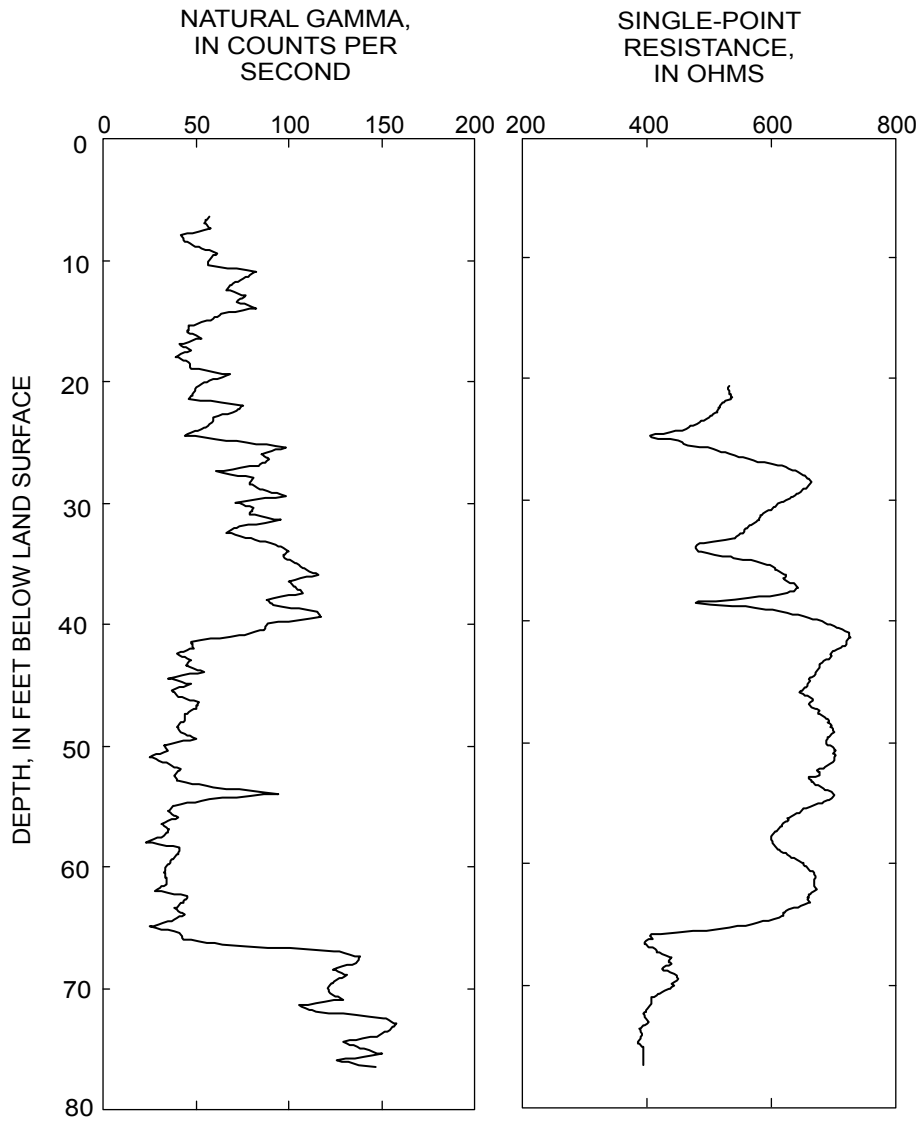
Caliper, natural-gamma, and single-point-resistance logs (fig. 11) were collected in well HN-104-S by the USGS on June 8, 2007. The caliper log shows the well is 31 ft deep and is cased to 20 ft bls, and fractures are at 21, 27, and 31 ft bls. A heatpulse-flowmeter measurement was made at 25 ft bls under nonpumping conditions. No vertical borehole flow was measurable.



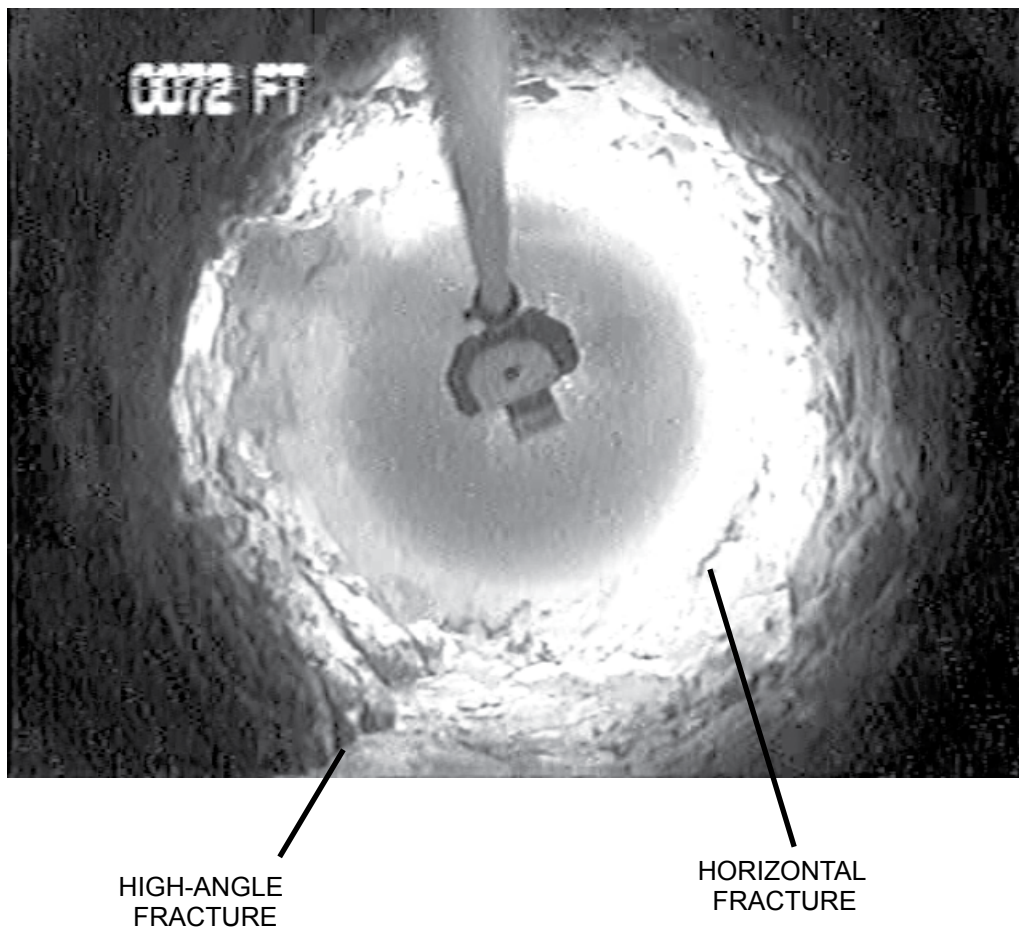
**Figure 11.** Borehole geophysical logs for well HN-103-S (BK-3036), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

**Well HN-105-S (BK-3041)**

Natural-gamma and single-point-resistance logs (fig. 12) were collected in well HN-105-S by the USGS on August 21, 2007. The well is 75 ft deep and cased to 18 ft bls. Heatpulse-flowmeter measurements were made at 29, 36, 43, 58, and 70 ft bls under nonpumping and pumping conditions. No vertical borehole flow was measurable under nonpumping conditions. When the well was pumped at 0.7 gal/min, the fracture at 70 ft bls produced all the water. The water-bearing zone at 70 ft bls is at the intersection of a high-angle and a bedding-plane (horizontal) fracture (fig. 13).



**Figure 12.** Borehole geophysical logs for well HN-105-S (BK-3041), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.



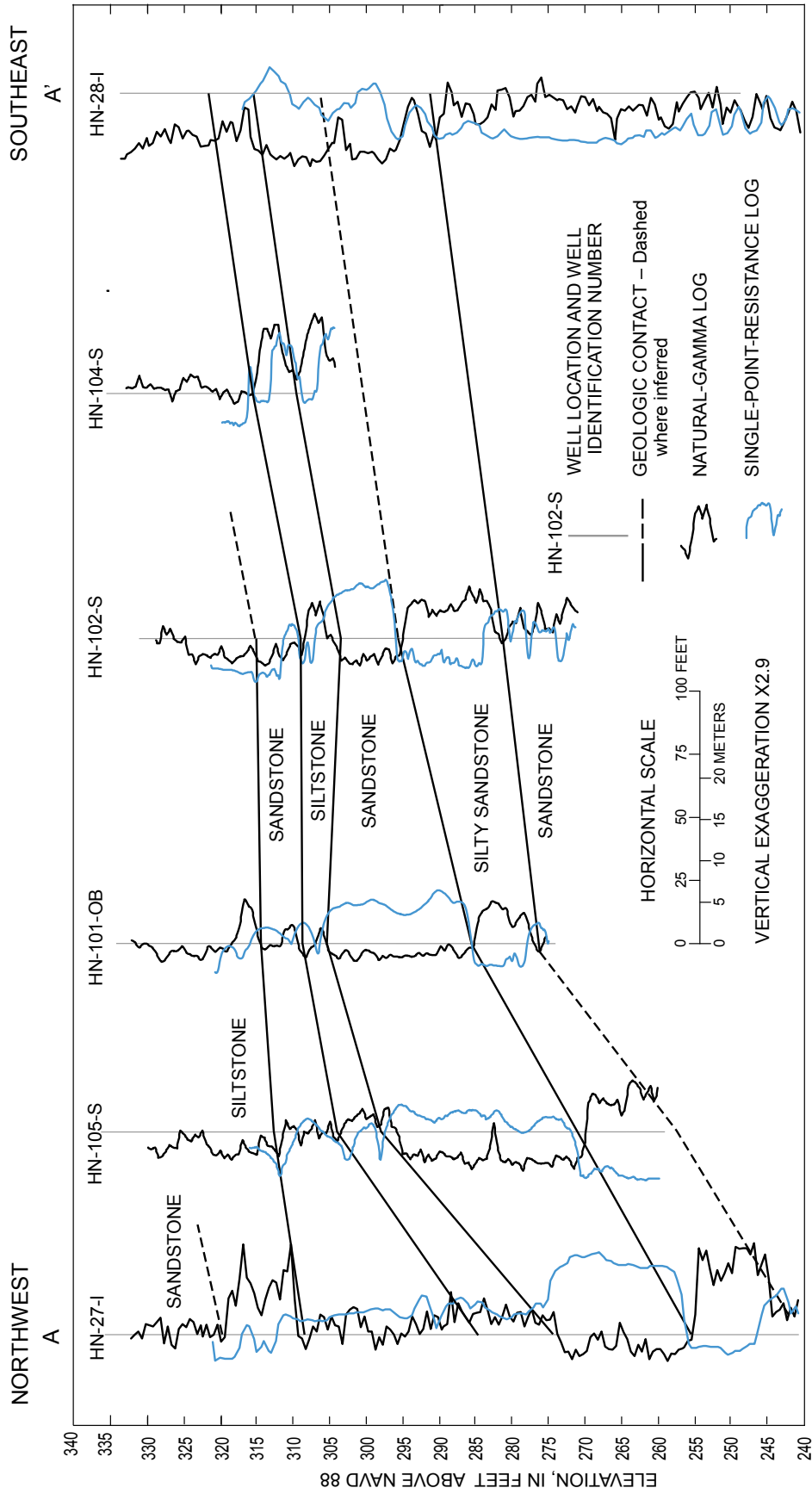
**Figure 13.** Image from borehole television survey showing a high-angle and horizontal fracture at 70 feet below land surface in well HN-105-S (BK-3041), former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

## Correlation of Borehole Geophysical Logs

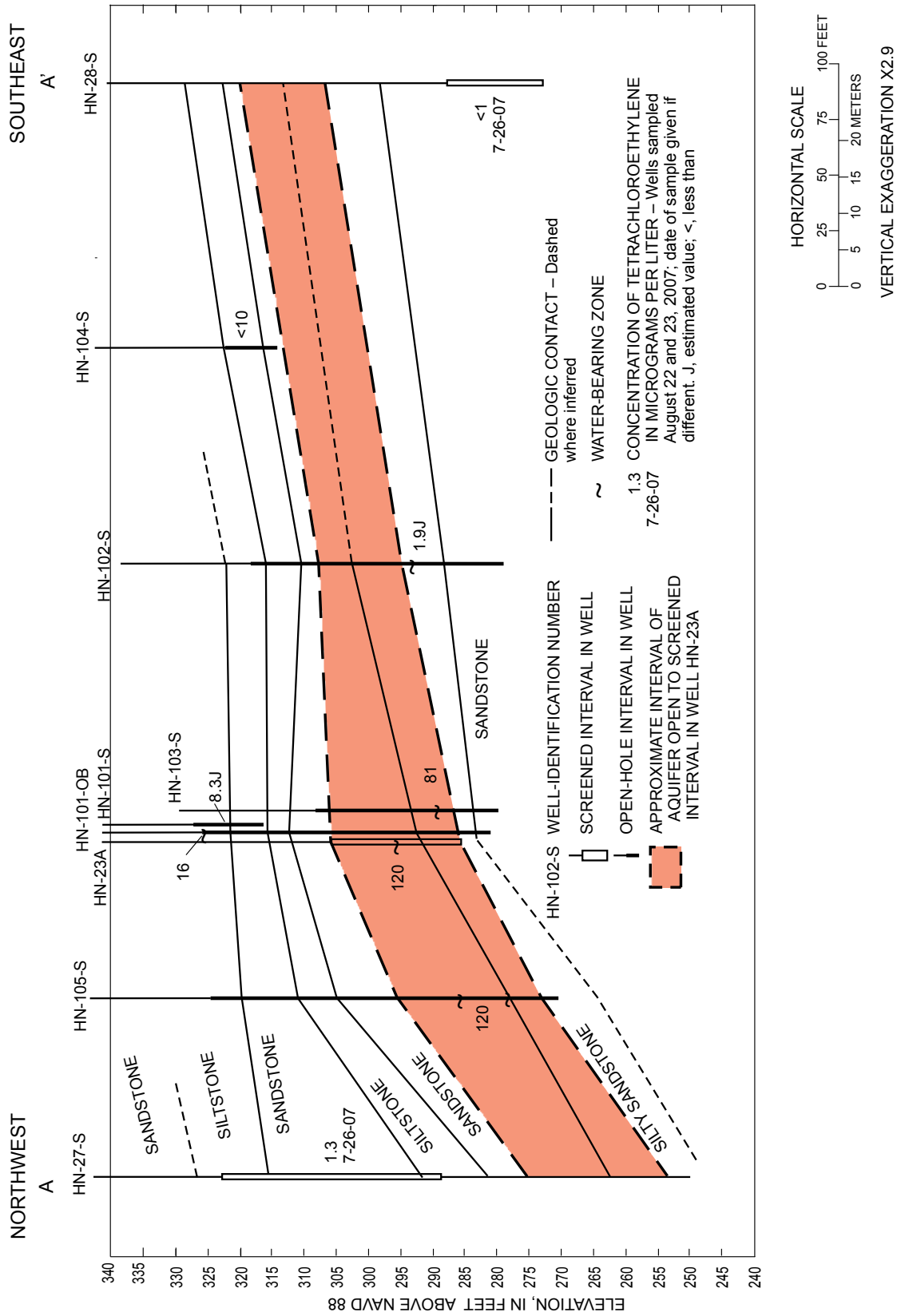
Lithologic units penetrated by the six new monitor wells were correlated using natural-gamma and single-point-resistance logs along a line from well HN-27-S to well HN-28-S (line A-A' on figure 2). Borehole geophysical logs from well HN-27-I, which was drilled adjacent to well HN-27-S and later abandoned, and well HN-27-I, which was drilled adjacent to well HN-27-S and later abandoned, were used for the correlation. Borehole geophysical data for wells HN-27-S, HN-27-I, HN-28-S, and HN-28-I were presented by Sloto and Low (2001). The interpreted lithology across Area C is shown on figure 14.

The water-bearing zones, screened intervals, open-hole intervals, and PCE concentrations were superimposed on the lithologic model for Area C (fig. 15). PCE concentrations were measured in water samples collected in July and August 2007. PCE concentration data for wells HN-27-S and HN-29-S were taken from ECOR Solutions, Inc. (2007), and PCE concentration data for the other wells were taken from Tetra Tech NUS, Inc. (2007). Water samples from wells with water-bearing zones in the same interval as the screened interval in well HN-23A have higher PCE concentrations than water samples from wells that do not have water-bearing zones in that interval. Wells HN-23A and HN-105-S, which had the highest concentrations of PCE, yielded less than 0.5 gal/min. The zone containing elevated concentrations of PCE appears to extend in the upgradient direction toward well HN-103-S (fig. 16).

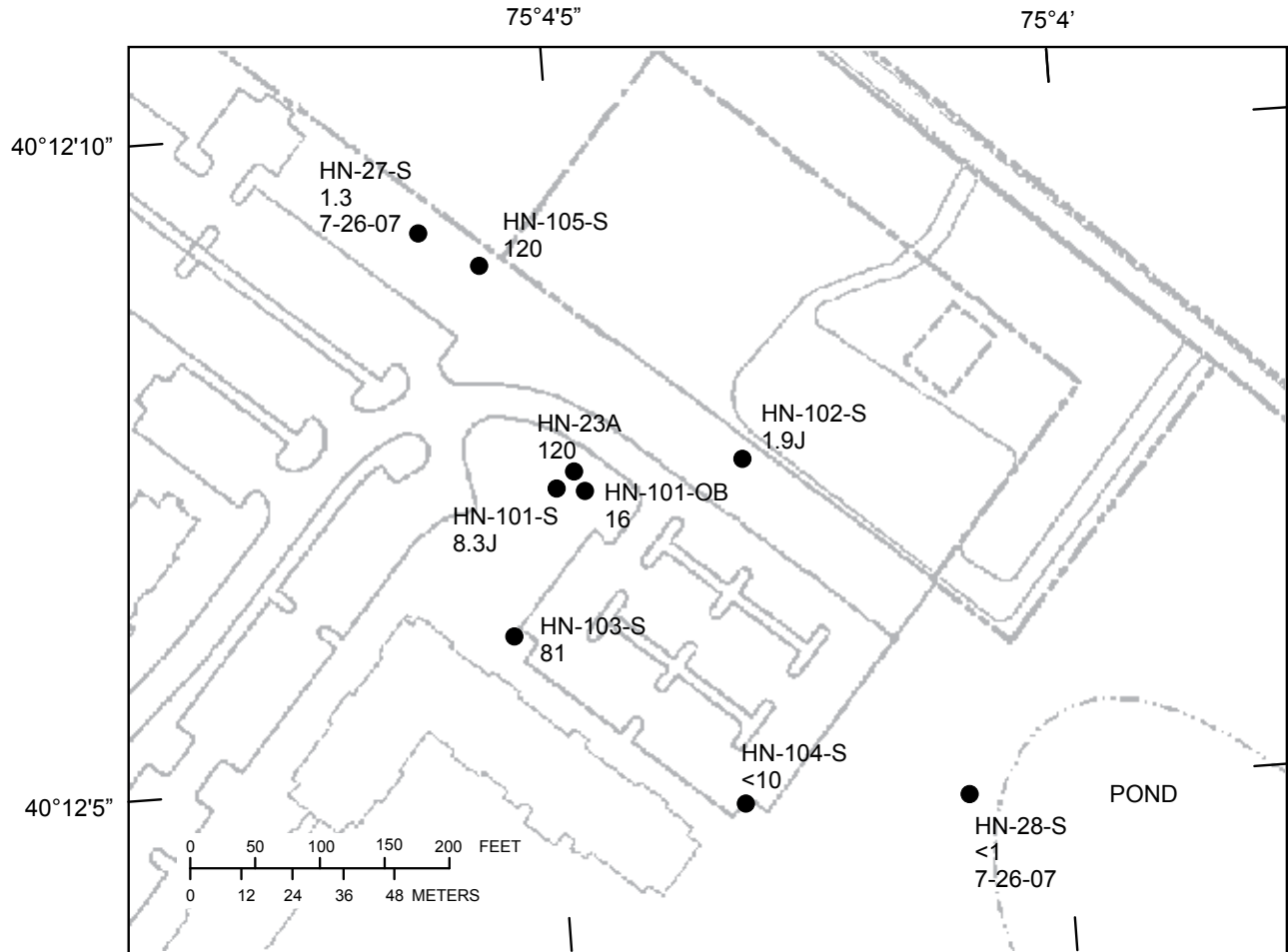




**Figure 14.** Correlation of borehole geophysical logs, Area C, former Naval Air Warfare Center, Bucks County, Pa. Line of section is shown on figure 2. Units shown are part of the Stockton Formation of Upper Triassic age.



**Figure 15.** Tetrachloroethylene (PCE) concentrations in water samples from selected wells in Area C, former Naval Air Warfare Center, Warminster Township, Bucks County, Pa. Line of section is shown on figure 2. Well HN-103-S was projected to line of section Tetrachloroethylene data from Tetra Tech NUS (2007) and ECORE Solutions (2007).



Base modified from ECOR Solutions, Inc. (2006)

EXPLANATION

HN-27-S  
 1.3  
 7-26-07 ●

MONITOR WELL – Upper number is well-identification number.  
 Lower number is tetrachloroethylene concentration in micrograms per liter. Wells sampled August 22 and 23, 2007; date of sample given if different. J, estimated value; <, less than

**Figure 16.** Areal distribution of tetrachloroethylene (PCE) in water samples from selected wells in Area C at the former Naval Air Warfare Center, Warminster Township, Bucks County, Pa.

## Summary and Conclusions

This study was done by the U.S. Geological Survey (USGS) in cooperation with the U.S. Navy at Area C of the former Naval Air Warfare Center (NAWC) in Warminster Township, Bucks County, Pa., in support of hydrogeological investigations conducted by the Navy to address ground-water contamination. The report presents an interpretation of borehole geophysical logs, heatpulse-flowmeter measurements, borehole television surveys, and PCE data for nine wells. The former NAWC is underlain by the Stockton Formation, which consists of sedimentary rocks of Triassic age that form a complex, dipping, heterogeneous aquifer with partially connected zones of high permeability.

For this study, borehole geophysical logs were collected, heatpulse-flowmeter measurements were made, and borehole television surveys were run in seven boreholes ranging from 31 to 75 ft deep. Caliper logs and borehole television surveys were used to identify fractures and the location of possible water-bearing zones. Heatpulse-flowmeter measurements were used to identify the fractures that were water-bearing zones. Natural-gamma and single-point-resistance logs were used to correlate lithology across Area C and develop a lithologic model.

Concentrations of PCE as high as 120 µg/L were measured in water samples from wells with water-bearing zones in the same interval of the aquifer where well HN-23A is screened. Water samples from wells with water-bearing zones above or below this interval had substantially lower concentrations of PCE (<1 to 8.3 µg/L). Wells screened or open to this interval yielded less than 0.5 gal/min, indicating the interval has low permeability, which may account for the small areal extent and slow migration of PCE.

## Acknowledgments

PCE data presented in this report were provided by Tetra Tech NUS, Inc., and ECOR Solutions, Inc. Borehole geophysical logs were collected by Randall Conger of the USGS. Borehole television surveys were made by Philip Bird of the USGS. Critical reviews of this report were completed by Randall Conger and Jason Sorenson of the USGS.

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