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Geohydrology and Distribution of Volatile Organic Compounds in Ground Water in the Casey Village Area, Bucks County, Pennsylvania

by Ronald A. Sloto, Randall W. Conger, and Kevin E. Grazul

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	.003785	cubic meters per day
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius
	Specific Capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter

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, called Sea Level of 1929.

Abbreviated water-quality unit used in report:
micrograms per liter (µg/L)

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ABSTRACT

Casey Village and the adjoining part of the U.S. Naval Air Warfare Center (NAWC) are underlain by the Late Triassic-age Stockton Formation, which consists of a dipping series of siltstones and sandstones.

The direction of vertical ground-water gradients in the Stockton Formation varies among well locations and sometimes with time. Vertical gradients can be substantial; the difference in water levels at one well pair (two wells screened at different depths) was 7.1 ft (feet) over a 32-ft vertical section of the aquifer.

Potentiometric-surface maps show a ground-water divide that bisects the Casey Village area. For wells screened between 18 and 64 ft below land surface (bls), the general ground-water gradient is to the east and northeast on the east side of the divide and to the south and southwest on the west side of the divide. For wells screened between 48 and 106 ft bls, the general ground-water gradient is to the northeast on the east side of the divide and to the southwest and northwest on the west side of the divide. An aquifer test at one well in Casey Village caused drawdown in wells on the opposite side of the ground-water divide on the NAWC and shifted the ground-water divide in the deeper potentiometric surface to the west. Drawdowns formed an elliptical pattern, which indicates anisotropy; however, anisotropy is not aligned with strike or dip. Hydraulic stress caused by pumping crosses stratigraphic boundaries.

Between 1993 and 1996, the trichloroethylene (TCE) concentration in water samples collected from wells in Casey Village decreased. The highest concentration of TCE measured in water from one well decreased from 1,200 µg/L (micrograms per liter) in 1993 when domestic wells were pumped in Casey Village to 140 µg/L in 1996, 3 years after the installation of public water and the cessation of domestic pumping. This suggests that pumping of domestic wells may have contributed to TCE migration. Between 1993 and 1996, the tetrachloroethylene (PCE) concentration in water samples collected from wells in Casey Village decreased only slightly. The highest concentration of PCE measured in water from one well decreased from 720 µg/L in 1993 to 630 µg/L in 1996.

The distribution of TCE and PCE in ground water indicates the presence of separate PCE and TCE plumes, each with a different source area. The TCE plume appears to be moving in two directions away from the ground-water divide area. The pumping of a domestic well may have caused TCE migration into the ground-water divide area. From the divide area, the TCE plume appears to be moving both to the east and the west under the natural hydraulic gradient.

Aquifer-isolation tests conducted in the well with the highest TCE concentrations showed that concentrations of TCE in water samples from the isolated intervals were similar but slightly lower in the deeper isolated zones than in the shallower isolated zones. Upward flow was measured in this well during geophysical logging. If the source of TCE to the well was from shallow fractures, upward flow of less contaminated water could be flushing TCE from the immediate vicinity of this well. This may help explain why the concentration of TCE in water from this well decreased an order of magnitude between 1993 and 1996.

INTRODUCTION

Casey Village is a suburban residential development east of the U.S. Naval Air Warfare Center (NAWC), formerly the Naval Air Development Center, in Warminster and Upper Southampton Townships, Bucks County, Pa. (fig. 1). Off-site ground-water sampling by the U.S. Navy in 1993 as part of a hydrologic investigation at the NAWC showed concentrations of trichloroethylene (TCE) as high as 1,200 µg/L and concentrations of tetrachloroethylene (PCE) as high as 720 µg/L in water samples from residential wells in Casey Village. At the Navy's expense, homes in Casey Village were connected to a public water-distribution system. Although Warminster Township regulations require the destruction of residential wells after the residences are connected to public water, the U.S. Environmental Protection Agency (USEPA) contacted homeowners and found 12 who were willing to have their wells used as monitor wells. In 1995, 9 of these 12 wells were reconstructed as screened monitor wells by the U.S. Geological Survey (USGS). Water levels were measured in the wells after reconstruction. In February and October of the following year, water samples were collected from these wells and from selected wells on the adjoining part of the NAWC. Water levels were measured during water sample collection. An aquifer and aquifer-isolation test were conducted in the well with the highest concentrations of TCE. The 12 former domestic wells make up the well network used in this investigation of ground-water contamination by volatile organic compounds (VOC's) conducted by the USGS in cooperation with the USEPA.

Purpose and Scope

This report describes the geohydrologic framework of Casey Village and the distribution of VOC's in ground water on the basis of the limited data collected for this investigation. In this report, borehole geophysical logs are used to help define the geologic framework. Borehole geophysical logs, heatpulse-flowmeter measurements, aquifer-test data, and water-level data are used to help describe the ground-water-flow system. Heatpulse-flowmeter and water-level data are used to determine ground-water-flow gradients. Results of analyses for VOC's in water samples collected by the USGS from 33 wells are used to determine the extent of ground-water contamination by VOC's.

Location and Physiography

The approximately 0.5-mi^2 study area includes most of the Casey Village residential development and the adjacent part of the NAWC (fig. 1). The study area 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 topography is flat to rolling.

A surface-water-drainage divide bisects the study area (fig. 1). The east side of the study area drains to Mill Creek, a tributary to Neshaminy Creek. The west side of the study area drains to Southampton Creek, a tributary to Pennypack Creek. Neshaminy and Pennypack Creeks are tributaries to the Delaware River.

Climate

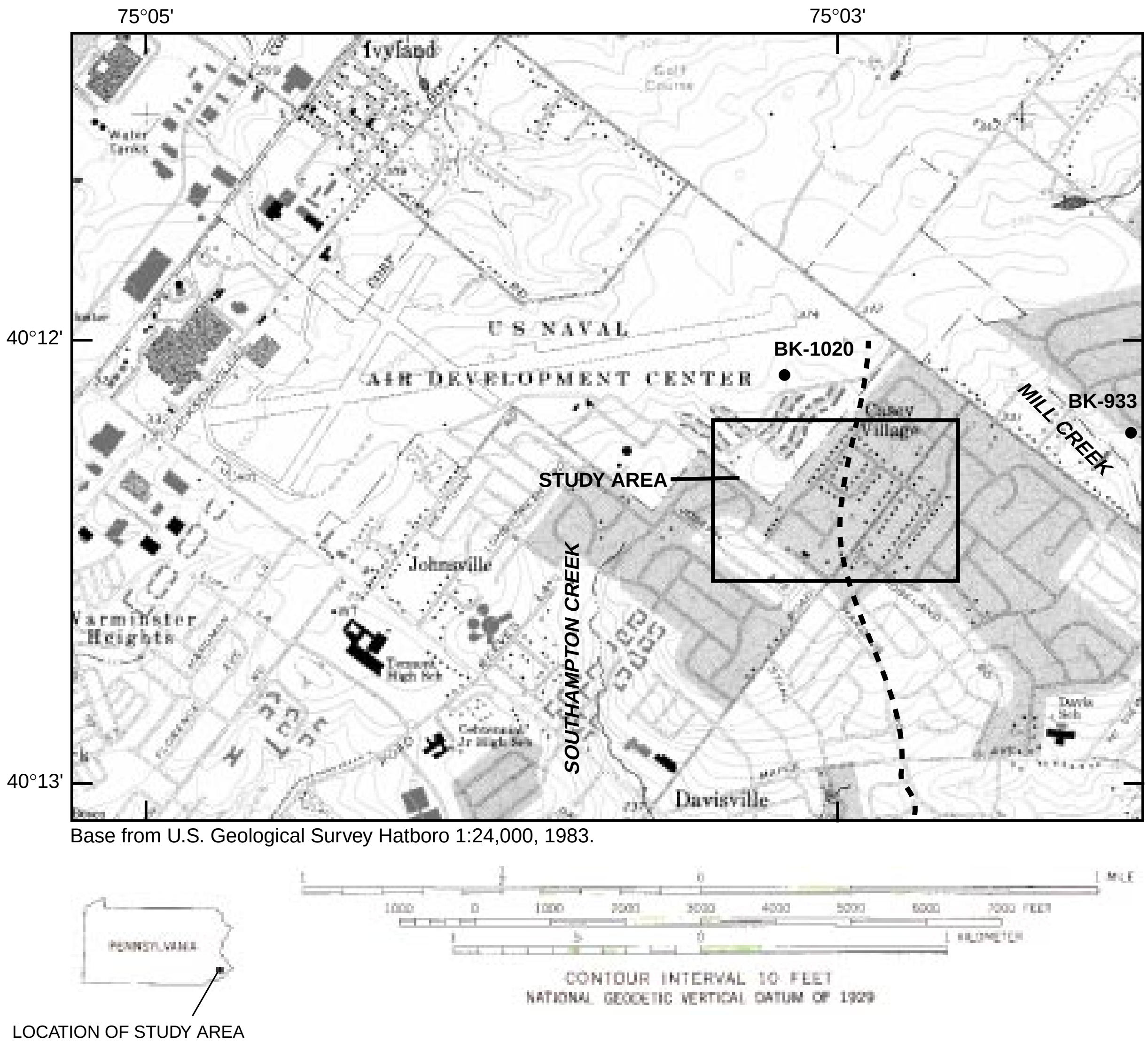
Bucks County has a humid, modified continental climate characterized by warm summers and moderately cold winters. The normal (1961-90) mean annual temperature at Neshaminy Falls, Pa., which is about 6 mi southeast of the study area, is 51.7°F. The normal mean temperature for January, the coldest month, is 28.3°F, and the normal mean temperature for July, the warmest month, is 73.8°F. Normal annual precipitation at the Neshaminy Falls station is 47.47 in. and is fairly evenly distributed; July is the wettest month (5.35 in.), and February is the driest month (3.30 in.) (Owenby and Ezell, 1992).

Previous Investigations

The geology and hydrology of the Stockton Formation in southeastern Pennsylvania were described by Rima and others (1962). Sloto and Davis (1983) described the effect of urbanization on the water resources of Warminster Township. Sloto and others (1992) and Sloto, Macchiaroli, and Towle (1966) described the use of borehole geophysical methods to determine the extent of aquifer cross-contamination by VOC's through open boreholes in the Stockton Formation in Hatboro Borough and Warminster Township. Potentiometric surfaces in the Casey Village area were mapped by Sloto and Grazul (1995) and Sloto (1996b). A study of the NAWC adjacent to Casey Village was done by the Haliburton NUS Corporation (1995).

Well-Numbering 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. U.S. Navy well-identification numbers are used for wells at the NAWC. U.S. Navy well-identification numbers begin with the prefixes HN and SW. U.S. Navy well-identification number suffixes are S (shallow well), I (intermediate-depth well), and D (deep well). A cross reference between numbers used by the USGS and the U.S. Navy is given



EXPLANATION

BK-1020 ● WELL LOCATION AND IDENTIFICATION NUMBER

- - - - - - - - SURFACE-WATER DIVIDE

Figure 1. Location of Casey Village and study area, Bucks County, Pennsylvania.

in table 1. Data on the interval open to the aquifer in table 1 includes the length of the well screen plus the thickness of the filter pack above and below the well screen. Locations of wells are shown on figure 2.

ACKNOWLEDGMENTS

The authors thank the residents of Casey Village who allowed access to their wells so that they could be logged, reconstructed, tested, and sampled; the U.S. Navy for access to their wells and for providing funding for borehole geophysical logging and collection and analysis of water samples from wells at the NAWC; and Brown and Root Environmental, Inc. for providing chemical data and the base map. Lonnie Monico and Jeff Dale of the U.S. Navy and Jeff Orient and Garth Glenn of Brown and Root Environmental, Inc. were especially helpful. The authors also acknowledge the Report Team for this project, who were instrumental in the planning and technical review of this report: Kathryn Davies of the USEPA and Pierre J. Lacombe and Bruce D. Lindsey of the USGS. B. Craig McManus and Cynthia J. Rowland of the USGS assisted with ground-water sampling.

Table 1. *Record of selected wells and water-level measurements for August 3, 1995, February 15, 1996, and October 7, 1996, Casey Village area, Bucks County, Pennsylvania*

[USGS, U.S. Geological Survey; --, no data]

USGS well-identification number	Site well-identification number	Well diameter (inches)	Interval open to aquifer (feet below land surface)[1]	Elevation of measuring point (feet above sea level)	Altitude of water level (feet above sea level)		
					August 3, 1995	February 15, 1996	October 7, 1996
Casey Village Wells							
BK-1021	--	2	50-64	353.69	322.10	326.18	325.09
BK-2767	--	2	28-57	356.41	328.60	332.50	330.88
BK-2768	--	2	28-42	354.68	329.69	334.02	332.41
BK-2769	--	2	40-59	355.19	344.80	339.61	337.51
BK-2770	--	2	26-39	359.25	337.27	339.87	338.66
BK-2788	--	2	18-32	347.15	330.28	333.29	332.21
BK-2789	--	2	30-54	344.36	327.10	329.76	328.58
BK-2790	--	2	28-42	357.96	322.17	324.79	323.14
BK-2791	--	2	20-34	359.46	343.15	347.94	345.64
BK-2795	--	2	88-106	356.44	328.17	332.04	330.42
BK-2796	--	2	67-75	358.02	327.43	330.53	329.22
BK-2797	--	2	48-61	359.45	337.50	340.84	339.31
BK-2798	--	6	Open hole to 108	357.29	327.92	331.17	329.83
BK-2799	--	6	Open hole 20-102	358.67	328.00	331.71	330.45
BK-2800	--	6	Open hole to 89	356.92	321.99	325.00	323.78
Naval Air Development Center Wells[2]							
BK-2544	HN-5-S	4	36-55	339.11	--	[3] 331.60	330.74
BK-2542	HN-5-I	4	70-88	337.70	--	331.30	326.48
BK-2543	HN-5-D	4	180-204	338.30	--	328.89	330.92
BK-2547	HN-6-S	4	30-53	345.62	328.63	331.69	330.34
BK-2546	HN-6-I	4	80-103	345.52	330.50	334.22	332.45
BK-2545	HN-6-D	4	134-154	345.54	329.96	333.73	332.08
BK-2550	HN-7-S	4	29-45	352.86	328.80	332.59	330.94
BK-2544	HN-7-I	4	64-85	352.54	328.45	332.00	330.26
BK-2548	HN-7-D	4	144-162	350.59	328.59	331.96	330.45
BK-2553	HN-8-S	4	29-48	356.07	329.00	335.37	332.61
BK-2552	HN-8-I	4	60-78	356.23	321.95	327.92	325.47
BK-2551	HN-8-D	4	157-178	355.55	323.74	328.85	327.03
BK-2556	HN-9-S	4	29-52	355.01	329.76	334.88	332.74
BK-2555	HN-9-I	4	75-103	354.32	327.86	331.81	329.95
BK-2554	HN-9-D	4	138-161	353.98	327.72	330.90	329.58
BK-2670	HN-49-S	2	36-51	352.72	328.51	333.15	330.91
BK-2671	HN-49-I	2	55-75	352.45	328.05	331.91	329.64
BK-2672	HN-49-D	2	118-135	352.96	327.78	330.88	329.63
BK-2830	HN-61-S	2	81-95	350.75	--	330.33	329.65
BK-2831	HN-61-I	2	110-124	352.03	--	332.22	329.51
BK-2828	HN-62-S	2	35-50	345.94	--	334.19	331.74
BK-2829	HN-62-I	2	70-85	345.13	--	331.54	329.57
BK-1020	SW-11	6	57-400	370 est.	--	340.50	336.53

[1] Includes length of screen plus thickness of filter pack above and below screen.
[2] Measuring-point elevations from Haliburton NUS Corporation (1995).
[3] Water level measured on February 20, 1996.

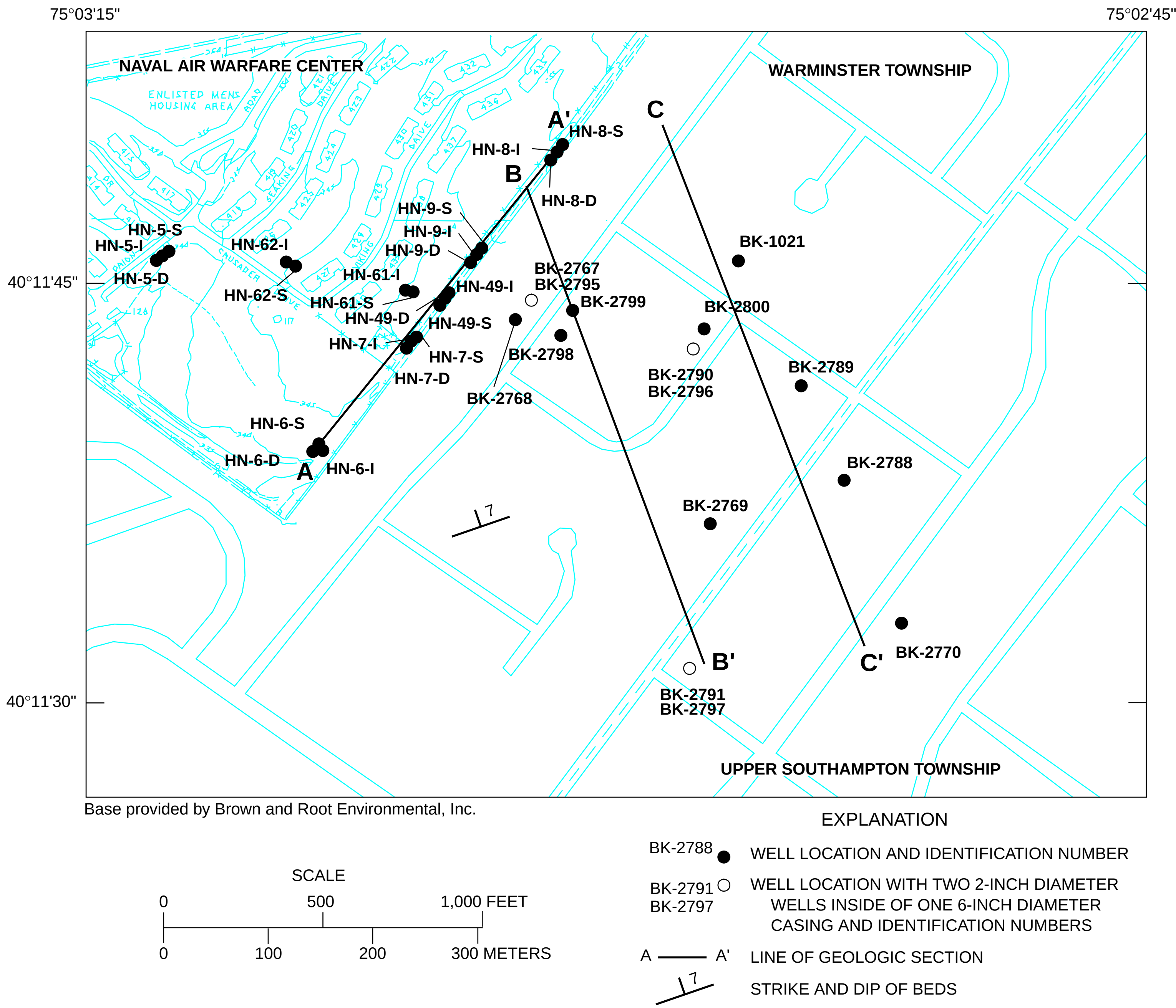


Figure 2. Location of selected wells and geologic sections in the Casey Village area, Bucks County, Pennsylvania.

METHODS OF STUDY

Borehole Geophysics

Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs were run in 10 former domestic wells in Casey Village that were 40 to 111 ft deep. No data were available for these wells. The logs were used to locate water-bearing fractures, determine probable zones of vertical borehole-fluid movement, and determine the depth interval to set screens when the wells were converted to monitor wells. The logs also were used to develop the hydrogeologic framework.

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. Caliper logs were used to help correlate lithostratigraphy and to identify fractures and possible water-bearing openings. Correlation of caliper logs with fluid-resistivity and fluid-temperature logs was used to identify water-producing and water-receiving fractures or zones.

Natural-gamma logs, also called gamma-ray logs, record the natural-gamma radiation emitted from rocks penetrated by the borehole. Gamma radiation can be measured through casing, but the gamma response is dampened. Uranium-238, thorium-232, and the progeny of their decay series and potassium-40 are the most common emitters of natural-gamma radiation. These radioactive elements may be concentrated in clay by adsorption and ion exchange; therefore, fine-grained sedimentary rocks (siltstone units) usually emit more gamma radiation than do coarse-grained sedimentary rocks (sandstone units). Natural-gamma logs were used to differentiate between sandstone (sandy) and siltstone (silty) units and for lithostratigraphic correlation.

Single-point-resistance 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-bearing fractures, and increasing dissolved-solids concentration of borehole fluid (Keys, 1990). A fluid-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 sometimes help to identify the location of water-bearing zones because a fluid-filled fracture is less resistive than solid rock.

Fluid-temperature logs provide a continuous record of the temperature of the fluid in the borehole. Fluid-temperature logs were used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones usually were identified by sharp changes in temperature, and intervals of vertical borehole flow were identified by little or no temperature gradient. In the study area, fluid-temperature logs from wells with no borehole flow commonly show a decrease in fluid temperature with depth caused by surface heating in the upper part of the borehole and an increase in fluid temperature with depth as a function of the geothermal gradient in the lower part of the borehole.

Fluid-resistivity logs measure the electrical resistance of fluid in the borehole. Resistivity is the reciprocal of fluid conductivity, and fluid-resistivity logs reflect changes in the dissolved-solids concentration of the borehole fluid. Fluid-resistivity logs were used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones usually were identified by sharp changes in resistivity, and intervals of borehole flow were identified by a low resistivity gradient between water-producing and water-receiving zones.

Measurement of Vertical Borehole Flow

The direction and rate of borehole-fluid movement were measured with a 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 measurement is about 0.01-1.0 gal/min in a 2- to 8-in. diameter borehole. Heatpulse-flowmeter measurements may be influenced by poor seal integrity between the borehole and the flowmeter or contributions of water from storage within the borehole. 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 to identify fluid-producing zones.

The heatpulse flowmeter was used under both nonpumping and pumping conditions. The direction of borehole flow during pumping is always upwards. If the heatpulse-flowmeter measurements indicated very low or no vertical borehole flow under nonpumping conditions, a pump was lowered approximately 10 ft below the top of the water surface, and the well was pumped at a rate less than 1 gal / min. During pumping, flow measurements were made at the same depths as the nonpumping measurements to help identify the fracture or fractures in the borehole with the greatest fluid production.

Monitor-Well Construction Procedures

Nine domestic wells drilled in the 1950's in Casey Village were reconstructed as 2-in. diameter monitor wells by the USGS in 1995. The top of the wells were buried about 3 ft below land surface (bls) (below the frost line), a common domestic well-construction practice in the 1950's. The wells were located and excavated, the pipes in the well were removed, and the casings were extended to the land surface. A suite of geophysical logs was run in each well and used to determine the depth to set a screen to convert the open-hole domestic well to a screened monitor well.

Each well was constructed as a screened monitor well in the following manner. One or two intervals to be screened were selected on the basis of the caliper, fluid-resistivity, and fluid-temperature borehole geophysical logs and heatpulse-flowmeter measurements. The well was backfilled with bentonite to the bottom of the interval selected for screening. A layer of coarse sand was placed on top of the bentonite, and a 2-in. diameter Schedule 40 polyvinyl chloride (PVC) flush joint threaded 0.020-in. well screen with an end cap on the lower end and a 2-in. diameter Schedule 40 PVC flush joint threaded inner casing was installed in the center of each well. A filter pack consisting of coarse sand was placed from the top of the bentonite backfill to approximately 2 ft above the top of the well screen in the annulus between the 6-in. diameter well and the 2-in. diameter PVC screen. A bentonite seal was installed above the filter pack in the annulus, and the annulus was grouted to land surface with a 90-percent cement grout and 10-percent bentonite mixture pumped down the annulus with a tremie pipe. In three of the wells (BK-2767, BK-2790, and BK-2791), two intervals were screened. Well-construction diagrams are included in Appendix A.

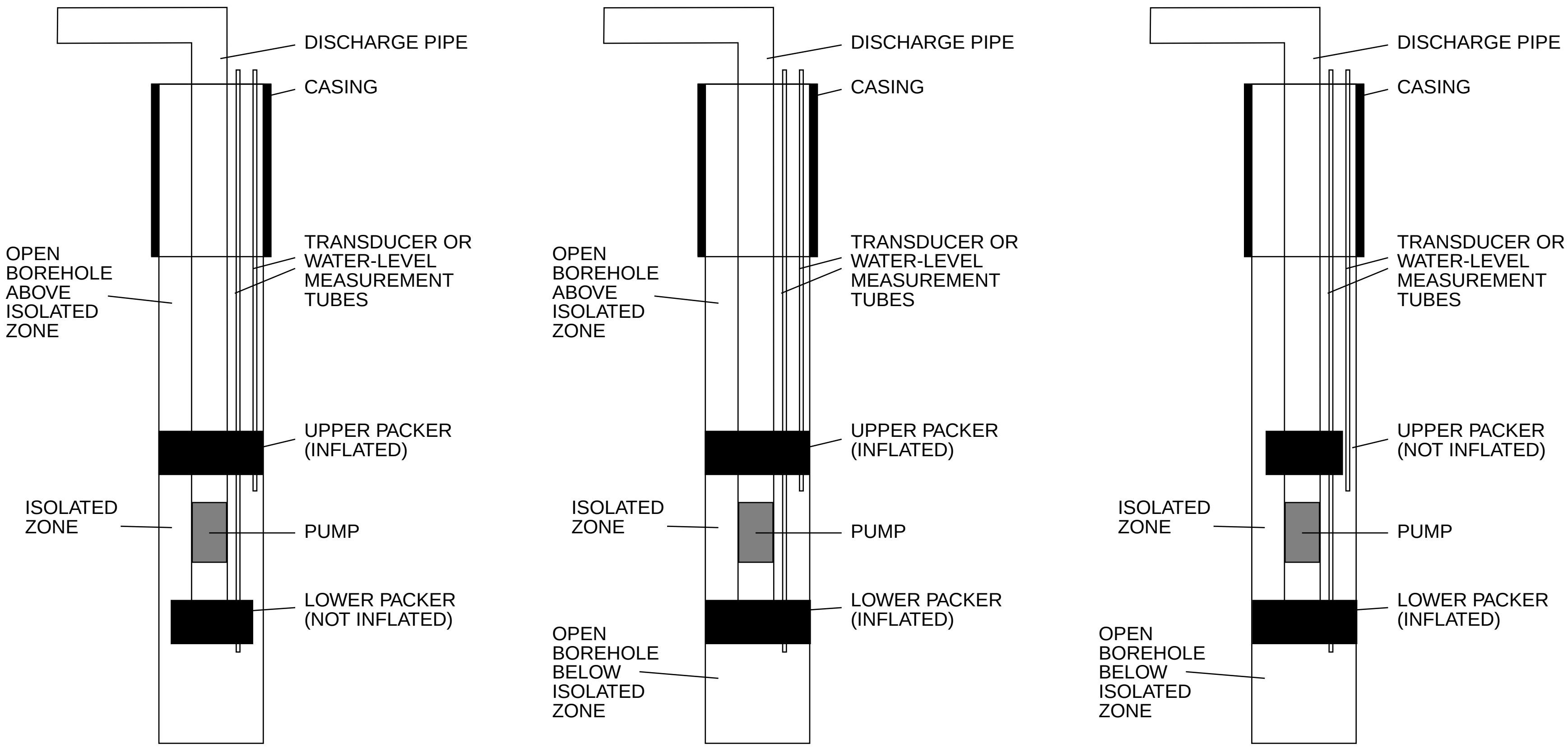
Water-Level Measurements

Water-level measurements needed to construct potentiometric-surface maps were made on August 3, 1995, after well reconstruction and on February 15, 1996, and October 7, 1996, during sampling for VOC's. Water levels were measured as depth to water below an established measuring point. Depth to water was subtracted from the surveyed elevation of the measuring point at each well to compute the altitude of the potentiometric surface. Water-level measurements were made in 1 day by the same person using the same electric water-level-measuring tape. Well HN-5-S was buried under snow on February 15, 1996; the water level was measured on February 20, 1996. Water-level data are presented in table 1.

Hydraulic Tests

A constant-drawdown aquifer test was conducted to determine the effect of pumping well BK-2799 on water levels in nearby wells. About 57 ft of drawdown was maintained in well BK-2799 throughout the test, and water levels were monitored in nearby wells to determine how they responded to pumping. Seven observation wells in Casey Village and 11 observation wells at the NAWC were monitored during the test by use of pressure transducers and data loggers.

An aquifer-isolation test, commonly known as a packer test, was run in well BK-2799. A straddle-packer assembly was used to isolate discrete fracture zones in the well to obtain depth-discrete water samples for VOC analysis. The packer assembly consisted of two inflatable packers set on 2-in. diameter lift pipe with a pump set between the packers. The packer assembly was lowered to the selected depth in the well, and the packers were inflated against the borehole wall to isolate the selected interval. Inflation of the packers created three zones--an upper zone above the upper packer, the isolated zone between the packers, and a lower zone below the lower packer (fig. 3).



A. UPPER PACKER INFLATED B. BOTH PACKERS INFLATED C. LOWER PACKER INFLATED

Figure 3. Generalized sketch of packer assembly and pump used in aquifer-isolation test of well BK-2799, Casey Village, Bucks County, Pennsylvania.

GROUND-WATER SAMPLING

Water samples for VOC analysis were collected from wells after approximately three well volumes were purged and pH, specific conductance, and temperature stabilized. Samples were collected using a 2-in. diameter submersible pump, except at three wells. Wells BK-2798, BK-2799 (in February 1996 only), and BK-2800 were sampled through existing household pumps and plumbing after USGS personnel ascertained that all filters or conditioners were bypassed. Between each well sampled, all used discharge pipe was discarded, and the submersible pump was decontaminated by washing with detergent and rinsing with deionized water. Wells were sampled in order of lowest to greatest VOC concentration on the basis of water samples collected by the U.S. Navy in 1993-94 (U.S. Navy, written commun., 1996). Samples were collected in 40 milliliter septum vials and preserved with 200 microliters of 50 percent hydrochloric acid. The vials were packed in ice and shipped to the laboratory within 24 hours of sample collection. Chain-of-custody protocol was followed. All samples were analyzed by Quanterra Environmental Services in Arvada, Colo., for VOC’s by gas chomatagraph / mass spectrometer using USEPA method 8260. Data validation was done by Dames and Moore, Inc.

Daily field blank samples, laboratory blank samples, duplicate samples, and samples of water from well BK-1021 for matrix spike treatment were included for quality assurance. For the February 1996 samples, three lab blanks, six trip blanks, and four duplicates were submitted to the laboratory. Quality-assurance samples made up 29 percent of the samples submitted. For the October 1996 samples, two lab blanks, four trip blanks, and two duplicates were submitted to the laboratory. Quality-assurance samples made up 33 percent of the samples submitted. All samples submitted to the laboratory were included in the data-validation process. Laboratory analytical data are validated to ensure that the data are acceptable for the intended purpose. Data validation takes into consideration the analytical methodology and laboratory standard operating procedures.

GEOHYDROLOGY

The Casey Village area is underlain by the Stockton Formation, which comprises a bedrock-aquifer system. The residents of Warminster and Upper Southampton Townships depend on ground water withdrawn from the Stockton Formation for their drinking water supply. The Stockton Formation is one of the most important aquifers in southeastern Pennsylvania and provides the water supply for more than 1 million residents.

GEOLOGIC FRAMEWORK

The Casey Village area is underlain by sedimentary rocks of the Stockton Formation of Upper Triassic age. The Stockton Formation is the basal unit of the Newark Supergroup rocks in the Triassic-Jurassic Newark Basin. This basin contains 16,000 to 20,000 ft of nonmarine sedimentary rocks, is approximately 140 mi long and 32 mi wide, and is the largest of the 13 major exposed Triassic-Jurassic rift basins stretching from Nova Scotia to South Carolina. Sediments in the basin are the result of infilling during the initial stages of continental breakup (Turner-Peterson and Smoot, 1985, p. 10). Sedimentation in the Newark Basin began with an influx of arkosic detritus from uplifted crystalline rocks to the south not far from the present day southern basin margin (Glaeser, 1966, p. 26). One characteristic of the Stockton Formation is the thick-bedded to locally massive arkosic sandstones. The sediments were deposited on folded and deeply eroded Precambrian and Paleozoic rocks. The basin filled with thousands of feet of sediments over a period of about 45 million years.

The Stockton Formation was subdivided into three units called the lower arkose, middle arkose, and upper shale members by Rima and others (1962). The rocks that underlie the Casey Village area belong to the middle arkose member. The Stockton Formation is 6,000 ft thick near the Bucks-Montgomery County boundary; the middle arkose member accounts for 70 percent of its thickness. In the Casey Village area, the Stockton Formation has a strike of approximately N. 71° E. and a dip of approximately 5–8° NW. (Haliburton NUS Corporation, 1995, p. 3-1). The rocks are chiefly arkosic sandstone and siltstone. Quartz and feldspar are the dominant minerals.

The Stockton Formation includes alluvial fans, fluvial and lacustrine sandstones, and fluvial and near-shore lacustrine siltstones (Turner-Peterson and Smoot, 1985). Near the southern margin, the Stockton contains laterally coalescing alluvial fans deposited by well-established streams. Thick, poorly defined, upward fining cycles possibly were deposited by large, perennial, meandering rivers.

A generalized lithostratigraphic model of the Casey Village area was developed from natural-gamma borehole geophysical logs. Three cross-sections were developed (fig. 2). Generalized cross-section A-A’ along strike was developed by use of natural-gamma-log data from wells at the NAWC (fig. 4). Two cross-sections in the direction of dip (B-B' and C-C') were developed by use of natural-gamma-log data from wells in Casey Village and at the NAWC (figs. 5 and 6).

Because the lithologic units of the Stockton Formation grade, interfinger, and coalesce, none of the units could be used as marker beds within the lithostratigraphic sequence. Therefore, the interpreted lithology of each well was extended along strike (N. 71° E.) or dip (7° NW.) to the next nearest well location to correlate lithostratigraphy. Correlations between wells generally are consistent with strike and dip but show the thinning and thickening of some units across the area. The accuracy of the correlations deteriorate near land surface because of weathering of the formation and dampened natural-gamma response caused by casing. Some lithologic units correlated slightly above or below the expected projection line, probably because of the lens-like structure characteristic of alluvial-fan environments. The units have been interpreted to be continuous, dipping to the northwest with only localized shifts in dip because of thinning or thickening. Driller or geologist logs, where available, helped lithologic interpretations. The units are lettered so that they can be traced among the cross-sections. Units are identified on the generalized cross-sections as either sandy (predominately sandstone) units (units B, D, and F) or silty (predominantly siltstones or silty, fine-grained sandstone) units (units A, C, and E).

HYDROLOGIC FRAMEWORK

In the Stockton Formation, ground water in the weathered zone moves through intergranular openings that have formed as a result of weathering. In some places, permeability of the weathered zone may be low because of a high percentage of clay derived from weathering of siltstone or feldspar. Ground water in the unweathered zone mainly moves through a network of interconnecting secondary openings—fractures, bedding planes, and joints. Beds within the Stockton Formation are hydraulically connected by vertical joints.

In general, the sandstone units are the principal water-bearing units, but some of the finer-grained units may contain water-bearing openings. Because of the ease of weathering and fine grain size of the siltstone units, openings tend to be clogged. In addition, soft siltstone beds deform without breaking under stress and, as a result, have lower permeability than the harder sandstone beds, which tend to develop fractures and joints that increase permeability.

Some water-bearing openings may be slightly enlarged by circulating ground water that has weathered and eroded mineral constituents in the walls of fractures. Primary porosity that may have originally existed in the rock has been almost eliminated by compaction and cementation. Some water may move through intergranular openings in the rock below the weathered zone where the cement has dissolved and the permeability has increased, but this generally is restricted to a few coarse-grained sandstone and conglomerate beds. Laboratory hydraulic-conductivity tests were conducted on core sections collected 3 mi southwest of the Casey Village area (Sloto, Macchiaroli, and Towle, 1996, p. 19). Siltstone had a hydraulic conductivity of 5×10^{-7} ft / d; silty, fine-grained sandstone had a hydraulic conductivity of 3×10^{-6} ft / d; fine-grained sandstone had a hydraulic conductivity of 1×10^{-4} ft / d; and medium- to coarse-grained sandstone (with some cement removed) had a hydraulic conductivity of 0.2 ft / d.

The rocks of the Stockton Formation form a complex, heterogeneous, multiaquifer system. This aquifer system comprises a series of gently dipping lithologic units with different hydraulic properties. The ground-water system can be visualized as a series of beds with relatively high transmissivity separated by beds with relatively low transmissivity. The beds, from a few inches to a few feet thick, act as a series of alternating aquifers and confining or semiconfining units that form a leaky, multiaquifer system. Each bed generally has different hydraulic properties.

Ground water is unconfined in the shallower part of the aquifer and confined or semiconfined in the deeper part of the aquifer. Ground water is confined under pressure greater than atmospheric by overlying, less permeable lithologic units. Differences in the ratio of vertical to horizontal hydraulic conductivity, as well as differences in vertical hydraulic conductivity within and among lithologic units, create confining conditions.

Nearly all deep, open-hole wells in the Stockton Formation are open to several water-bearing zones and are multiaquifer wells. Each water-bearing zone usually has a different hydraulic head. The hydraulic head in a deep, open-hole well is the composite of the heads in the several water-bearing zones penetrated. This causes water levels in adjacent wells of different depths to be different. Where differences in hydraulic head exist between water-bearing zones, water in the well bore flows under nonpumping conditions in the direction of decreasing head.

Near horizontal fractures observed in bore-hole television surveys are aligned with bedding. Some near horizontal fractures are within beds, and other horizontal fractures are at the contact between beds, such as the fracture at 59.9 ft bls in well HN-9-I (fig. 7), which is at the contact between a siltstone (upper unit) and sandstone (lower unit). Steeply dipping or nearly vertical fractures within sandstone units commonly yield water to a well. A large, steeply dipping fracture intersected by bore-hole BK-2799 at 55.3 ft bls is shown in figure 8. The borehole intersects this fracture between 51 and 56 ft bls. The borehole geophysical logs indicate that this fracture is a water-receiving fracture.

IDENTIFICATION OF WATER-BEARING ZONES

Nine domestic wells in Casey Village were reconstructed as 2-in. diameter monitor wells by the USGS. The wells were drilled in the 1950's, and no data were available for them. After the top of casing of each well was excavated and the casing was extended to land surface, borehole geophysical logs were run to determine well depth, casing length, and depth of water-bearing zones. The depth to set one or two screens in each well was selected on the basis of the caliper, fluid-resistivity, and fluid-temperature geophysical logs and heatpulse-flow-meter measurements. The geophysical logs in this section are presented at the same scale to facilitate comparison and correlation.

Table 2. *Heatpulse-flowmeter measurements for wells in Casey Village, Bucks County, Pennsylvania*

[gal/min, gallons per minute; --, no data]

Depth (feet below land surface)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Upward flow rate under pumping conditions (gal/min)
BK-1021			
50	0	No flow	0.29
62	0	No flow	.07
72	0	No flow	.08
82	0	No flow	.08
92	0	No flow	0
BK-2767			
44	.01	Down	.29
60	.01	Down	.15
70	.01	Down	.15
88	.02	Down	.11
BK-2768			
44	.02	Down	.01
60	.02	Down	.01
70	.02	Down	.01
84	0	No flow	0
96	0	No flow	0
BK-2769			
40	--	--	.32
50	.02	Down	.14
70	.02	Down	.02
BK-2788			
32	0	No flow	.04
40	--	--	.03
54	0	No flow	0
BK-2789			
28	0	No flow	--
46	0	No flow	--
48	--	--	.27
64	0	No flow	0
BK-2790			
44	.01	Up	--
46	.01	Up	.21
66	.03	Up	.24
BK-2791			
26	.05	Down	--
30	.08	Down	--
38	.08	Down	--
50	.09	Down	--
BK-2799			
44	.09	Up	--
48	--	--	1.18
60	.06	Up	.89
68	--	--	.81
92	.13	Up	.12
100	.11	Up	.09

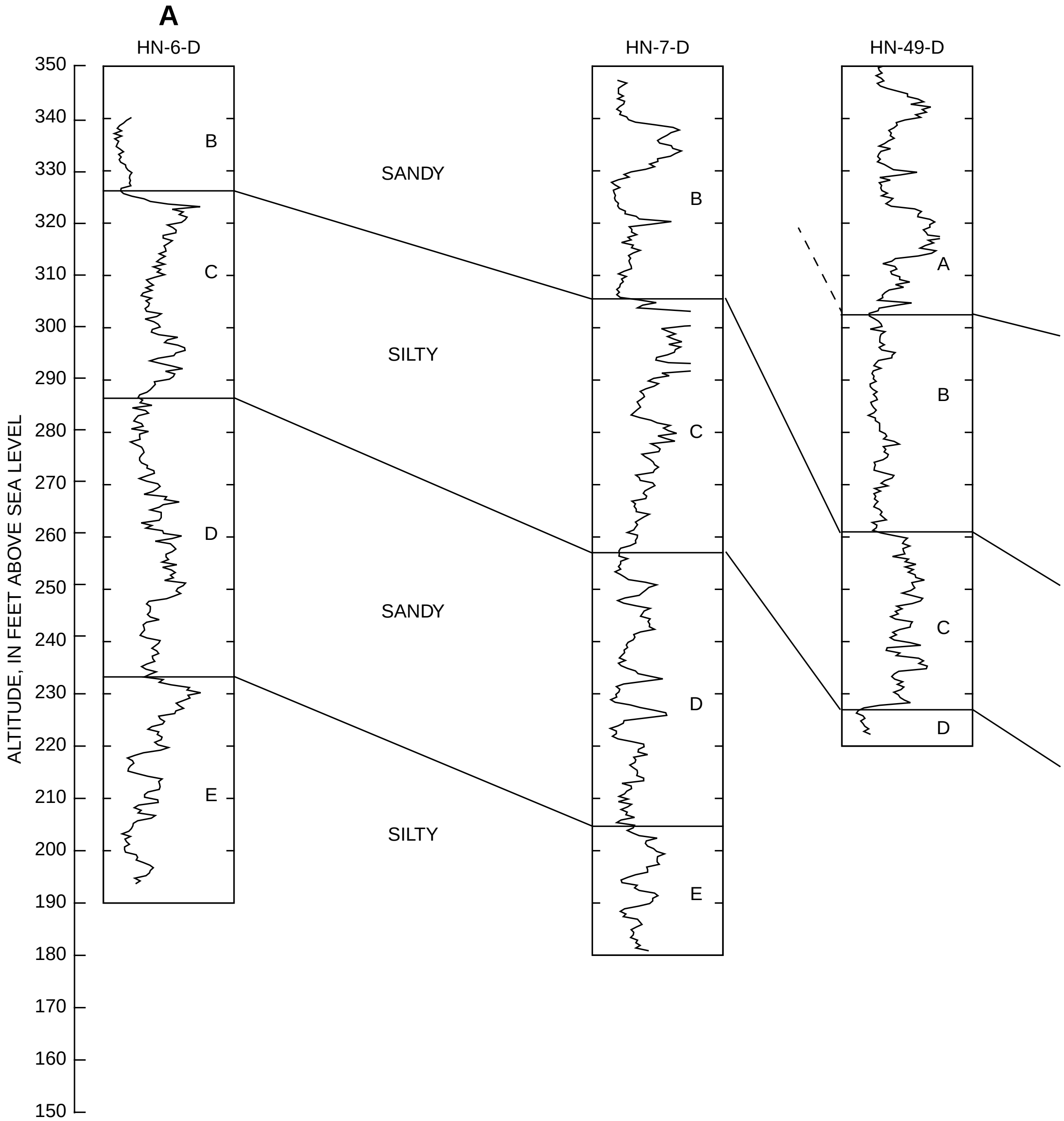
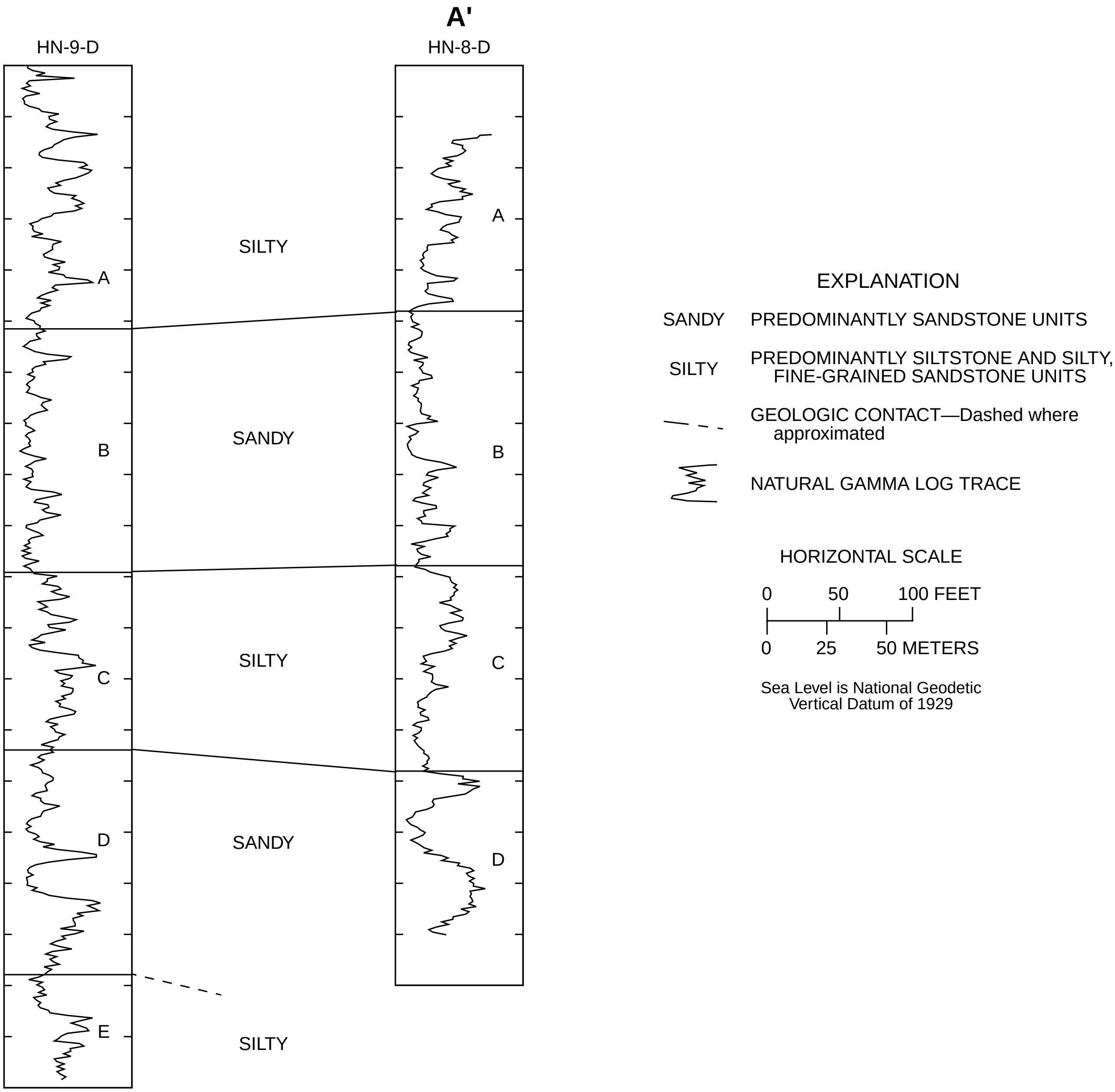


Figure 4. Generalized geologic cross-section A-A', along strike, Casey Village area, Bucks County, Pennsylvania.


A'
HN-9-D
HN-8-D
A
B
C
D
E
SILTY
SANDY
SILTY
SANDY
SILTY
EXPLANATION
SANDY PREDOMINANTLY SANDSTONE UNITS
SILTY PREDOMINANTLY SILTSTONE AND SILTY, FINE-GRAINED SANDSTONE UNITS
GEOLOGIC CONTACT—Dashed where approximated
NATURAL GAMMA LOG TRACE
HORIZONTAL SCALE
0 50 100 FEET
0 25 50 METERS
Sea Level is National Geodetic Vertical Datum of 1929

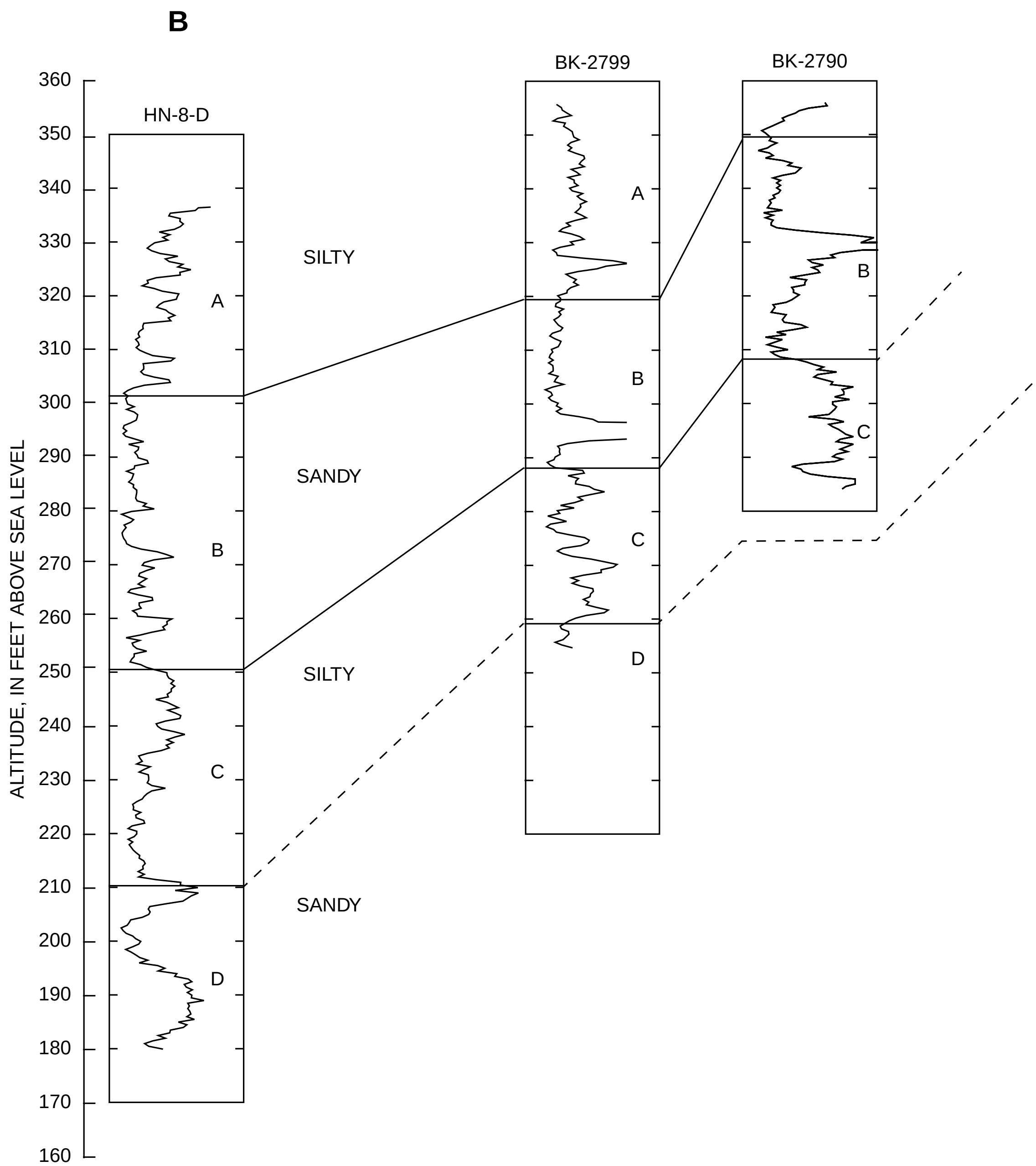
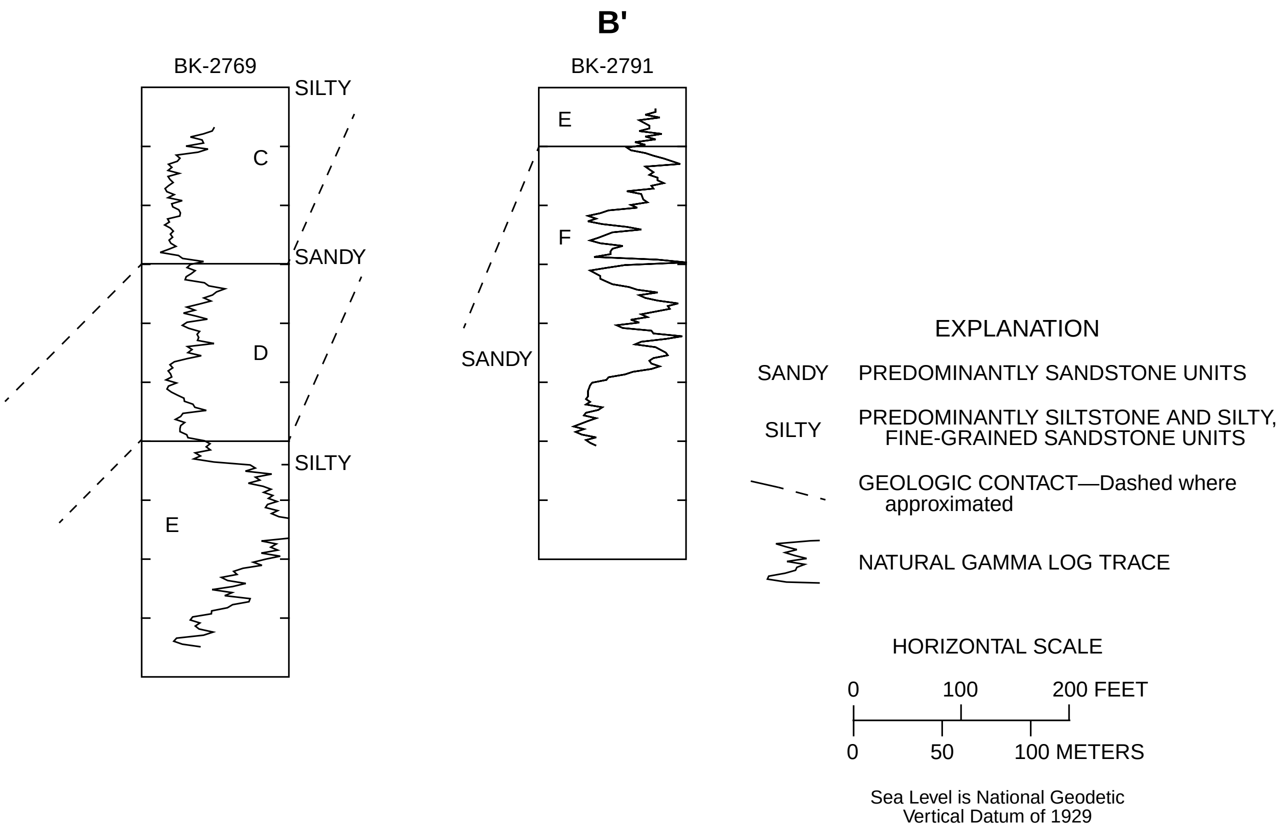


Figure 5. Generalized geologic cross-section B-B', perpendicular to strike, Casey Village area, Bucks County, Pennsylvania.


B'
BK-2769
BK-2791
SILTY
C
SANDY
D
SILTY
E
E
F
SANDY
EXPLANATION
SANDY PREDOMINANTLY SANDSTONE UNITS
SILTY PREDOMINANTLY SILTSTONE AND SILTY, FINE-GRAINED SANDSTONE UNITS
GEOLOGIC CONTACT—Dashed where approximated
NATURAL GAMMA LOG TRACE
HORIZONTAL SCALE
0 100 200 FEET
0 50 100 METERS
Sea Level is National Geodetic Vertical Datum of 1929

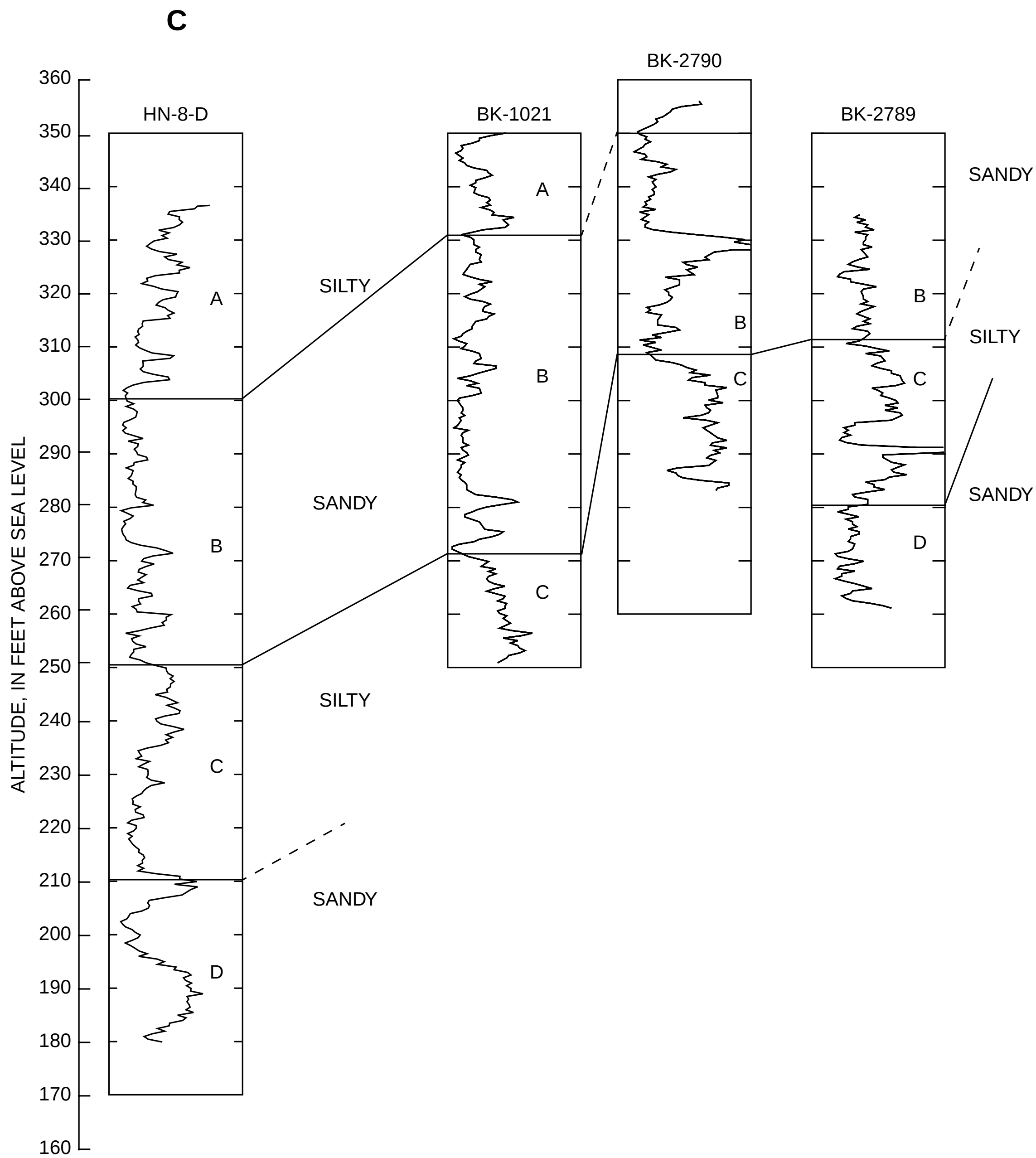
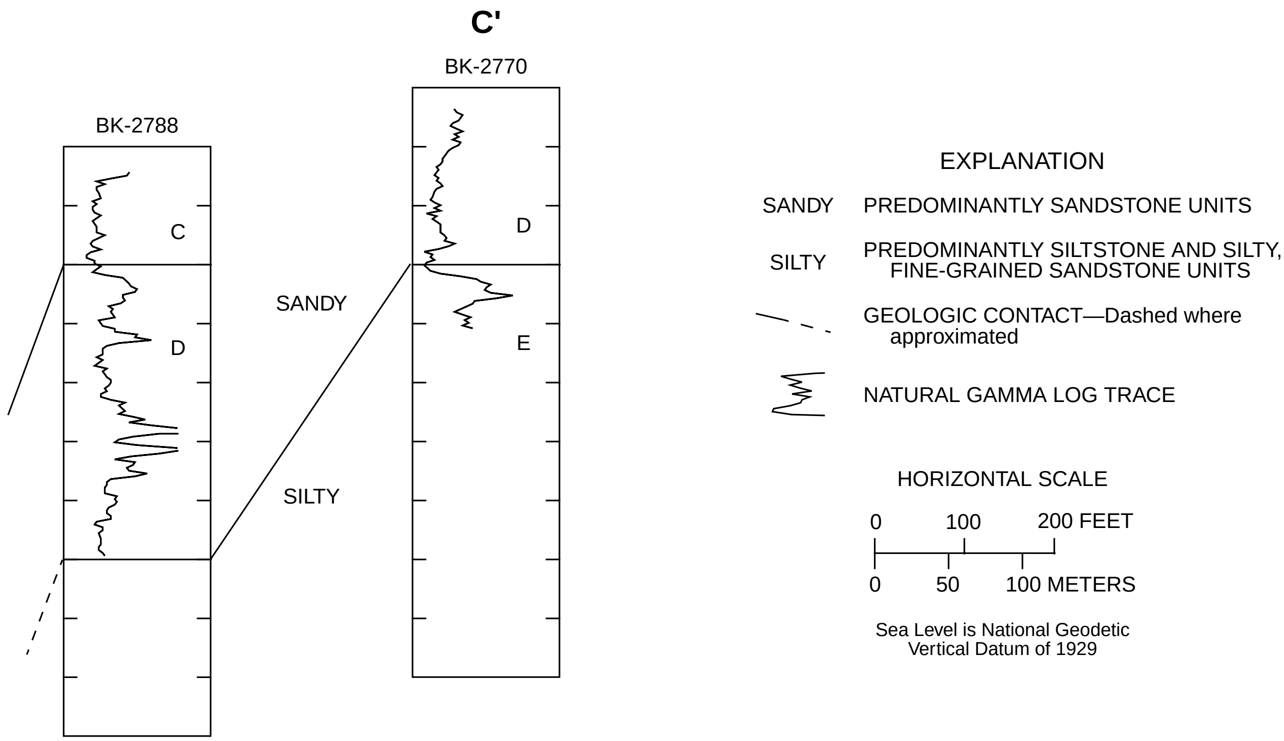


Figure 6. Generalized geologic cross-section C-C', perpendicular to strike, Casey Village area, Bucks County, Pennsylvania.


C'
BK-2788
BK-2770
C
D
D
E
SANDY
SILTY
EXPLANATION
SANDY
PREDOMINANTLY SANDSTONE UNITS
SILTY
PREDOMINANTLY SILTSTONE AND SILTY, FINE-GRAINED SANDSTONE UNITS
GEOLOGIC CONTACT—Dashed where approximated
NATURAL GAMMA LOG TRACE
HORIZONTAL SCALE
0
100
200 FEET
0
50
100 METERS
Sea Level is National Geodetic Vertical Datum of 1929

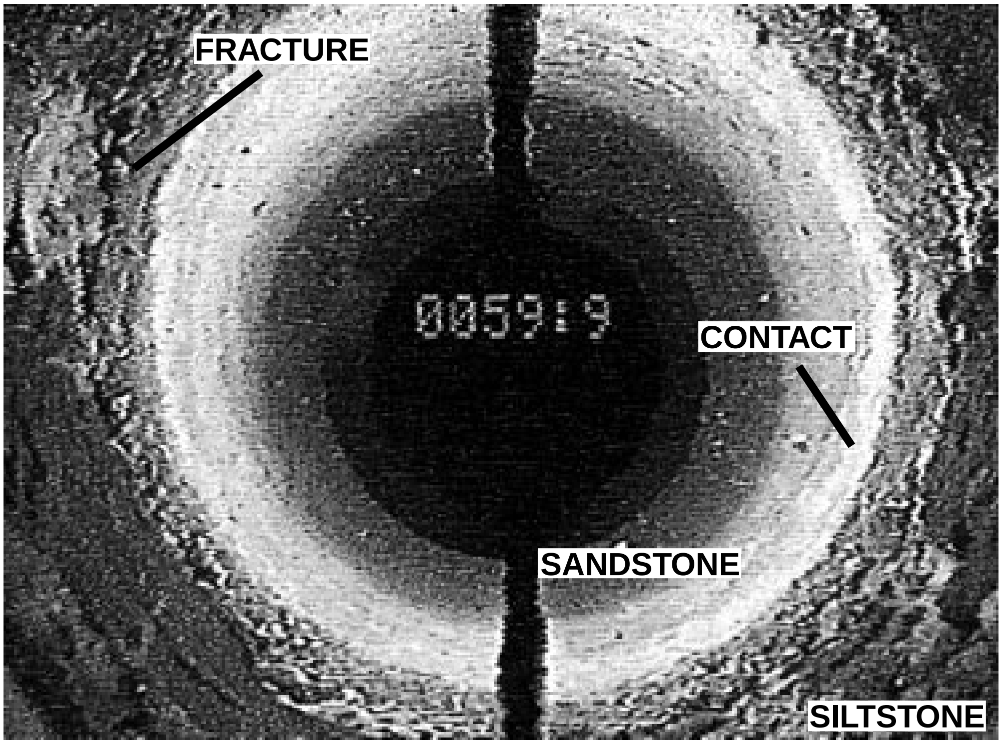


Figure 7. Image from borehole television survey showing horizontal fracture at 59.9 feet below land surface in well HN-9-I, Naval Air Warfare Center, Warminster, Pennsylvania.

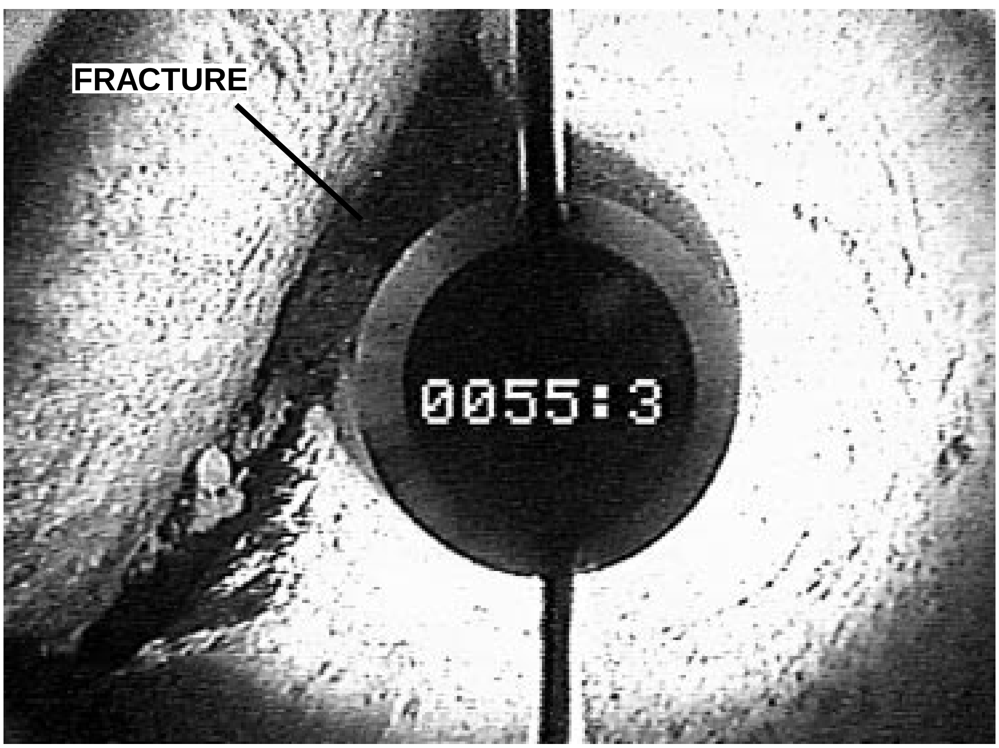
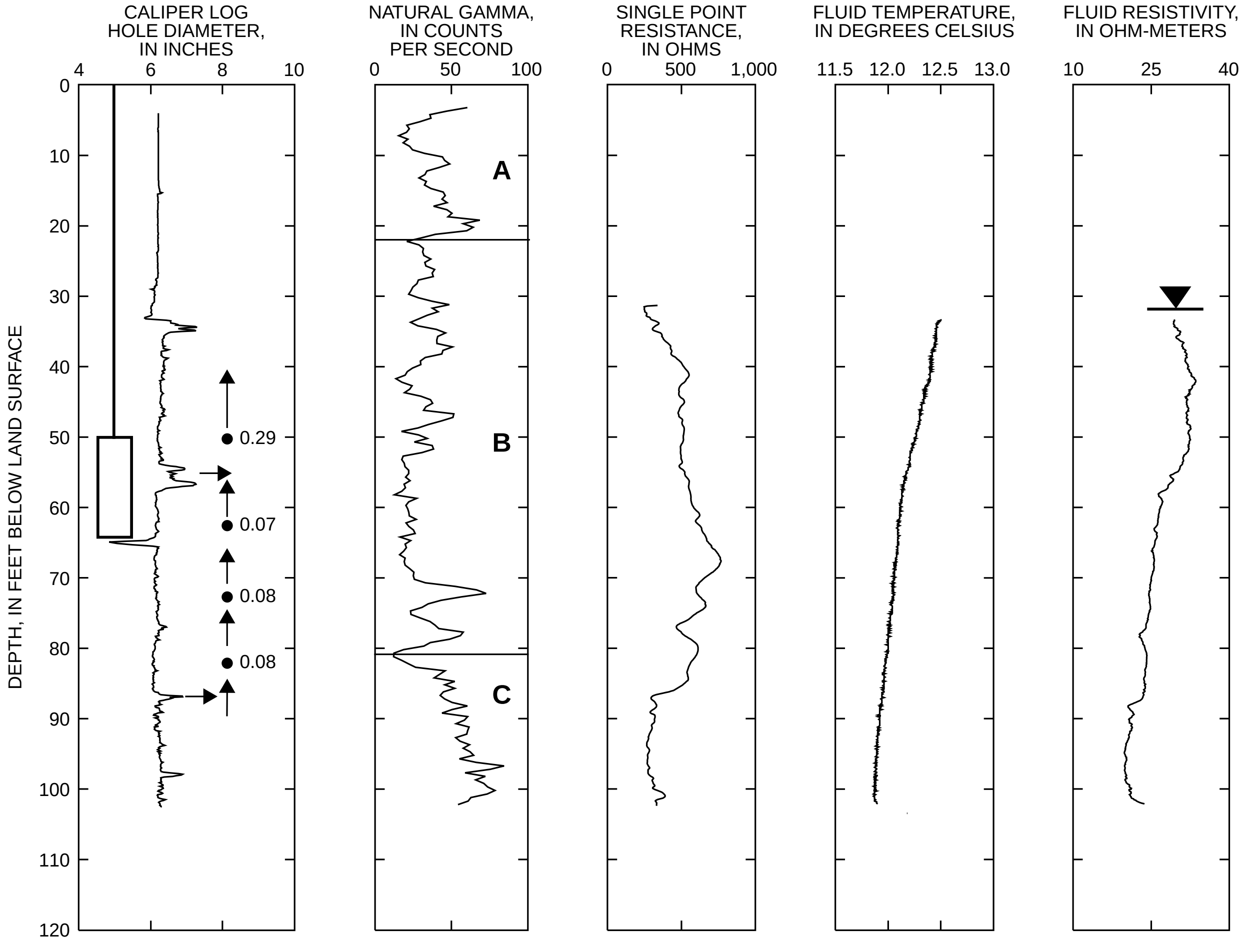


Figure 8. Image from borehole television survey showing vertical fracture at 55.3 feet below land surface in well BK-2799, Casey Village, Bucks County, Pennsylvania.



EXPLANATION

A GEOLOGIC UNIT—Letter designates geologic unit

▼ WATER LEVEL—Measured in well at the time of geophysical logging

● 0.29 BOREHOLE-FLOW MEASUREMENT UNDER PUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

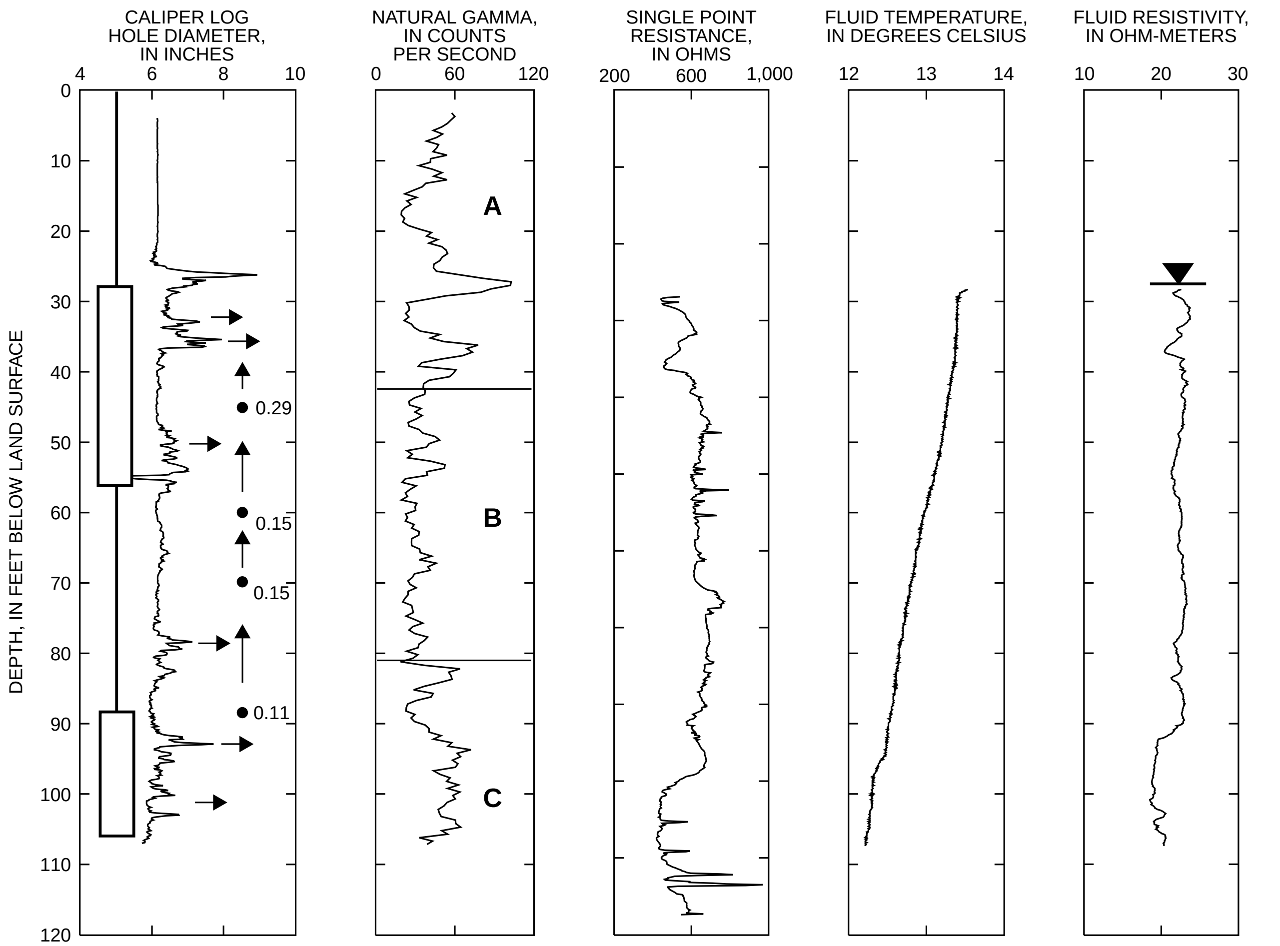
↑ DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

→ FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 9. Borehole geophysical logs from well BK-1021, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-1021 (fig. 9) shows the total well depth is 104 ft and it is cased with 6-in. diameter casing to 33 ft bls. The caliper log shows major fractures at 33-35, 54-58, 87, and 97 ft bls. The caliper log shows a constriction at 65 ft bls. Under nonpumping conditions, no borehole flow was measurable with the heatpulse flowmeter at 50, 62, 72, 82, and 92 ft bls. A submersible pump was placed at 44 ft bls, and the well was pumped at a rate less than 1 gal/min. Heatpulse-flowmeter measurements were again made at the same depths. Under pumping conditions, the highest rate of borehole flow (0.29 gal/min) was measured at 50 ft bls. Upward flow was 0.07-0.08 gal/min at 62, 72, and 82 ft, and no flow was measurable at 92 ft bls (table 2). The suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate the major water-producing zone is at 54-56 ft bls, and a minor water-producing zone is at about 87 ft bls. When the well was reconstructed as a monitor well, a screen was set at 52-62 ft bls to include the major water-bearing fracture zone at 54-56 ft bls (Appendix 1, fig. 1).



EXPLANATION

A — GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

● 0.29 — BOREHOLE-FLOW MEASUREMENT UNDER PUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 10. Borehole geophysical logs from well BK-2767, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2767 (fig. 10) shows the total well depth is 107 ft and it is cased with 6-in. diameter casing to 25 ft bls. The caliper log shows major fractures at 25-29, 32-37, 77-84, and 91-94 ft bls plus numerous smaller fractures. The caliper log shows a constriction at 55 ft bls. Under nonpumping conditions, the heatpulse-flowmeter measurements show 0.01 gal/min downward flow at 44, 60, and 70 ft bls and 0.2 gal/min downward flow at 88 ft bls (table 2). A submersible pump was placed at 40 ft bls, and the well was pumped at a rate less than 1 gal/min. Heatpulse-flowmeter measurements were again made at the same depths. The suite of borehole geophysical logs and the heatpulse-flowmeter measurements indicate the greatest quantity of water enters the well through the fracture at 30-38 ft bls, and lesser quantities are produced from the fractures at 48-54, 77-84, and 90-103 ft bls. When the well was reconstructed as a monitor well, screens were set at 30-55 (well BK-2767) and 90-105 (well BK-2795) ft bls to include the major water-bearing fractures at 32-37 ft bls and the minor water-bearing fractures at 90-103 ft bls, respectively (Appendix 1, fig. 7).

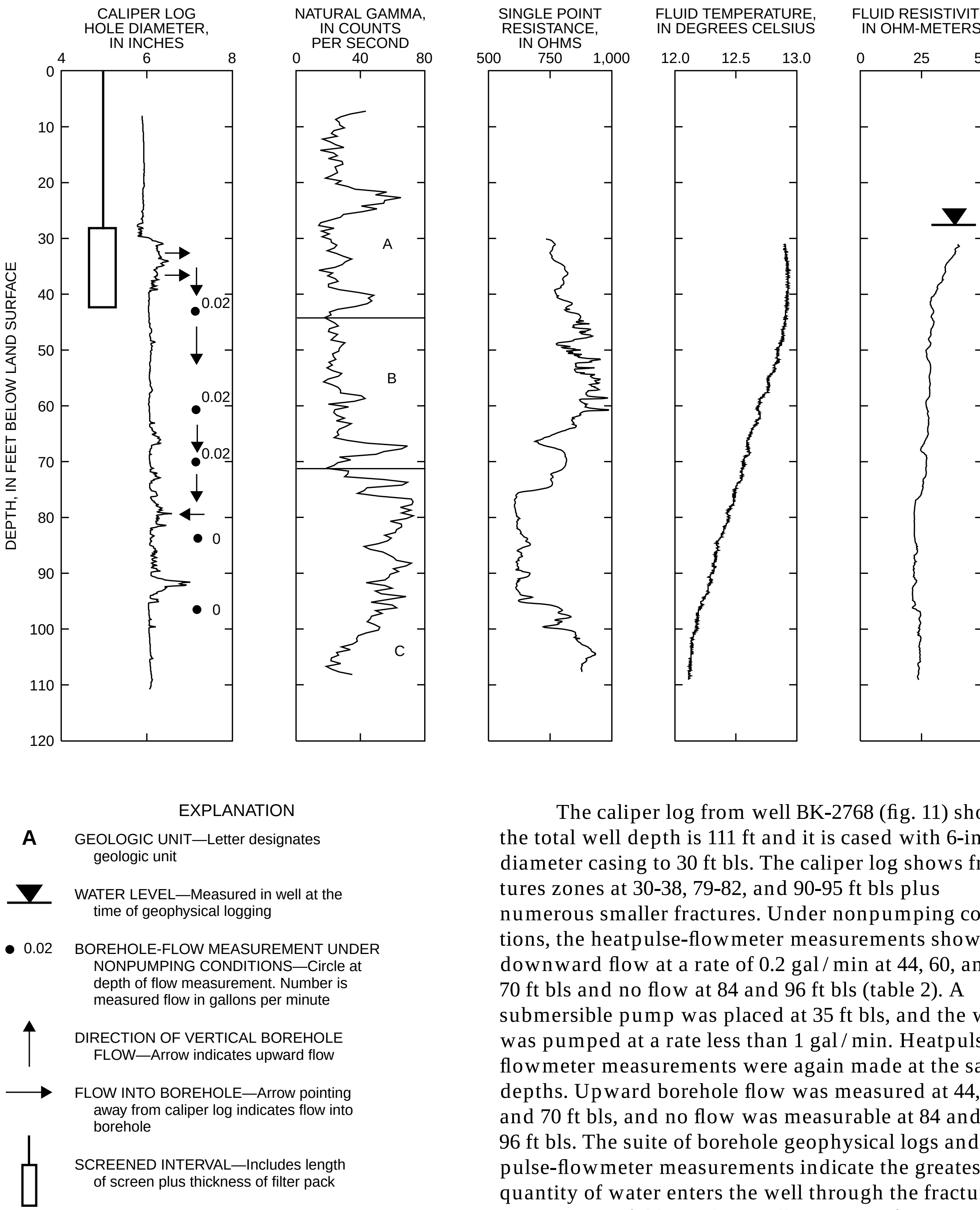
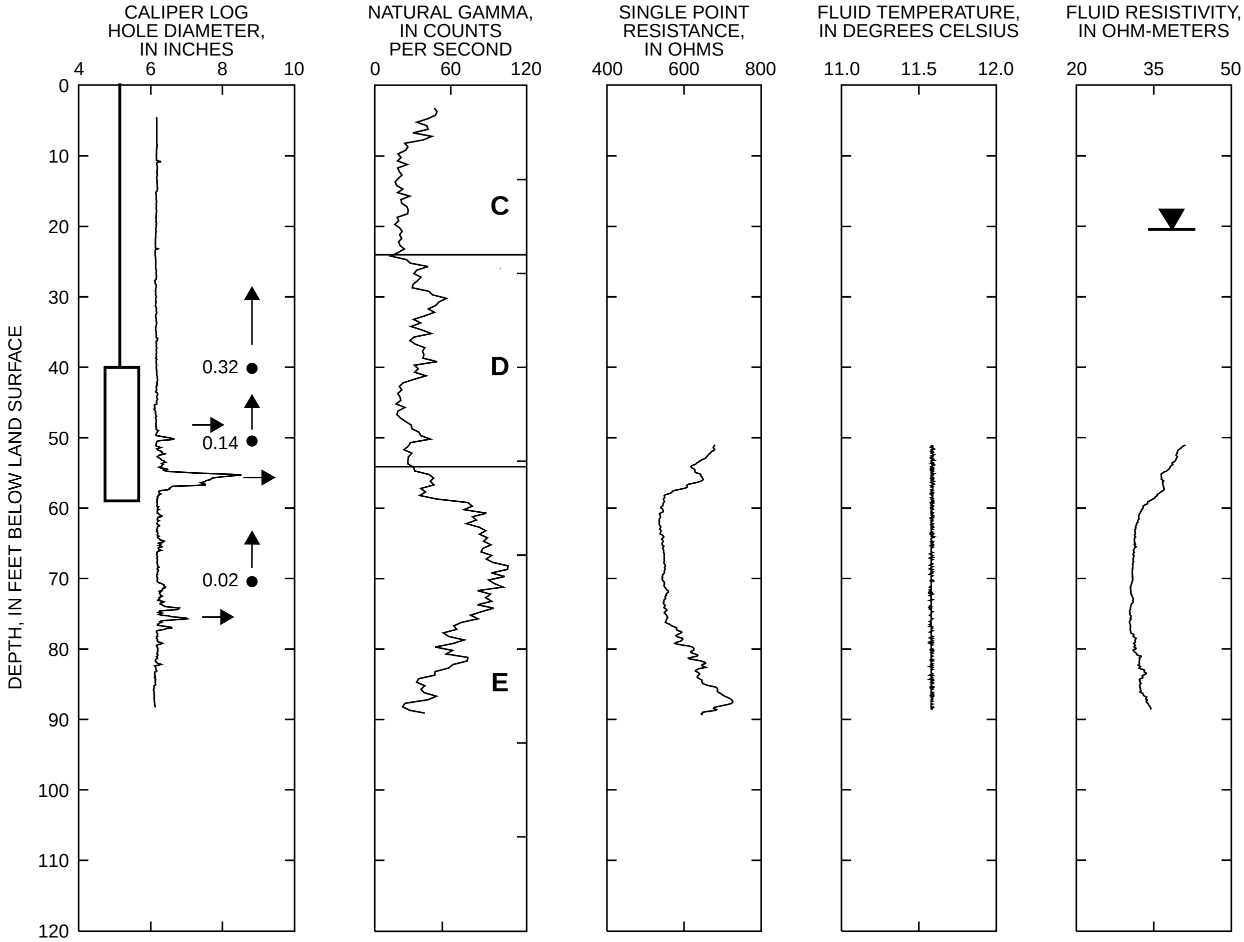


Figure 11. Borehole geophysical logs from well BK-2768, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2768 (fig. 11) shows the total well depth is 111 ft and it is cased with 6-in. diameter casing to 30 ft bls. The caliper log shows fractures zones at 30-38, 79-82, and 90-95 ft bls plus numerous smaller fractures. Under nonpumping conditions, the heatpulse-flowmeter measurements show downward flow at a rate of 0.2 gal / min at 44, 60, and 70 ft bls and no flow at 84 and 96 ft bls (table 2). A submersible pump was placed at 35 ft bls, and the well was pumped at a rate less than 1 gal / min. Heatpulse-flowmeter measurements were again made at the same depths. Upward borehole flow was measured at 44, 60, and 70 ft bls, and no flow was measurable at 84 and 96 ft bls. The suite of borehole geophysical logs and heat-pulse-flowmeter measurements indicate the greatest quantity of water enters the well through the fracture zone at 30-39 ft bls, and a small quantity of water is produced from the fractures at 76-82 ft bls. When the well was reconstructed as a monitor well, a screen was set at 30-40 ft bls to include the major water-bearing fractures at 30-39 ft bls (Appendix 1, fig. 2).



EXPLANATION

D — GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

● 0.32 — BOREHOLE-FLOW MEASUREMENT UNDER PUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 12. Borehole geophysical logs from well BK-2769, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2769 (fig. 12) shows the total well depth is 89 ft and it is cased with 6-in. diameter casing to 42 ft bls. The caliper log shows major fractures at 54-58 ft bls and minor fractures at 50 and 74-77 ft bls. The fluid-temperature log shows almost no gradient from 44 to 88 ft bls, which indicates a zone of vertical borehole flow. Under nonpumping conditions, the heatpulse-flowmeter measurements show downward flow at a rate of 0.02 gal/min at 50 and 70 ft bls (table 2). A submersible pump was placed at 35 ft bls, and the well was pumped at a rate less than 1 gal/min. Heatpulse-flowmeter measurements were made at 40, 50, and 70 ft bls. Under pumping conditions, upward borehole flow was measured at 40 and 50 ft bls, and a small quantity of upward flow was measured at 70 ft bls. The suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate most water is produced from the fracture zone at 50-58 ft bls. A minor quantity of water is produced from the fracture zone at 76-82 ft bls. When the well was reconstructed as a monitor well, a screen was set at 42-57 ft bls to include the major water-bearing fracture zone from 50-58 ft bls (Appendix 1, fig. 3).

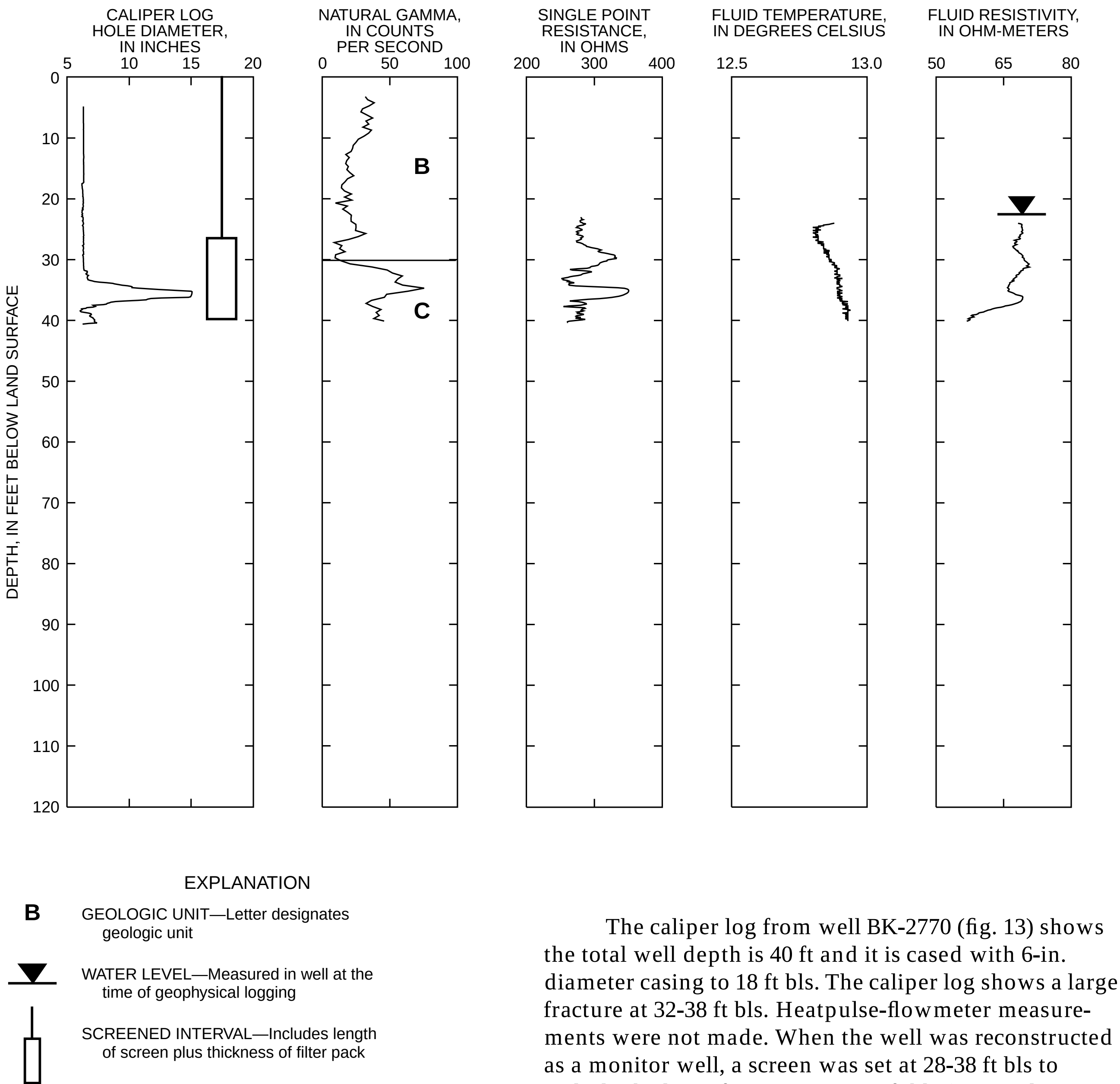
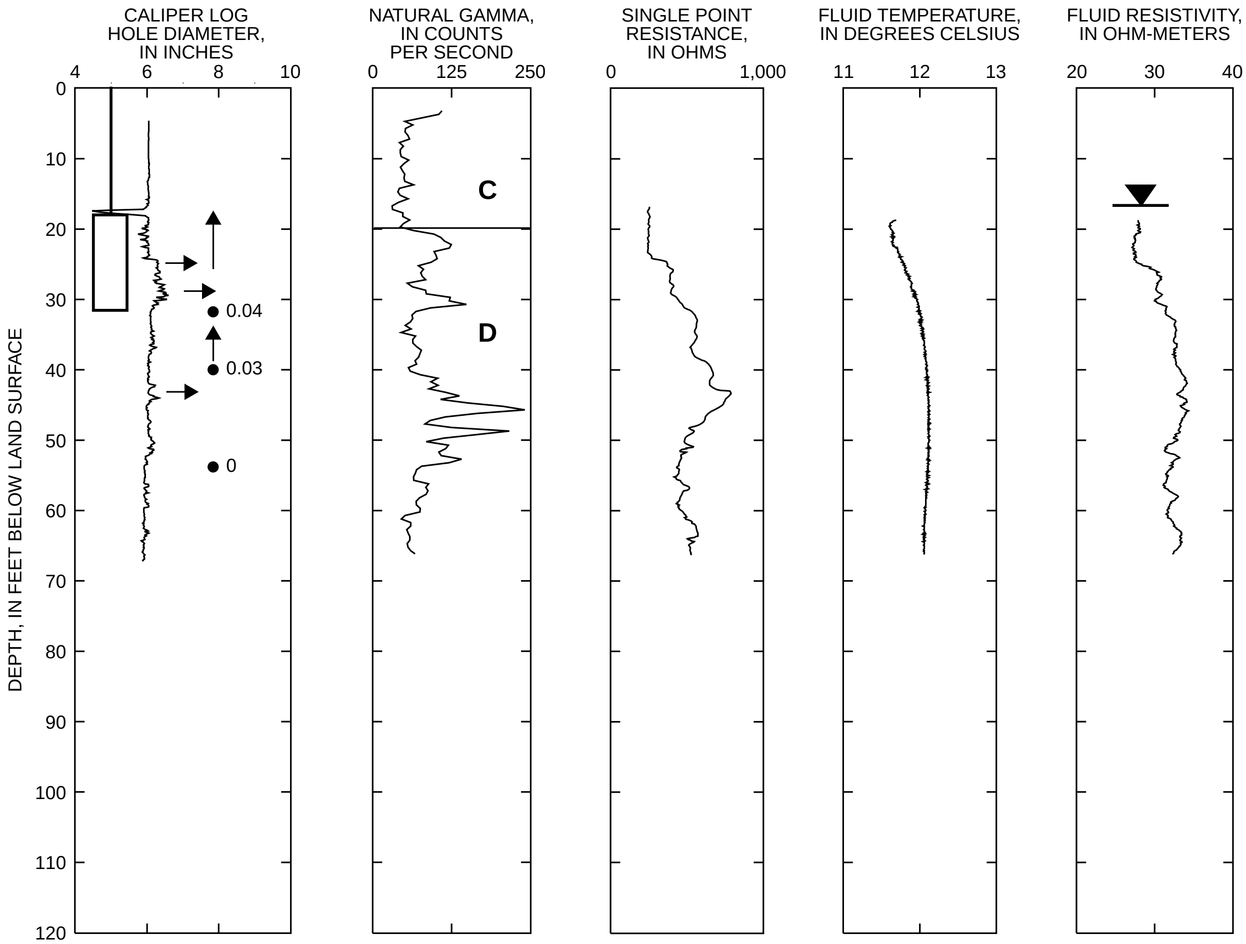


Figure 13. Borehole geophysical logs from well BK-2770, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2770 (fig. 13) shows the total well depth is 40 ft and it is cased with 6-in. diameter casing to 18 ft bls. The caliper log shows a large fracture at 32-38 ft bls. Heatpulse-flowmeter measurements were not made. When the well was reconstructed as a monitor well, a screen was set at 28-38 ft bls to include the large fracture at 32-38 ft bls (Appendix 1, fig. 4).



EXPLANATION

C GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

0.04 BOREHOLE-FLOW MEASUREMENT UNDER PUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

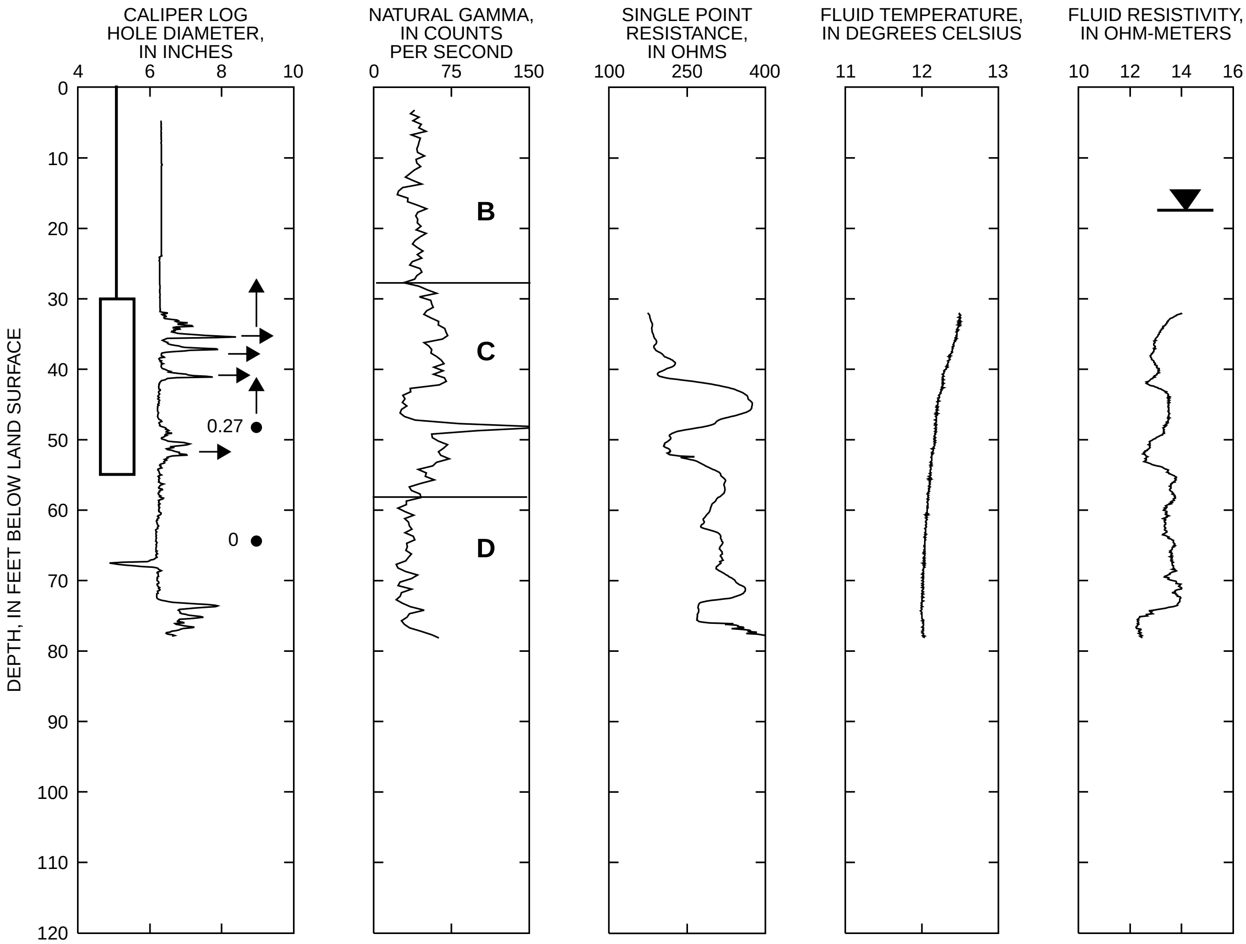
DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 14. Borehole geophysical logs from well BK-2788, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2788 (fig. 14) shows the total well depth is 68 ft and it is cased with 6-in. diameter casing to 17 ft bls. The caliper log shows a constriction at 17 ft bls at the bottom of casing. The caliper log shows a major fracture zone from 24 to 31 ft bls. Under nonpumping conditions, the heatpulse-flowmeter measurements show no measurable borehole flow at 32 and 54 ft bls. A submersible pump was placed at 25 ft bls, and the well was pumped at a rate less than 1 gal/min. Heatpulse-flowmeter measurements were made at the same depths. Under pumping conditions, no borehole flow was measurable at 54 ft bls, and a small quantity of upward flow was measured at 32 and 40 ft bls (table 2). The suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate the major water-producing zone is at 24-31 ft bls. When the well was reconstructed as a monitor well, a screen was set at 20-30 ft bls to include the water-bearing fracture zone at 24-31 ft bls (Appendix 1, fig. 5).



EXPLANATION

B GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

● 0.27 BOREHOLE-FLOW MEASUREMENT UNDER PUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

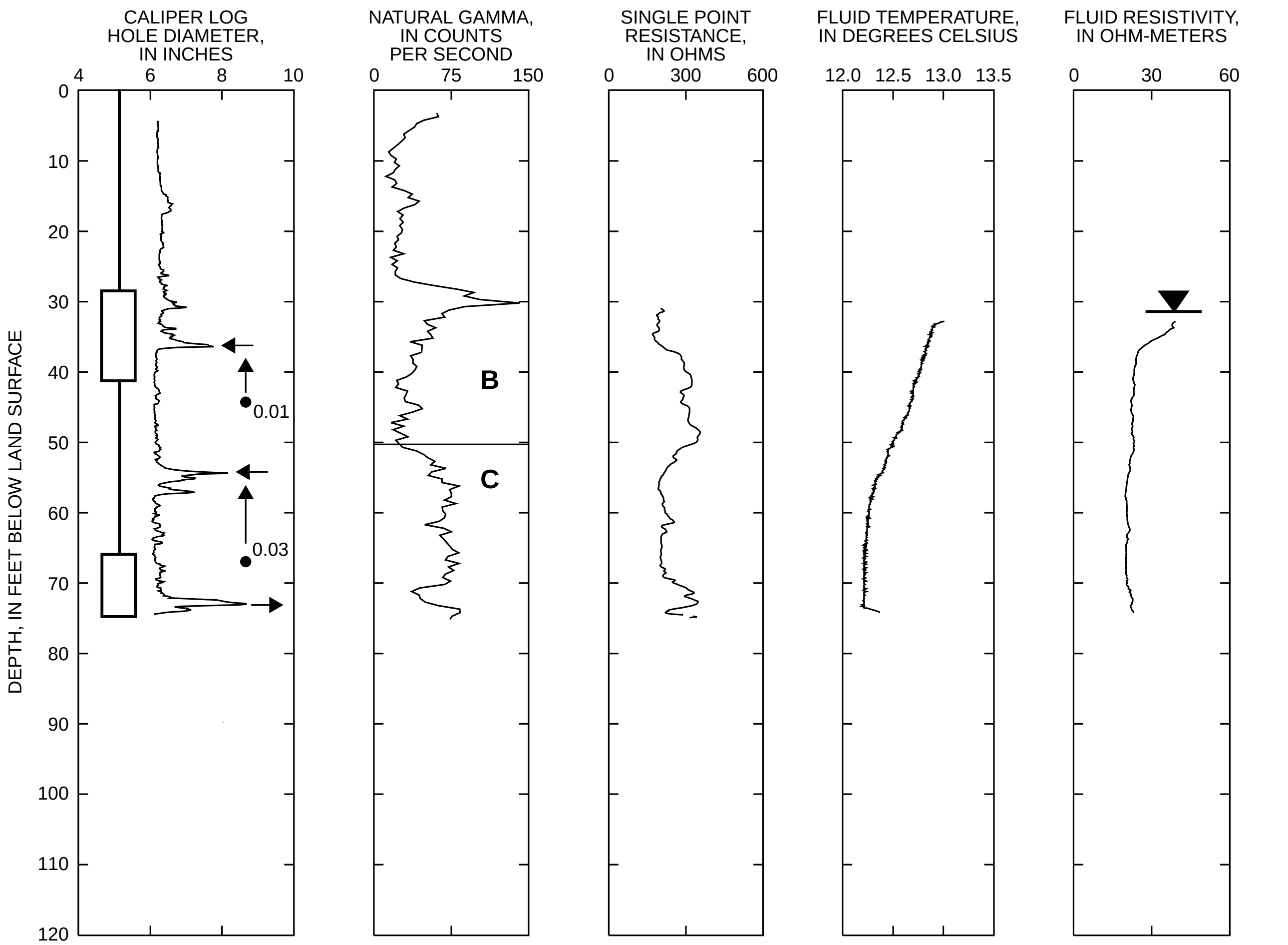
DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 15. Borehole geophysical logs from well BK-2789, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2789 (fig. 15) shows the total well depth is 78 ft and it is cased with 6-in. diameter casing to 32 ft bls. The caliper log shows major fractures at 32-38, 41, 48-53, and 73-76 ft bls. The caliper log shows a constriction at 68 ft bls. Under nonpumping conditions, the heatpulse-flowmeter measurements show no measurable borehole flow at 28, 46, and 64 ft bls. A submersible pump was placed at 25 ft bls, and the well was pumped at a rate less than 1 gal / min. Under pumping conditions, no borehole flow was measurable at 64 ft, and the flow rate at 48 ft bls was 0.27 gal / min (table 2). The suite of geophysical logs and heatpulse-flowmeter measurements indicate the major water-producing zone is at 48-53 ft bls. When the well was reconstructed as a monitor well, a screen was set at 32-52 ft bls to include the major water-bearing and fracture zones at 32-42 and 48-53 ft bls (Appendix 1, fig. 6).



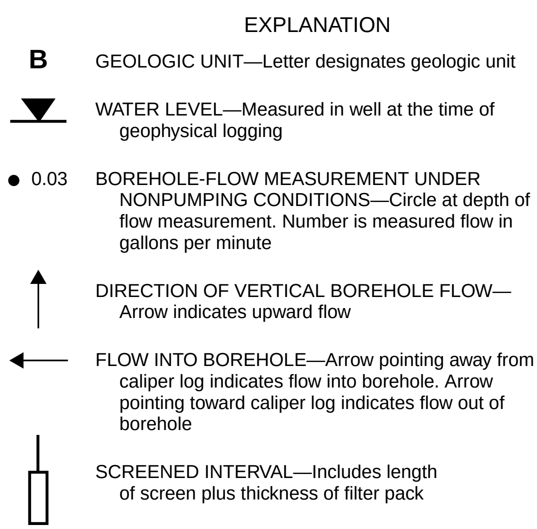
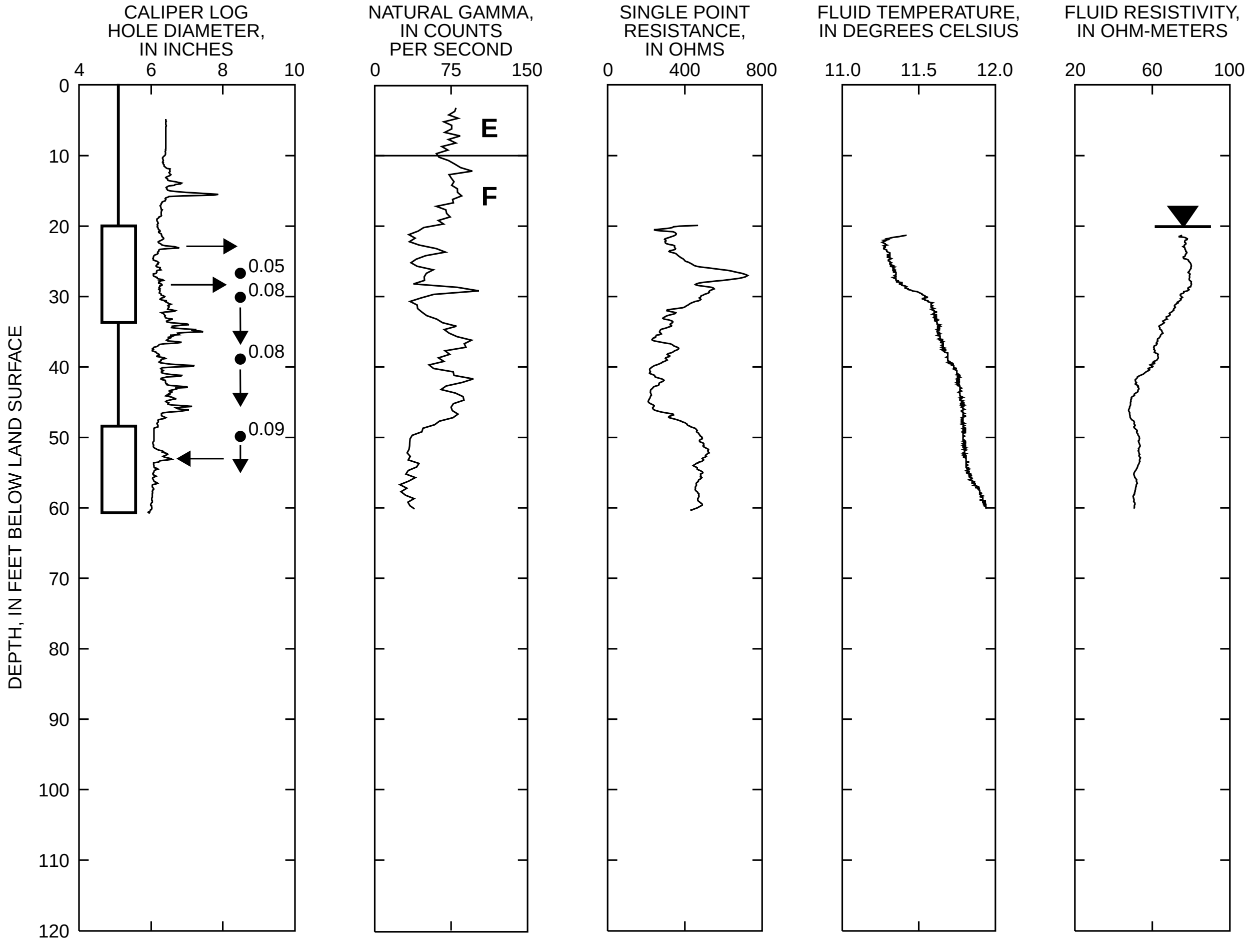


Figure 16. Borehole geophysical logs from well BK-2790, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2790 (fig. 16) shows the total well depth is 76 ft and it is cased with 6-in. diameter casing to 14 ft bls. The caliper log shows major fractures at 30-31, 34-37, 53-58, and 72-74 ft bls and several minor fractures. The fluid-temperature log shows almost no gradient from 54 to 73 ft bls, which indicates a zone of vertical borehole flow. Under nonpumping conditions, the heatpulse-flowmeter measurements show upward flow at 44, 46, and 66 ft bls (table 2). A submersible pump was placed at 40 ft bls, and the well was pumped at a rate less than 1 gal / min. Heatpulse-flowmeter measurements were made again at the same depths. Upward borehole flow at 46 and 66 ft bls was 0.21 and 0.24 gal / min, respectively. The suite of geophysical logs and heatpulse-flowmeter measurements indicate water is produced from the fractures at 34-37 and 72-74 ft bls. When the well was reconstructed as a monitor well, screens were set at 30-40 (well BK-2790) and 69-74 (well BK-2796) ft bls to include the water-bearing fracture zones at 34-37 and 72-74 ft bls, respectively (Appendix 1, fig. 8).



EXPLANATION

E GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

● 0.08 BOREHOLE-FLOW MEASUREMENT UNDER NONPUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

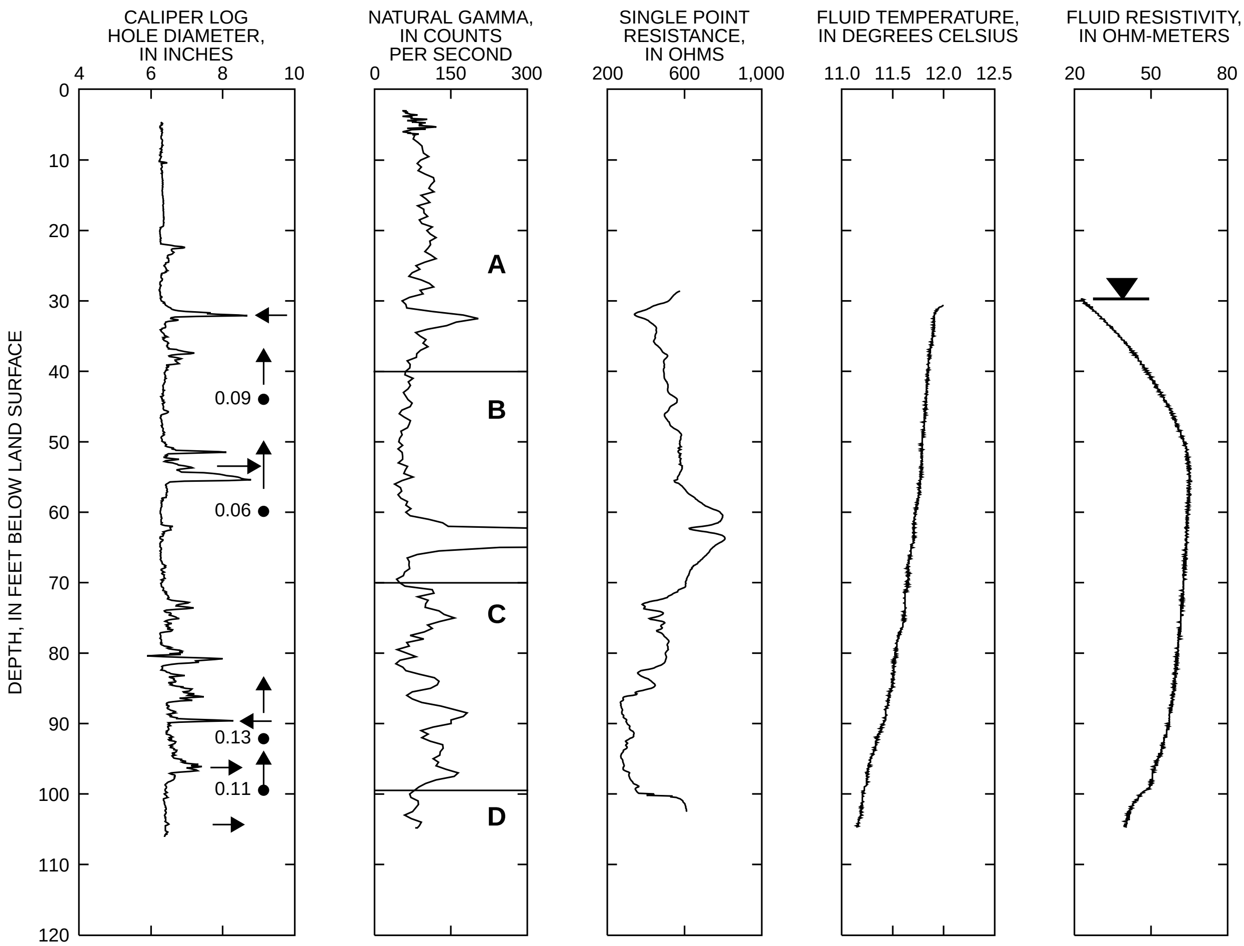
DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates downward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole. Arrow pointing toward caliper log indicates flow out of borehole

SCREENED INTERVAL—Includes length of screen plus thickness of filter pack

Figure 17. Borehole geophysical logs from well BK-2791, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2791 (fig. 17) shows the total well depth is 62 ft and it is cased with 6-in. diameter casing to 10 ft bls. The caliper log shows major fractures at 15.5, 23, 35, 40, 46, and 51.5-54 ft bls plus several minor fractures. The fluid-resistivity log shows changes in resistivity at about 29, 35, 46, and 56 ft bls. The fluid-temperature log shows changes in temperature at about 28-30 ft and about 54 ft bls. The change in temperature at 54 ft bls coincides with a major fracture shown on the caliper log. Under nonpumping conditions, the heatpulse-flowmeter measurements show downward borehole flow at 26, 30, 38, and 50 ft bls (table 2). The suite of geophysical logs and heatpulse-flowmeter measurements indicate that, under nonpumping conditions, water enters the borehole through fractures at 23 and 28 ft bls and moves downward at the rate of 0.08 gal/min. The water exits the borehole through a water-receiving fracture at 51.5-54 ft bls. When the well was reconstructed as a monitor well, screens were set at 22-32 (well BK-2791) and 50-60 (well BK-2797) ft bls to include the water-producing fractures at 23 and 28 ft bls and the water-receiving fracture at 51.5 ft bls, respectively (Appendix 1, fig. 9).



EXPLANATION

A GEOLOGIC UNIT—Letter designates geologic unit

WATER LEVEL—Measured in well at the time of geophysical logging

● 0.09 BOREHOLE-FLOW MEASUREMENT UNDER NONPUMPING CONDITIONS—Circle at depth of flow measurement. Number is measured flow in gallons per minute

DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates upward flow

FLOW INTO BOREHOLE—Arrow pointing away from caliper log indicates flow into borehole. Arrow pointing toward caliper log indicates flow out of borehole.

Figure 18. Borehole geophysical logs from well BK-2799, Casey Village, Bucks County, Pennsylvania.

The caliper log from well BK-2799 (fig. 18) shows the total well depth is 106 ft and it is cased with 6-in. diameter casing to 22 ft bls. The caliper log shows major fractures at 32, 51, 54-56, 81, and 89 ft bls. The fluid-resistivity log shows almost no gradient from 54 to 90 ft bls, which indicates a zone of vertical borehole flow. Under nonpumping conditions, the heatpulse-flowmeter measurements show upward borehole flow at 44, 60, 92, and 100 ft bls (table 2). A submersible pump was placed below the water surface, and the well was pumped at a rate of just over 1 gal/min. Heatpulse-flowmeter measurements were made at 48, 60, 68, 92, and 100 ft bls. The suite of geophysical logs and heatpulse-flowmeter measurements indicate that, under nonpumping conditions, approximately 0.11 gal/min of water flows upward from the bottom of the well. An additional 0.02 gal/min of water enters the well through a fracture at 90 ft bls and flows upward. Water exits the well through fractures at 54-56 and 31 ft bls. Under pumping conditions, the major water-producing fracture is at 90 ft bls.

Horizontal Ground-Water-Flow Gradients

Potentiometric-surface maps were constructed for the Casey Village area using water levels measured on August 3, 1995, after reconstruction of domestic wells as monitor wells. Potentiometric-surface maps also were constructed using water levels measured on February 15, 1996, and October 7, 1996, during collection of water samples for analysis for VOC's. Water-level measurements are given in table 1. The maps show ground-water-flow gradients at the time water samples were collected.

The water level for 1995-96 in USGS observation well BK-1020 (U.S. Navy well SW-11) on the NAWC near Casey Village (fig. 1) is shown in figure 19. The August 3, 1995, potentiometric-surface maps were made during a drought (fig. 19). Water levels recovered by November 1995, and 1996 was a wetter than average year. Water levels measured on February 15 and October 7, 1996, were during a time of above average water levels.

For each set of water-level measurements, two potentiometric surfaces were mapped--a shallow potentiometric surface measured in wells screened between 18 and 64 ft bls and a deeper potentiometric surface measured in wells screened between 48 and 106 ft bls. All but three of the monitor wells in Casey Village are screened at discrete depths; wells BK-2798, BK-2799, and BK-2800 are open-hole wells. These open-hole wells may influence water levels in nearby screened wells by acting as vertical conduits for ground-water flow, but sufficient data are not available to define the extent of their influence. Water levels from the open-hole wells were not used for contouring the potentiometric surface because they reflect composite hydraulic heads.

Water levels were measured in 15 wells in Casey Village and 15 wells at the NAWC on August 3, 1995. The general direction of the ground-water gradient in wells screened between 18 and 64 ft bls is to the north (fig. 20). The general direction of the ground-water gradient in wells screened between 48 and 106 ft bls is to the north and northeast (fig. 21).

Water levels were measured in 15 wells in Casey Village and 22 wells at the NAWC on February 15, 1996. A ground-water divide that bisects the mapped area is evident on the potentiometric surface in wells screened between 18 and 64 ft bls (fig. 22). Although sufficient data are not available to show the exact position of the ground-water divide, it coincides approximately with the surface-water drainage divide between Mill Creek and Southampton Creek (fig. 1). On the east side of the divide (towards Mill Creek), the general ground-water gradient in is to the east and northeast. On the west side of the divide (towards

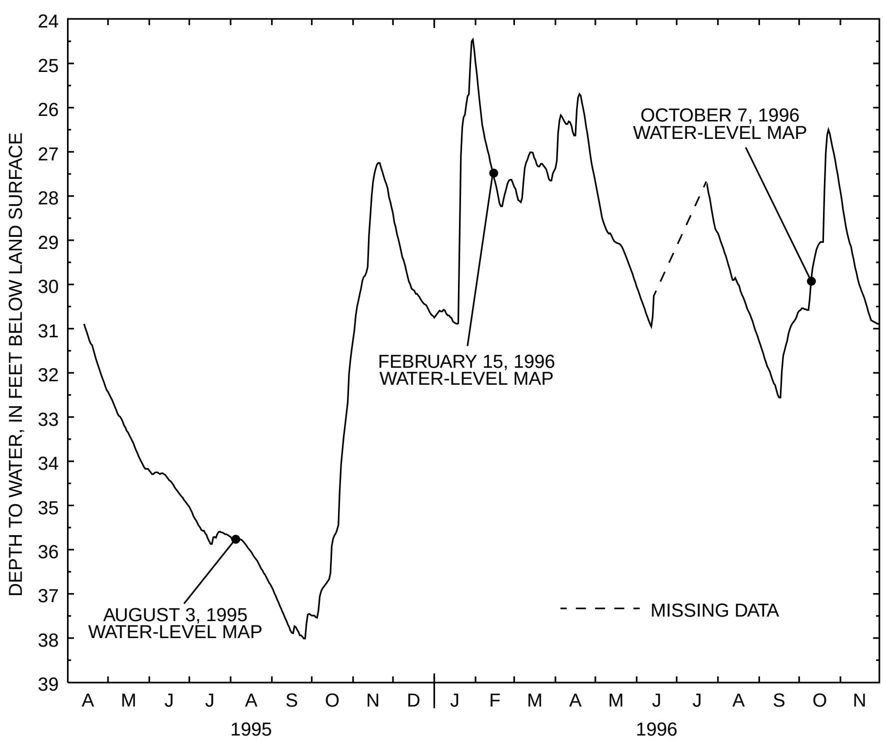


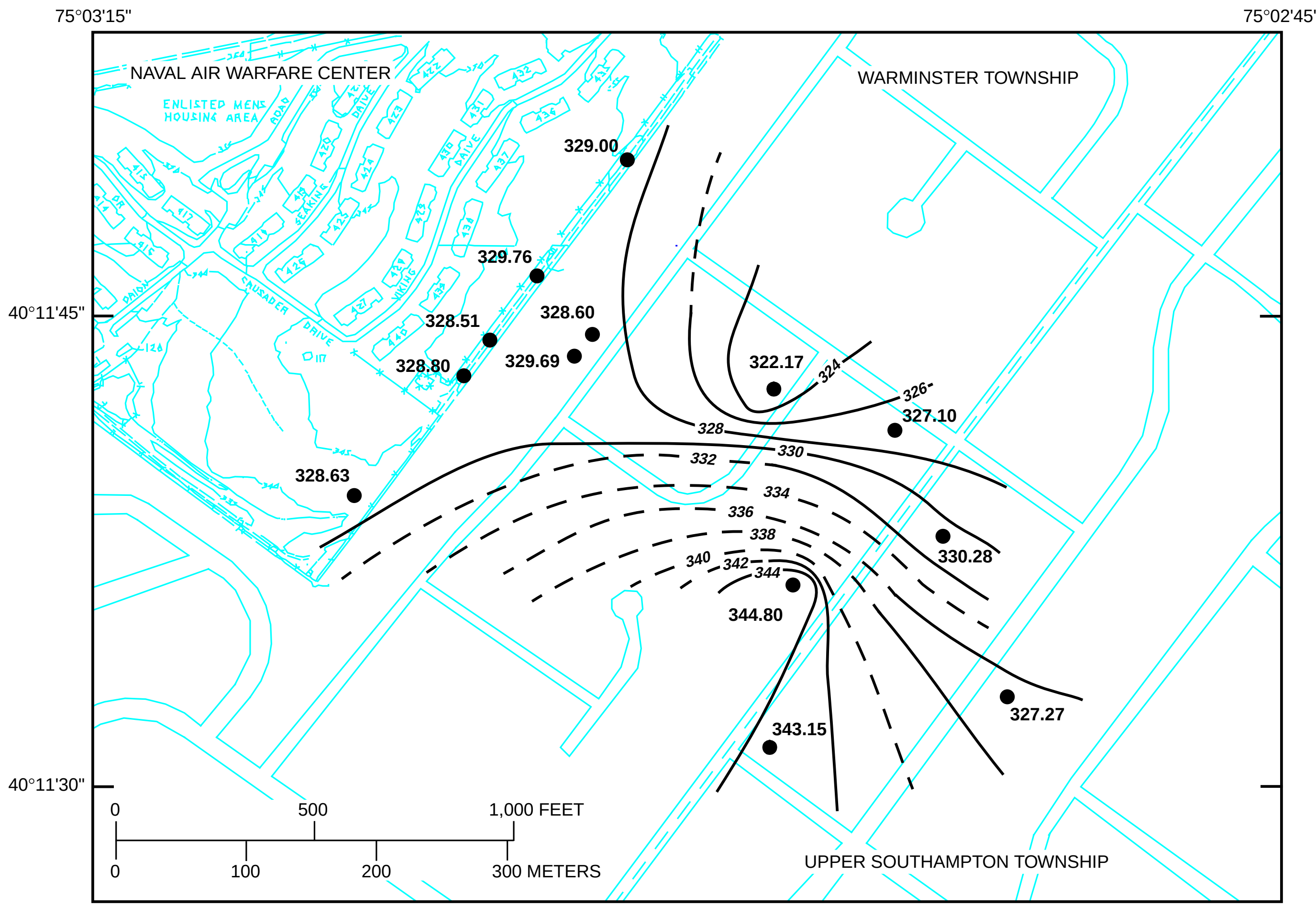
Figure 19. Hydrograph from well BK-1020, April 1995 to November 1996, Naval Air Warfare Center, Warminster, Pennsylvania.

Southampton Creek), the general ground-water gradient is to the southwest.

The location of the ground-water divide on the potentiometric-surface map of wells screened between 48 and 106 ft bls (fig. 23) is not obvious but is probably in nearly the same location as on figure 22. On the east side of the divide (towards Mill Creek), the general ground-water gradient is to the northeast. On the west side of the divide (towards Southampton Creek), the general ground-water gradient is to the southwest and northwest.

Water levels were measured in 15 wells in Casey Village and 22 wells at the NAWC on October 7, 1996. The potentiometric surfaces look similar to those measured earlier. On the October 7, 1996, potentiometric-surface maps of wells screened between 18 and 64 ft bls (fig. 24) and wells screened between 48 and 106 ft bls (fig. 25), the ground-water divide is in the same location as on the February 15, 1996, potentiometric-surface maps (figs. 22 and 23, respectively), and general ground-water-gradient directions are the same.

Mapping of the potentiometric surfaces in the Casey Village area in a relatively dry year (1995, figs. 20-21) and twice in a relatively wet year (1996, figs. 22-25) shows that horizontal ground-water gradients in the area are in the same direction for different climatic conditions.



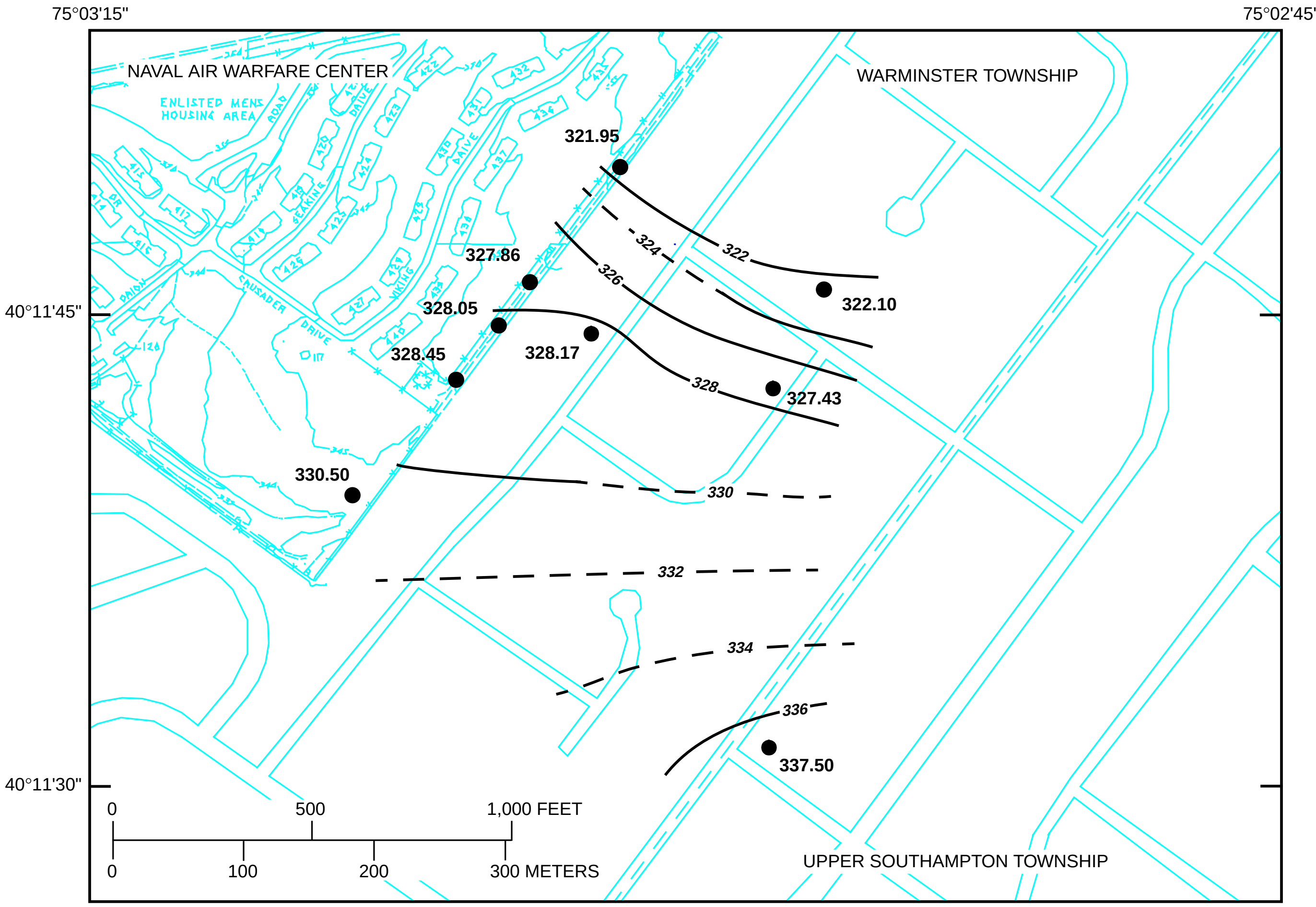
Base provided by Brown and Root Environmental, Inc.

EXPLANATION

330 POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

327.10 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

Figure 20. Altitude and configuration of the potentiometric surface in wells screened between 18 and 64 feet below land surface, August 3, 1995, Casey Village area, Bucks County, Pennsylvania. (Modified from Sloto and Grazul, 1995.)



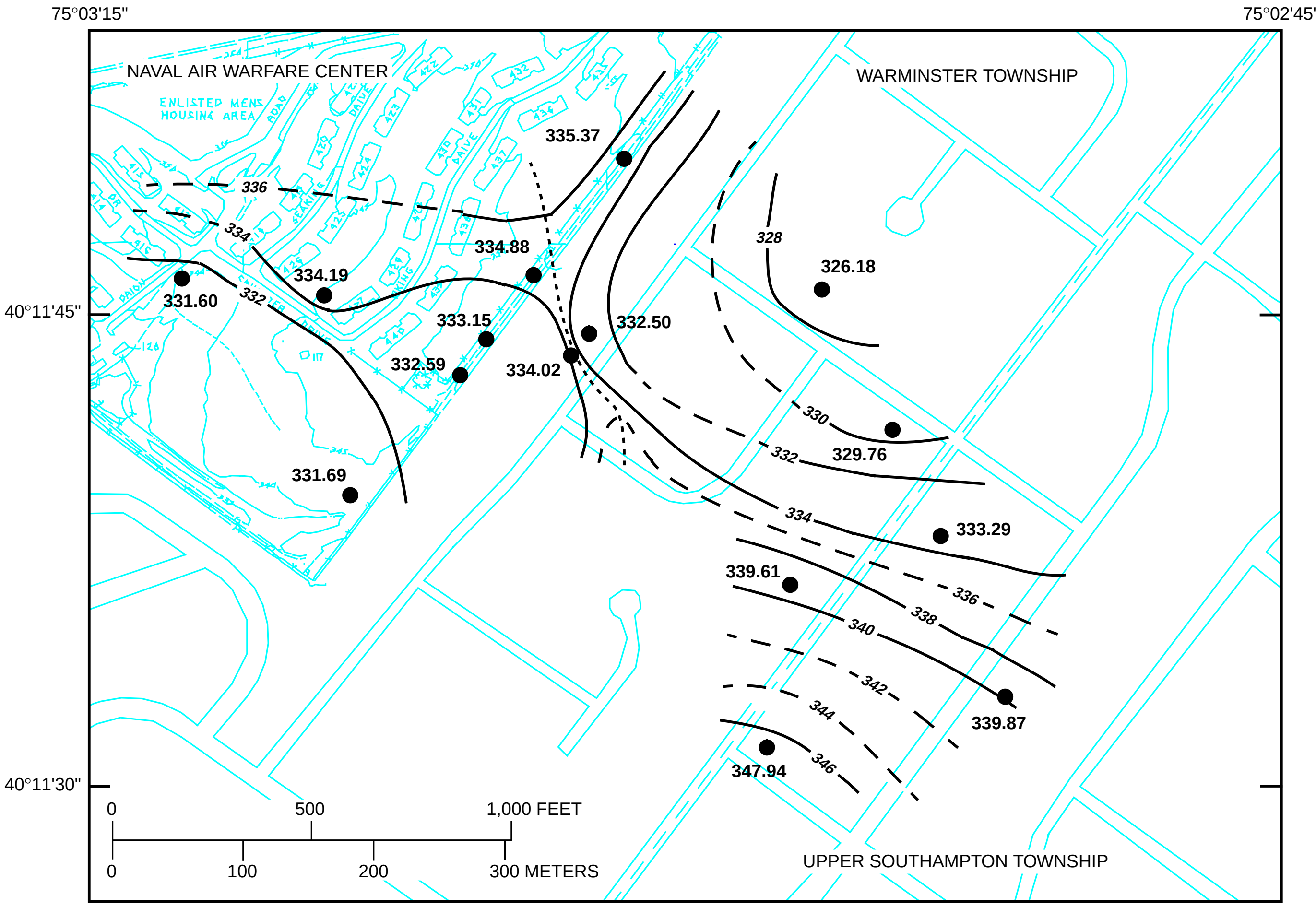
Base provided by Brown and Root Environmental, Inc.

EXPLANATION

330 — POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

327.43 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

Figure 21. Altitude and configuration of the potentiometric surface in wells screened between 48 and 106 feet below land surface, August 3, 1995, Casey Village area, Bucks County, Pennsylvania. (Modified from Sloto and Grazul, 1995.)



Base provided by Brown and Root Environmental, Inc.

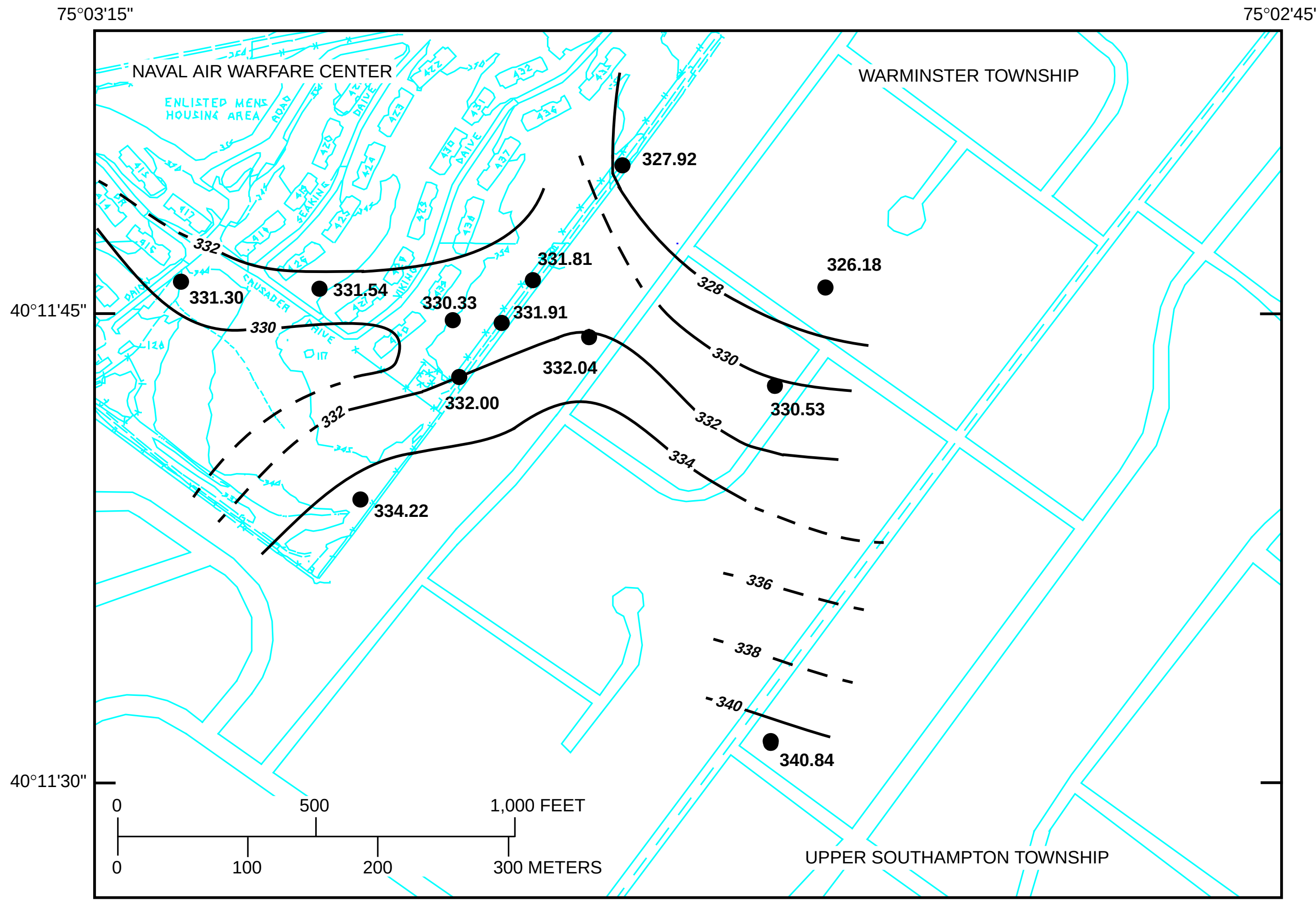
EXPLANATION

—— 330 —— POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

339.61 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

- - - - - - - GROUND-WATER DIVIDE

Figure 22. Altitude and configuration of the potentiometric surface in wells screened between 18 and 64 feet below land surface, February 15, 1996, Casey Village area, Bucks County, Pennsylvania. (Modified from Sloto, 1996b.)



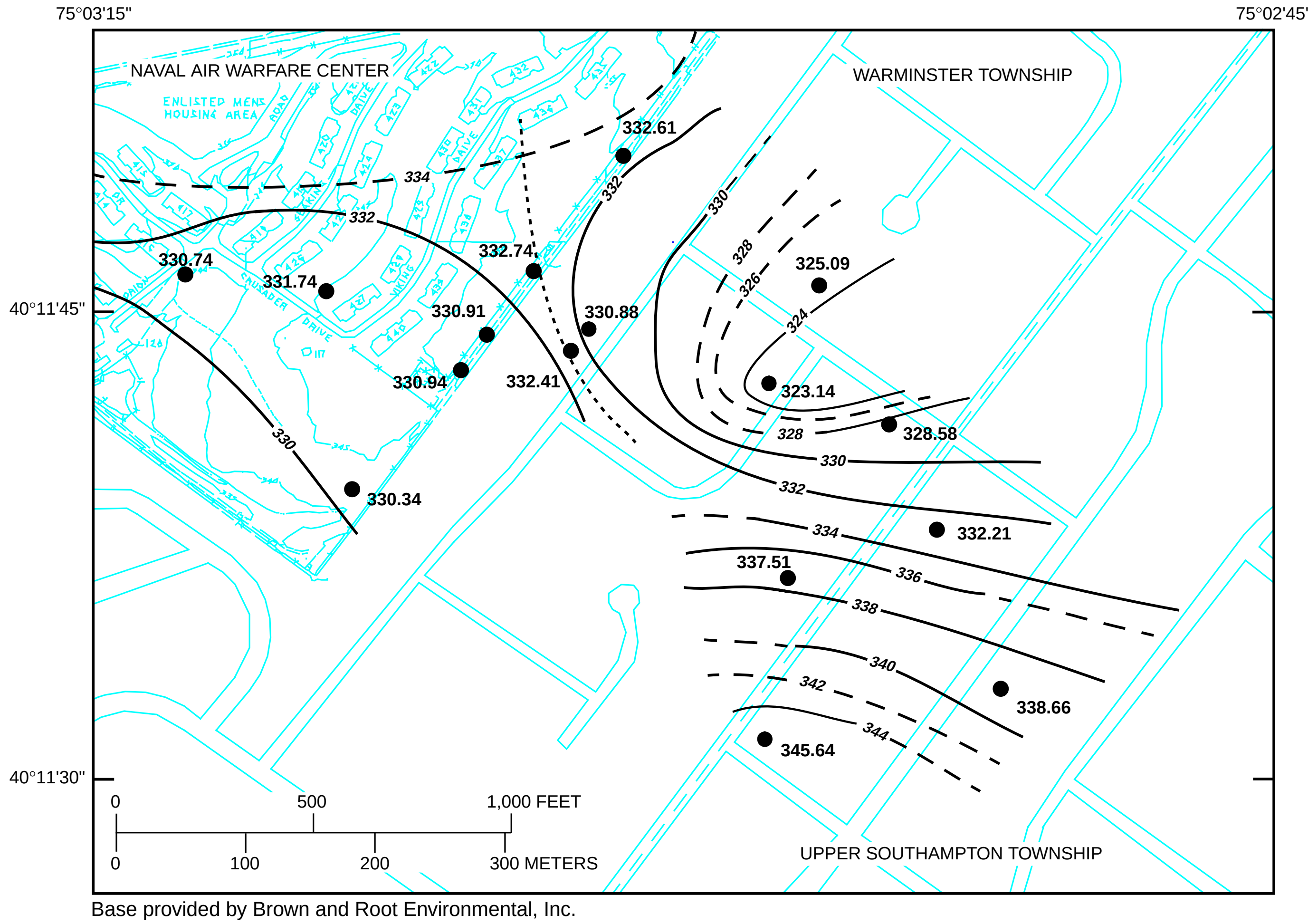
Base provided by Brown and Root Environmental, Inc.

EXPLANATION

— *330* — POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

340.82 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

Figure 23. Altitude and configuration of the potentiometric surface in wells screened between 48 and 106 feet below land surface, February 15, 1996, Casey Village area, Bucks County, Pennsylvania. (Modified from Sloto, 1996b.)



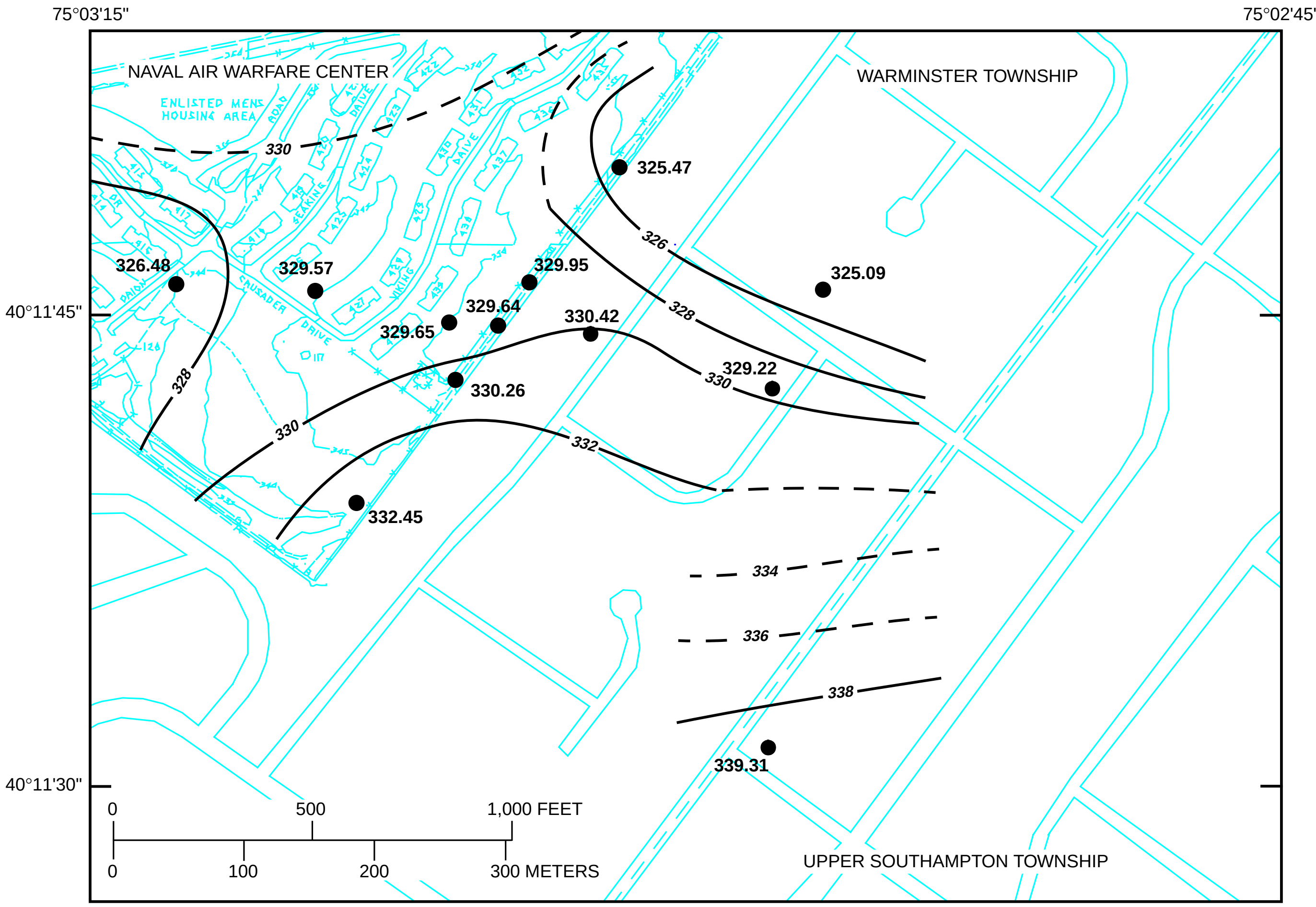
EXPLANATION

330 — POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

- - - - - - - GROUND-WATER DIVIDE

338.66 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

Figure 24. Altitude and configuration of the potentiometric surface in wells screened between 18 and 64 feet below land surface, October 7, 1996, Casey Village area, Bucks County, Pennsylvania.



Base provided by Brown and Root Environmental, Inc.

EXPLANATION

— 330 — POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface as defined by measured water levels. Dashed where inferred. Contour interval is 2 feet. Altitude is in feet above sea level

330.42 ● WATER-LEVEL MEASUREMENT SITE—Symbol gives location of site. Number is the altitude of a static water-level measurement in a drilled, screened well in feet above sea level.

Figure 25. Altitude and configuration of the potentiometric surface in wells screened between 48 and 106 feet below land surface, October 7, 1996, Casey Village area, Bucks County, Pennsylvania.

Vertical Ground-Water-Flow Gradients

Vertical ground-water-flow gradients were determined by use of the heatpulse flowmeter and by water-level measurements made in adjacent wells screened to different depths (well pairs and clusters). Heatpulse-flowmeter measurements were made in nine wells in Casey Village. Water-level measurements were made in three well pairs in Casey Village and in seven well clusters on the adjoining part of the NAWC.

On the basis of heatpulse-flowmeter measurements made in Casey Village, vertical gradients were downward in four wells (BK-2767, BK-2768, BK-2769, and BK-2791) and upward in two wells (BK-2790 and BK-2799) (table 2). No borehole flow was measurable in three wells (BK-1021, BK-2788, and BK-2789).

Vertical gradients measured in three well pairs constructed in Casey Village (well pairs BK-2767 / BK-2795, BK-2790 / BK-2796, and BK-2791 / BK-2797) confirmed gradient directions determined with the heatpulse flowmeter at these locations. For example, heatpulse-flowmeter measurements showed downward flow in well BK-2791 (table 2). Well BK-2791 was reconstructed as two 2-in. diameter screened wells (BK-2791 and BK-2797) constructed inside the same 6-in. diameter casing. On August 3, 1995, the water level in well BK-2791, which is screened between 22 and 32 ft bls, was 16.31 ft bls, and the water level in well BK-2797, which is screened between 50 and 60 ft bls, was 21.96 ft bls, indicating a downward gradient. The borehole geophysical logs (fig. 17) show that well BK-2791 is open to a water-bearing fracture at 20-22 ft bls, and well BK-2797 is open to a water-bearing fracture at 52-54 ft bls. The difference in head over a 32-ft vertical section of the aquifer was 5.65 ft. On February 15, 1996, the difference in head was 7.10 ft, and on October 7, 1996, the difference in head was 6.33 ft. The difference in head between the two zones is higher when water levels are higher.

In well clusters on the adjoining part of the NAWC, the direction of vertical ground-water gradients varies among well cluster locations and sometimes with time. A consistent downward gradient was measured at three well clusters (HN-9, HN-49, and HN-62). At well cluster HN-6, the vertical gradient measured between the intermediate-depth well and the shallow-depth well was consistently upward, while the vertical gradient measured between the intermediate depth well and the deep well was consistently downward. This pattern was present in water-level measurements made by the Haliburton NUS Corporation on April 27, 1994, August 17, 1994, and December 13, 1994 (Haliburton NUS Corporation, 1995, p. 2-12). At well cluster HN-8, the vertical gradient measured between the shallow-depth well and the intermediate-depth well was consistently downward, while the vertical gradient measured between the deep well and the intermediate-depth well was consistently upward. This pattern was present in water-level measurements made by the Haliburton NUS Corporation on April 27, 1994, August 17, 1994, and December 13, 1994 (Haliburton NUS Corporation, 1995, p. 2-13).

The direction of vertical ground-water gradients varies with time in well clusters HN-7 and HN-61. At well cluster HN-7, the vertical gradient was downward on February 15, 1996. This pattern was present in water-level measurements made by the Haliburton NUS Corporation on April 27, 1994, and December 13, 1994 (Haliburton NUS Corporation, 1995, p. 2-13). On August 3, 1995, and October 7, 1996, the vertical gradient measured between the shallow-depth well and the intermediate-depth well was downward, while the vertical gradient measured between the deep well and the intermediate-depth well was upward. This pattern was present in water-level measurements made by the Haliburton NUS Corporation on August 17, 1994 (Haliburton NUS Corporation, 1995, p. 2-13). At well cluster HN-61, the vertical gradient was upward on February 15, 1996, and downward on October 7, 1996.

Water levels in well clusters HN-7 and HN-9 appear to be affected by pumping. Water levels were monitored continuously from March 28 or 31 to April 27, 1994, in well clusters HN-5, HN-7, and HN-9 on the NAWC by the Haliburton NUS Corporation (Haliburton NUS Corporation, 1995, p. 2-15). Hydrographs from wells HN-7-I and HN-9-D show interference from pumping of up to 0.1 ft (Haliburton NUS Corporation, 1995, Appendix D). The likely source of pumping is 608-ft deep well BK-933 (Northampton Township well number 1), which is approximately 4,700 ft east of well cluster HN-9 (fig. 2).

Effect of Pumping on Water Levels

An aquifer test was conducted on October 28, 1996, using well BK-2799 as the pumped well to determine the effect of pumping on water levels in the Casey Village area. The pumping rate was modified as needed to hold a drawdown of approximately 57 ft (water level at approximately 82 ft bls) in well BK-2799. Water levels in the pumped well and 18 observation wells (fig. 26) were measured by pressure transducers and recorded by dataloggers. The pumped well and observation wells BK-2768 and BK-2800 are open-hole wells; all other observation wells are screened wells. Well BK-2799 was pumped for 335 minutes at an average rate of 3.7 gal / min. Recovery measurements were made for 130 to 200 minutes after pumping stopped.

Pumped well BK-2799 is open from 20 to 106 ft bls and is open to units A, B, C, and D. The major water-bearing zone is at 90 ft bls in unit C; minor water-bearing zones are at 31 ft bls in unit A and 54-56 ft bls in unit B. The maximum drawdown in well BK-2799 was 62.97 ft; drawdown at the end of the test was 57.13 ft.

Well BK-2798 is 78 ft from the pumped well and is the closest observation well. It is an open-hole well also open to units A, B, C, and D; however, the depth of water-bearing zones is not known. Drawdown in well BK-2798 was only 1.27 ft. Drawdown in well HN-61-I, which is 525 ft from the pumped well and is open to unit B, was 2.21 ft. The reason for the lower than expected drawdown in well BK-2798 is not known. Wells BK-2799 and HN-61-I may be located in a narrow zone of high hydraulic conductivity or a fault that may offset water-bearing beds and act as a geohydrologic discontinuity may be present between wells BK-2798 and BK-2799. The fault also may run between well clusters HN-7 and HN-49. The correlation of natural-gamma logs (fig. 5) shows that the beds between well clusters HN-7 and HN-49 dip more steeply than between the other well clusters. This apparent steeper dip may be caused by a minor fault. However, no faults have been mapped in this area (Willard and others, 1959, plate 2).

The aquifer test demonstrates how pumping can change vertical gradients. Prior to the test, a downward gradient was present at well cluster HN-49 (fig. 27). Drawdown in well HN-49-I was greater than drawdown in the other wells in the cluster. Prior to the test, the vertical gradient between well HN-49-I and well HN-49-D was downward. During the test, the water level in well HN-49-I dropped below the water level in well HN-49-D. This caused the direction of the gradient to reverse so that there was an upward gradient between wells HN-49-D and HN-49-I. Pumping well BK-2799 induced flow from unit C upward to unit B at the HN-49 well cluster. Prior to and during the test, the vertical gradient between the well HN-49-S and well HN-49-I was downward.

Drawdown measured in wells screened below 53 ft bls on the opposite side of the ground-water divide from the pumped well indicates that the pumping of well BK-2799 shifted the ground-water divide in the deeper potentiometric surface to the west or northwest. No drawdown was measured in wells at the NAWC that were screened above 53 ft bls.

Water levels were measured in four wells screened in unit A, a silty unit. Response to the pumping of well BK-2799 ranged from no response in wells HN-9-S and HN-49-S to 4.94 ft of drawdown in well BK-2767 (fig. 28). Data from open-hole wells BK-2798 and BK-2800 were not used to prepare drawdown contour maps because they are open to more than one unit, and the drawdown represents a composite of the drawdown in all units to which the wells are open. Although data from only four wells are available, the drawdown pattern for wells screened in unit A appears to be elliptical with the long axis of the ellipse oriented N. 75° W. (fig. 29). The orientation of the ellipse does not correspond to strike, dip, or regional jointing patterns. Rima and others (1962, p. 22) state that vertical joints most commonly occur perpendicular to strike. Two other sets of joints also commonly occur; one is parallel or nearly parallel to strike and one trends northwestward at an angle of approximately 50° to strike. In the Casey Village area, these joint sets would be at approximately N. 20° W., N. 70° E., and N. 20° E., respectively.

Water levels were measured in five wells screened in unit B, a sandy unit. Response to the pumping of well BK-2799 ranged from no response in wells BK-2790 and HN-7-S to 4.13 ft of drawdown in well HN-49-I (fig. 30). The drawdown pattern for wells screened in unit B is elliptical with the long axis of the ellipse oriented N. 75° W. (fig. 31), the same orientation as the drawdown pattern in unit A. The ellipse appears to stretch further in the downdip direction than in the updip direction.

Water levels were measured in five wells screened in unit C, a silty unit. Response to the pumping of well BK-2799 ranged from 0.29 ft of drawdown in well BK-2796 to 5.59 ft of drawdown in well BK-2795 (fig. 32). The drawdown pattern for wells screened in unit C appears to be elliptical with the long axis of the ellipse oriented approximately east-west (fig. 33), but it probably is somewhat irregular. This differs from the orientation of the drawdown patterns in units A and B. Drawdown measured in well HN-9-D, which is screened in unit D, was 0.31 ft. No drawdown was measured in well HN-7-D, which is screened in unit E.

Drawdowns form an elliptical pattern indicating anisotropy. However, anisotropy is not aligned with strike or dip. Hydraulic stress caused by pumping crosses stratigraphic boundaries. In general, drawdown was greatest for wells screened in unit B, a sandy unit. Cross-section D-D’ (fig. 34) shows that drawdown was greatest in wells screened in unit B, except for well pair BK-2790 / BK-2796, where drawdown was greater in unit C (well BK-2796) than in unit B (well BK-2790). Cross-section E-E’ (fig. 35) shows drawdown is greatest in wells screened in unit B, except for well cluster HN-7, where drawdown is greater in unit C (well HN-7-I) than in unit B (well HN-7-S). Over most of the area influenced by pumping, unit B is at approximately 270-310 ft above sea level. At well cluster HN-7 and well pair BK-2790 / BK-2796, unit C is at this altitude. Wells screened between 55 and 106 ft bls fall in this horizon. When drawdown for these wells is plotted without regard to geologic unit, it forms an elliptical pattern oriented N. 75° W. (fig. 36). It appears, therefore, that the response to pumping is controlled as much or more by depth of water-bearing zones below land surface than by geologic unit. Sloto, Macchiaroli, and Towle (1995, p. 42) noted that in the Stockton Formation, water levels in wells screened in individual geologic units could not be contoured but water levels in wells screened at similar depth intervals below land surface could be contoured.

Water levels were monitored in wells HN-49-I and HN-9-I before, during, and after the aquifer-isolation tests conducted in well BK-2799 (fig. 37). Two tests were performed on October 23, and four tests were performed on October 24. The response to each aquifer-isolation test can be clearly seen in the hydrograph of well HN-49-I. Drawdown in well HN-49-I was about 2 ft on October 23 and 2.1 ft on October 24. The response to each day’s pumping can be seen in the hydrograph of well HN-9-I. Drawdown in well HN-9-I was about 0.6 ft on October 23 and 0.5 ft on October 24.

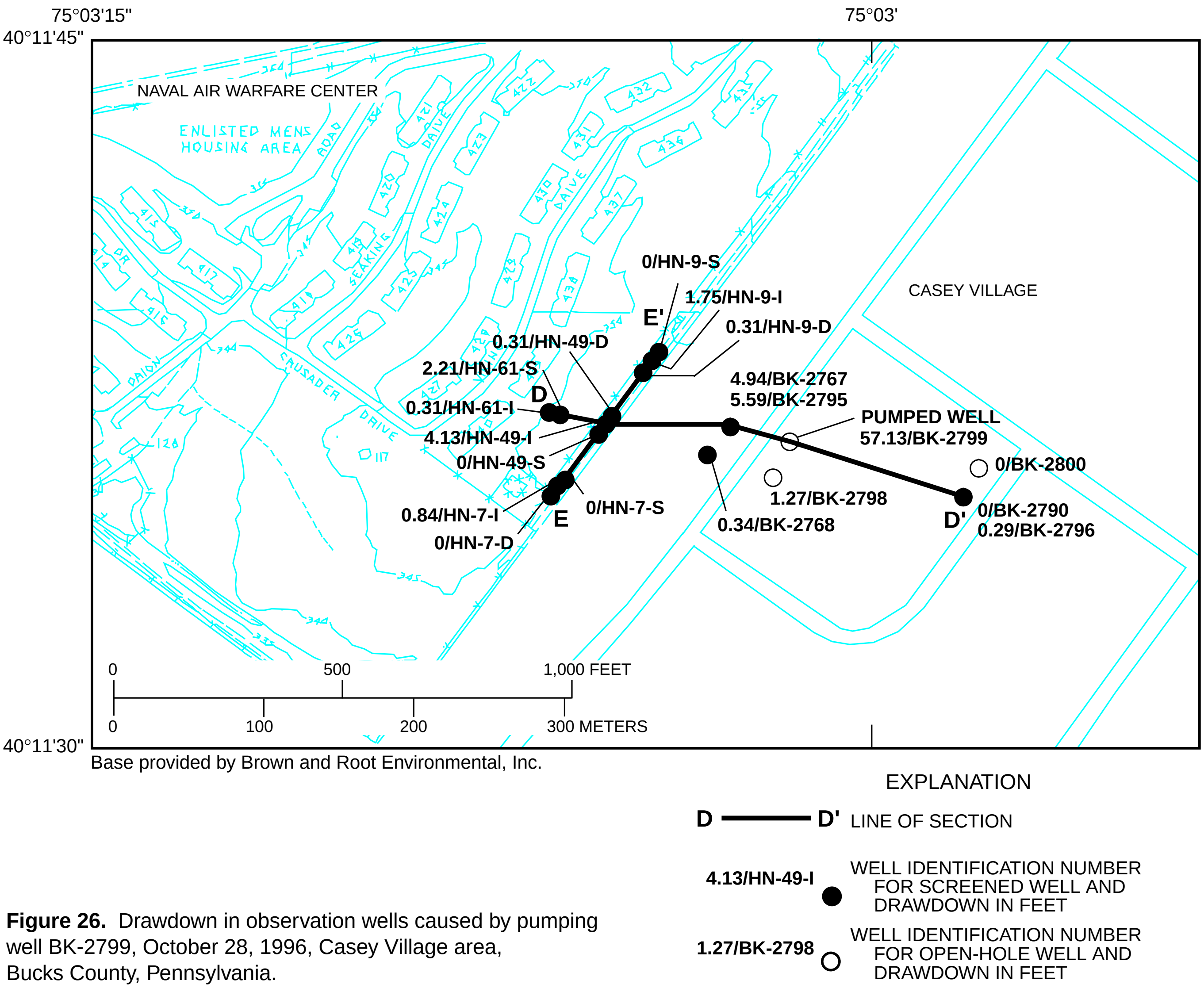


Figure 26. Drawdown in observation wells caused by pumping well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

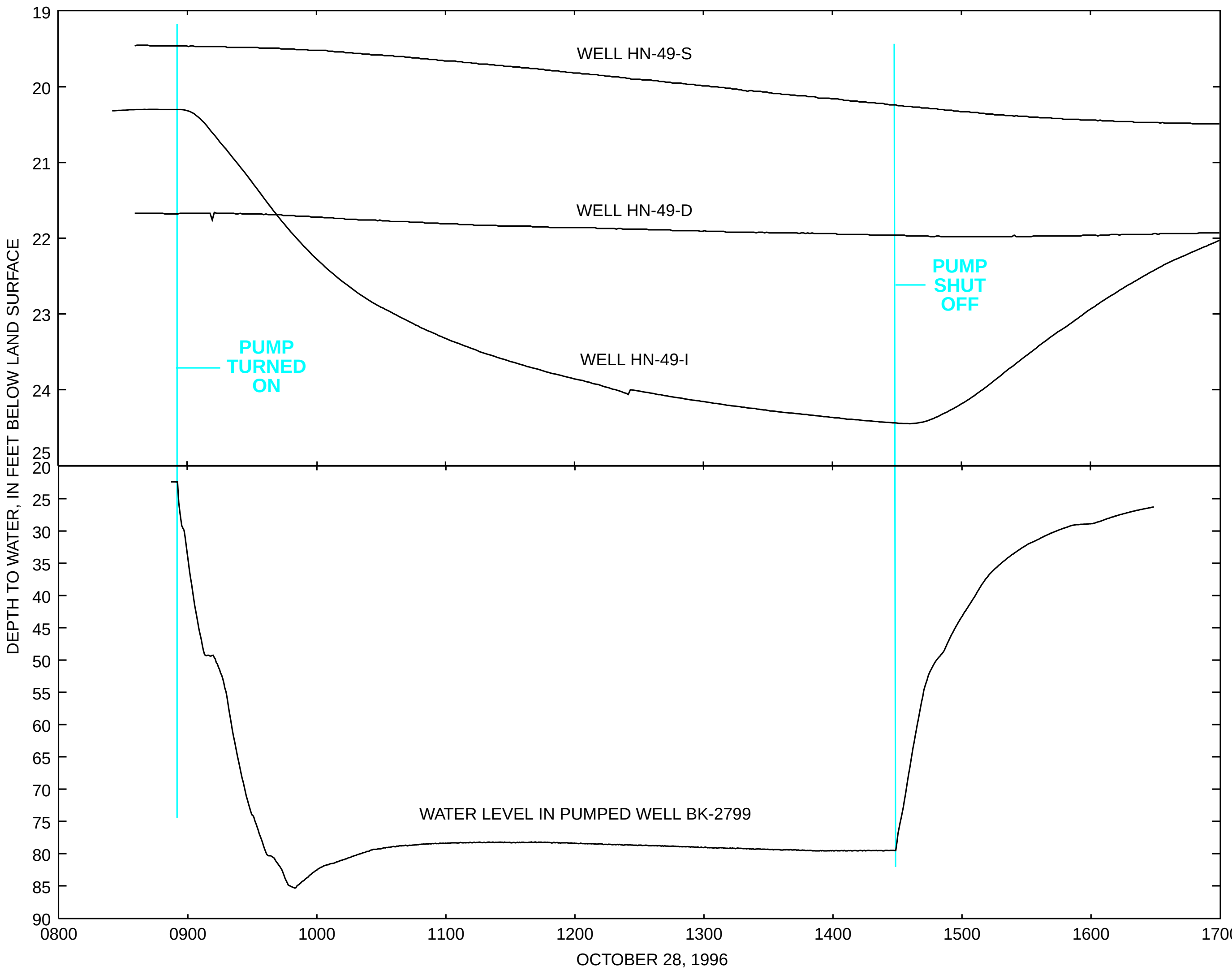


Figure 27. Water levels in wells BK-2799, HN-49-S, HN-49-I, and HN-49-D during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

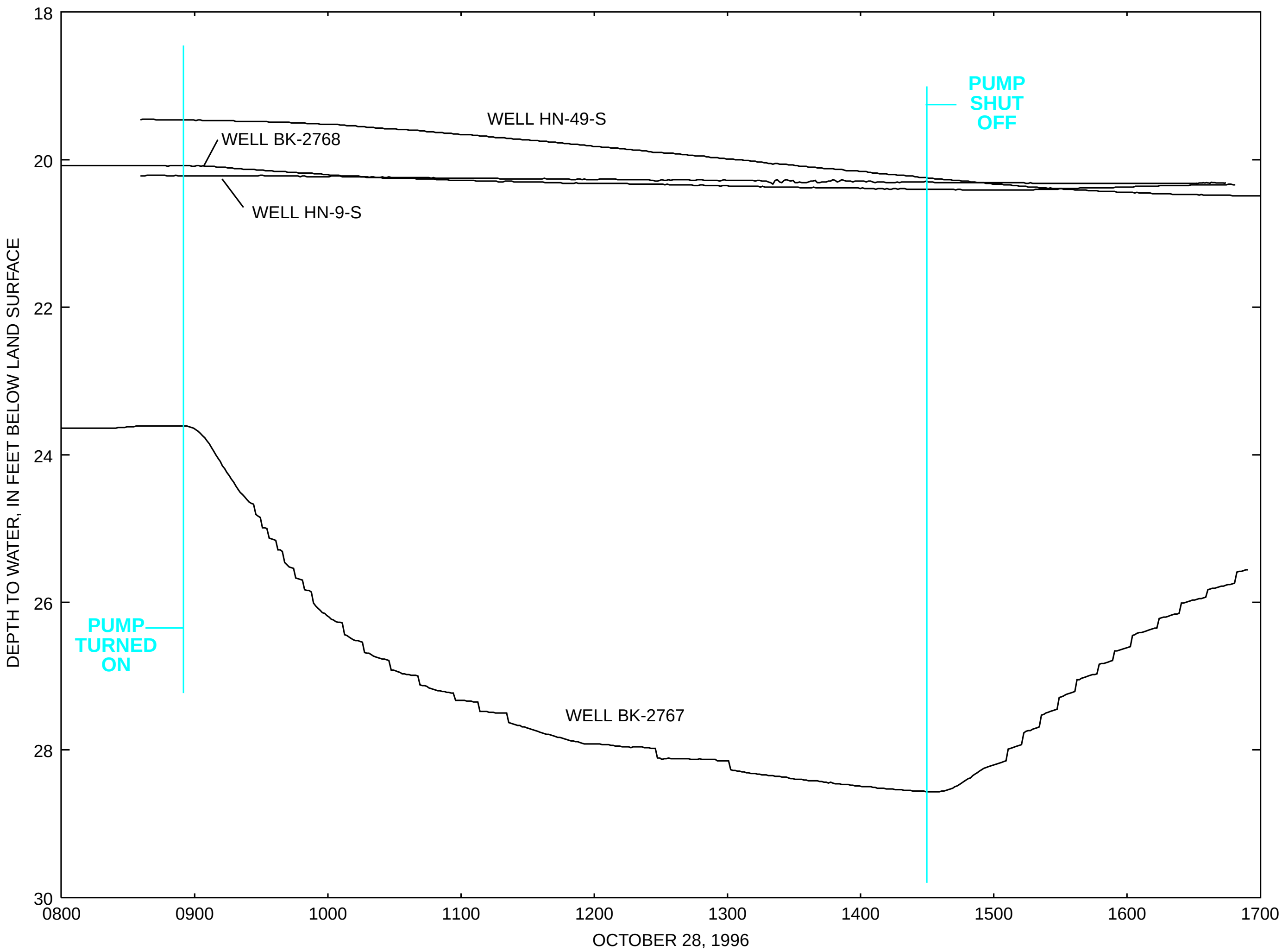
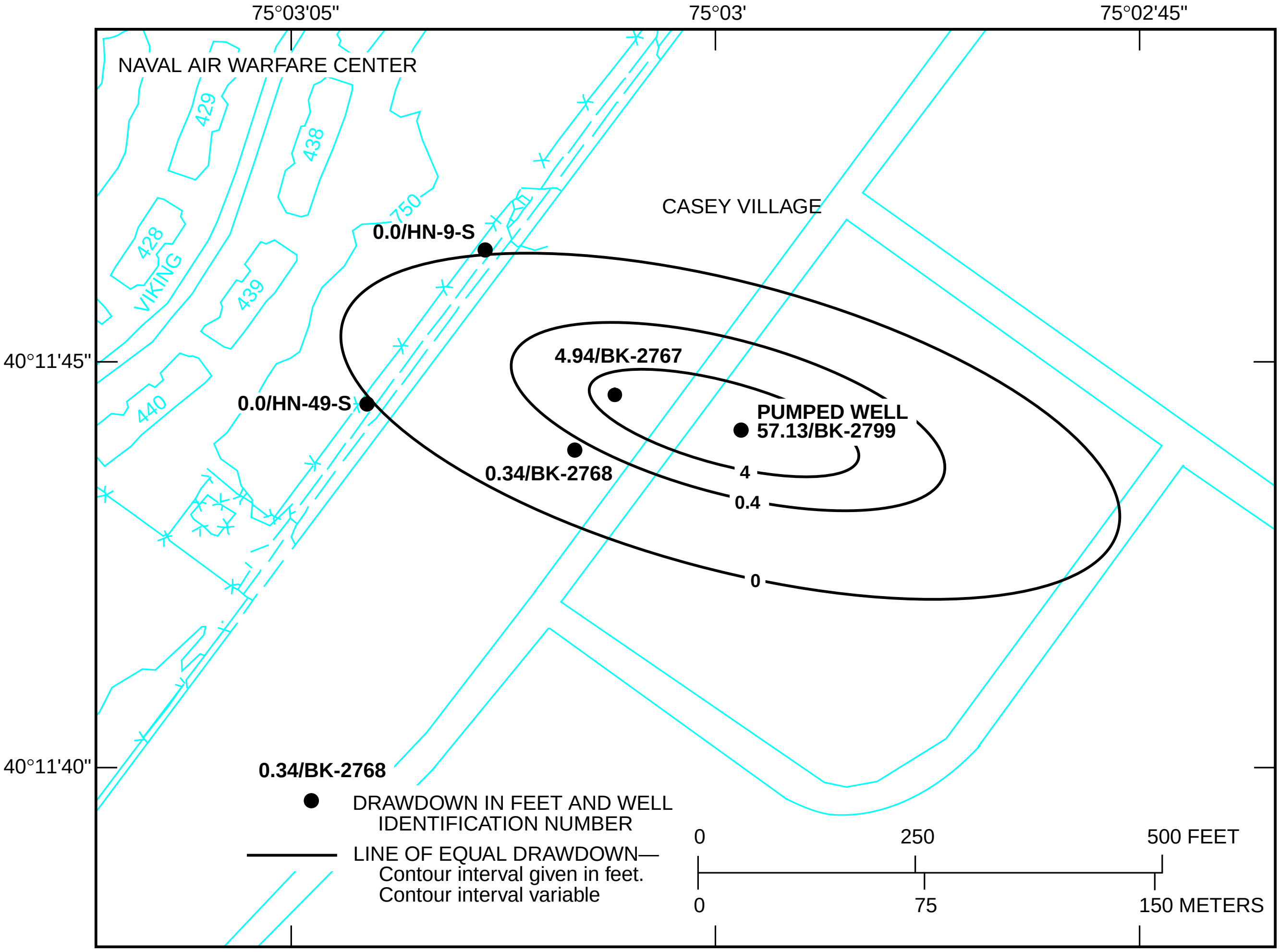


Figure 28. Water levels in wells screened in unit A (BK-2767, BK-2768, HN-9-S, and HN-49-S) during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.



Base provided by Brown and Root Environmental, Inc.

Figure 29. Drawdown measured in observation wells screened in unit A caused by pumping well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

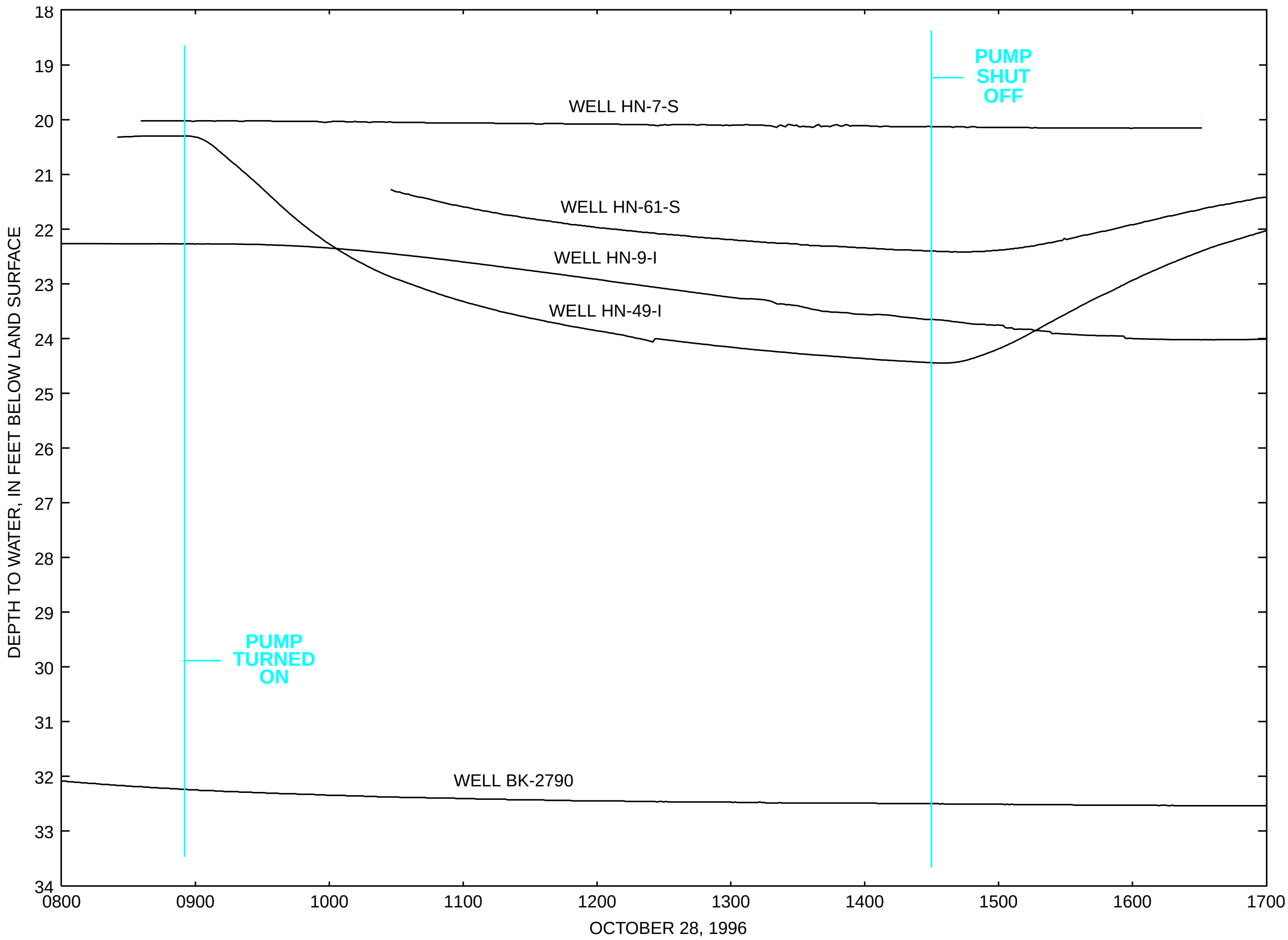
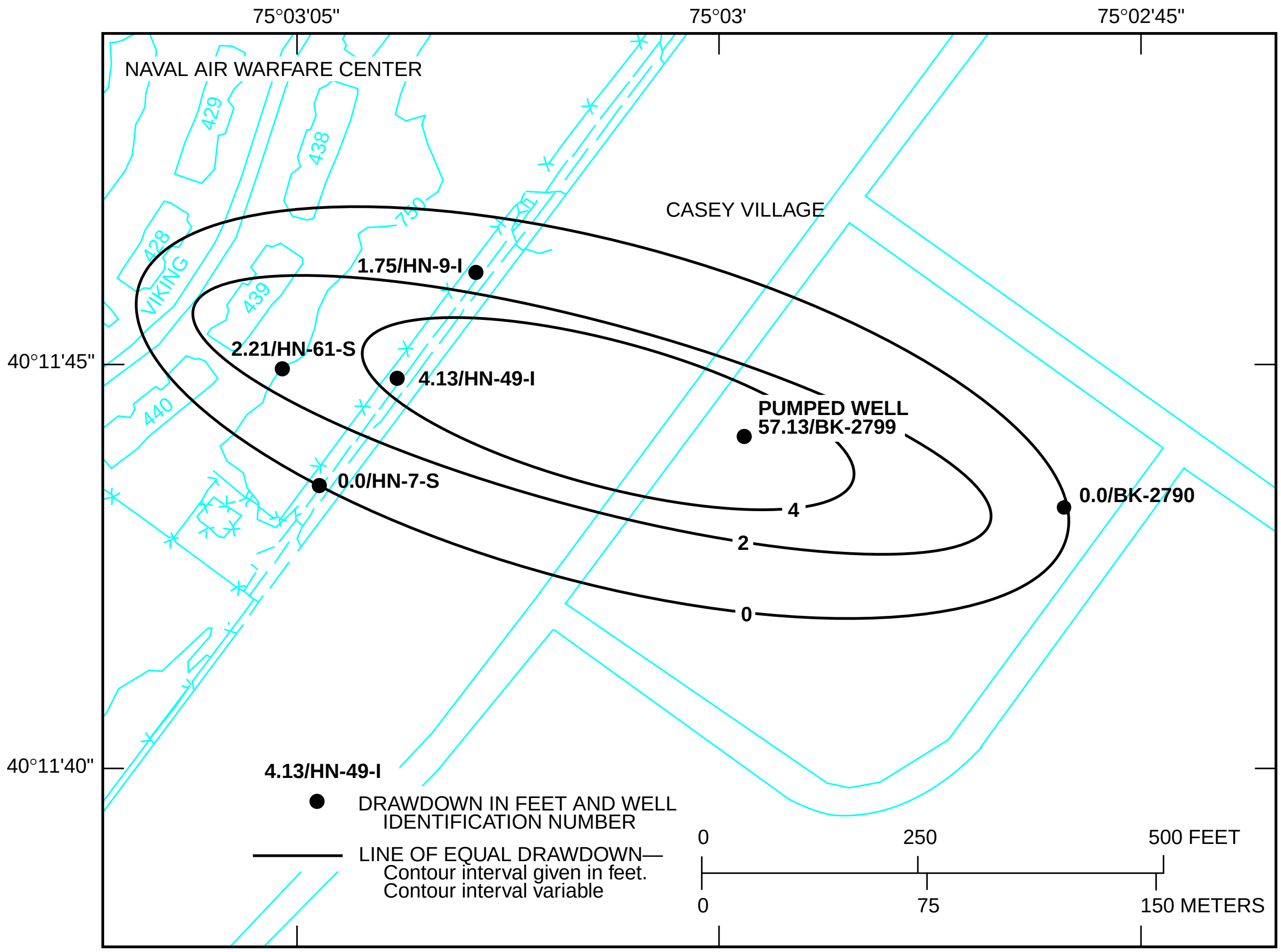


Figure 30. Water levels in wells screened in unit B (BK-2790, HN-7-S, HN-9-I, HN-49-I, and HN-61-S) during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.



Base provided by Brown and Root Environmental, Inc.

Figure 31. Drawdown measured in observation wells screened in unit B caused by pumping well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

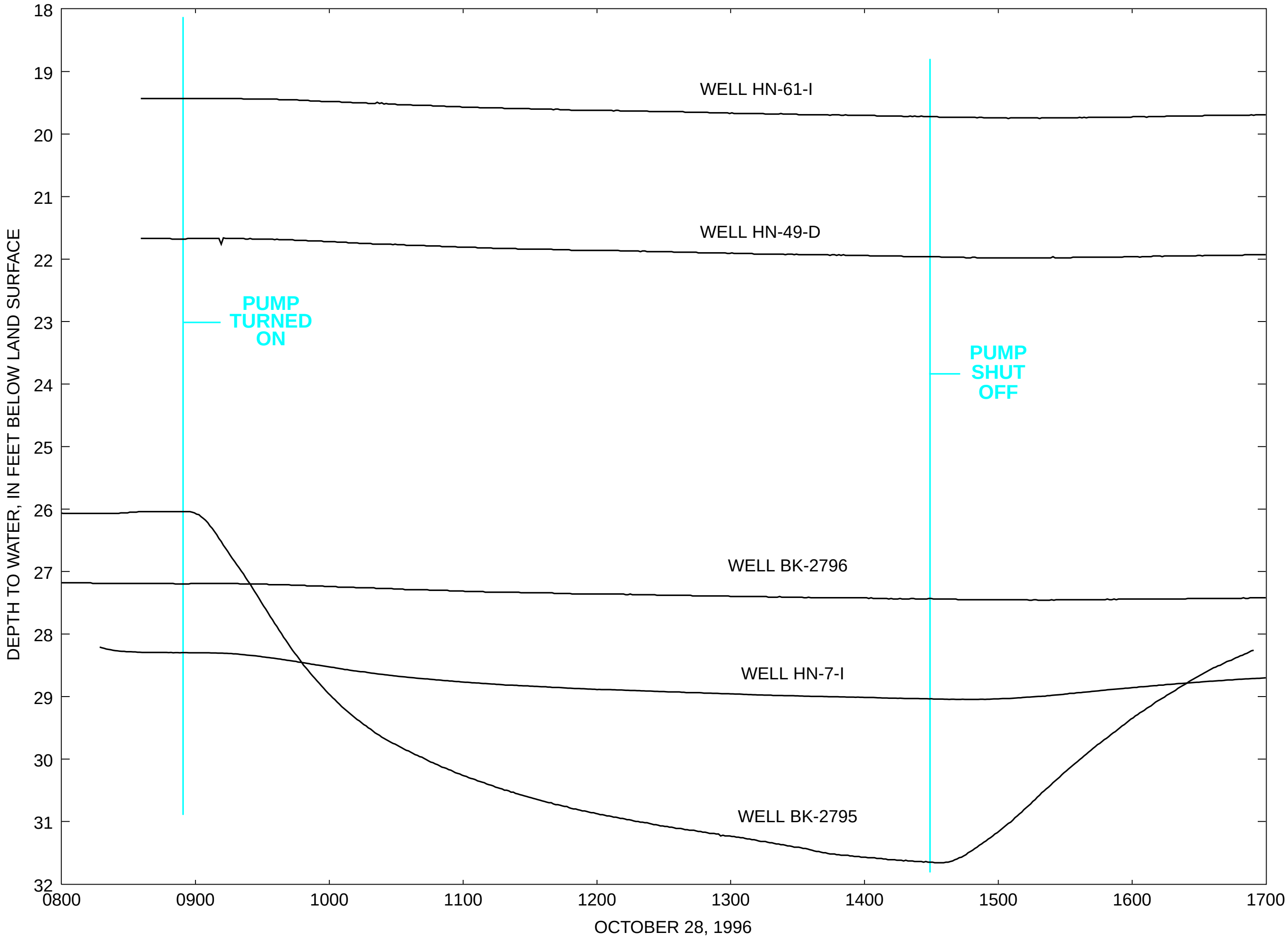
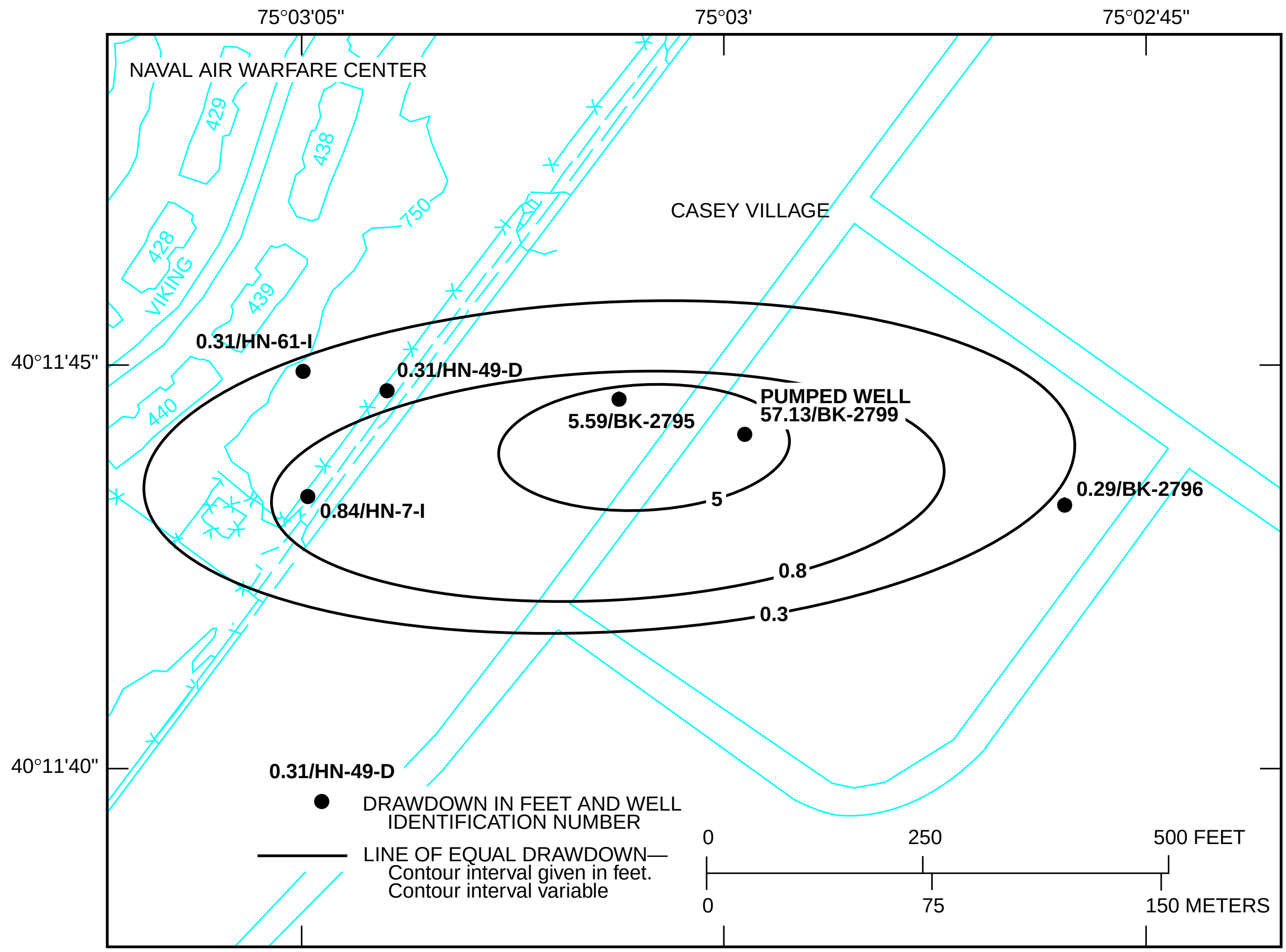


Figure 32. Water levels in wells screened in unit C (BK-2795, BK-2796, HN-7-I, HN-49-D, and HN-61-I) during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.



Base provided by Brown and Root Environmental, Inc.

Figure 33. Drawdown measured in observation wells screened in unit C caused by pumping well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

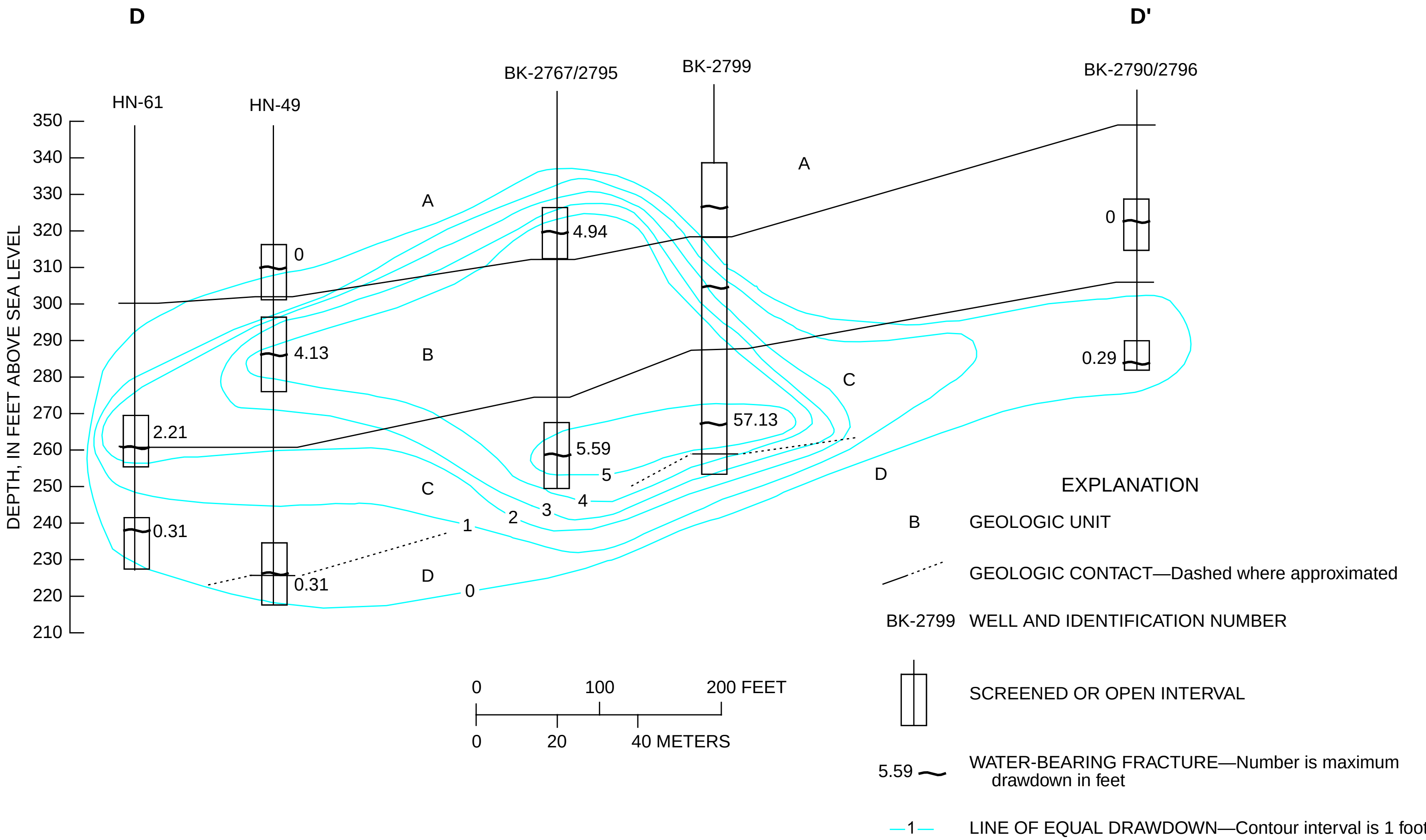


Figure 34. Generalized cross-section D-D' showing maximum drawdowns in observation wells during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania. (The location of the cross-section is shown on figure 33.)

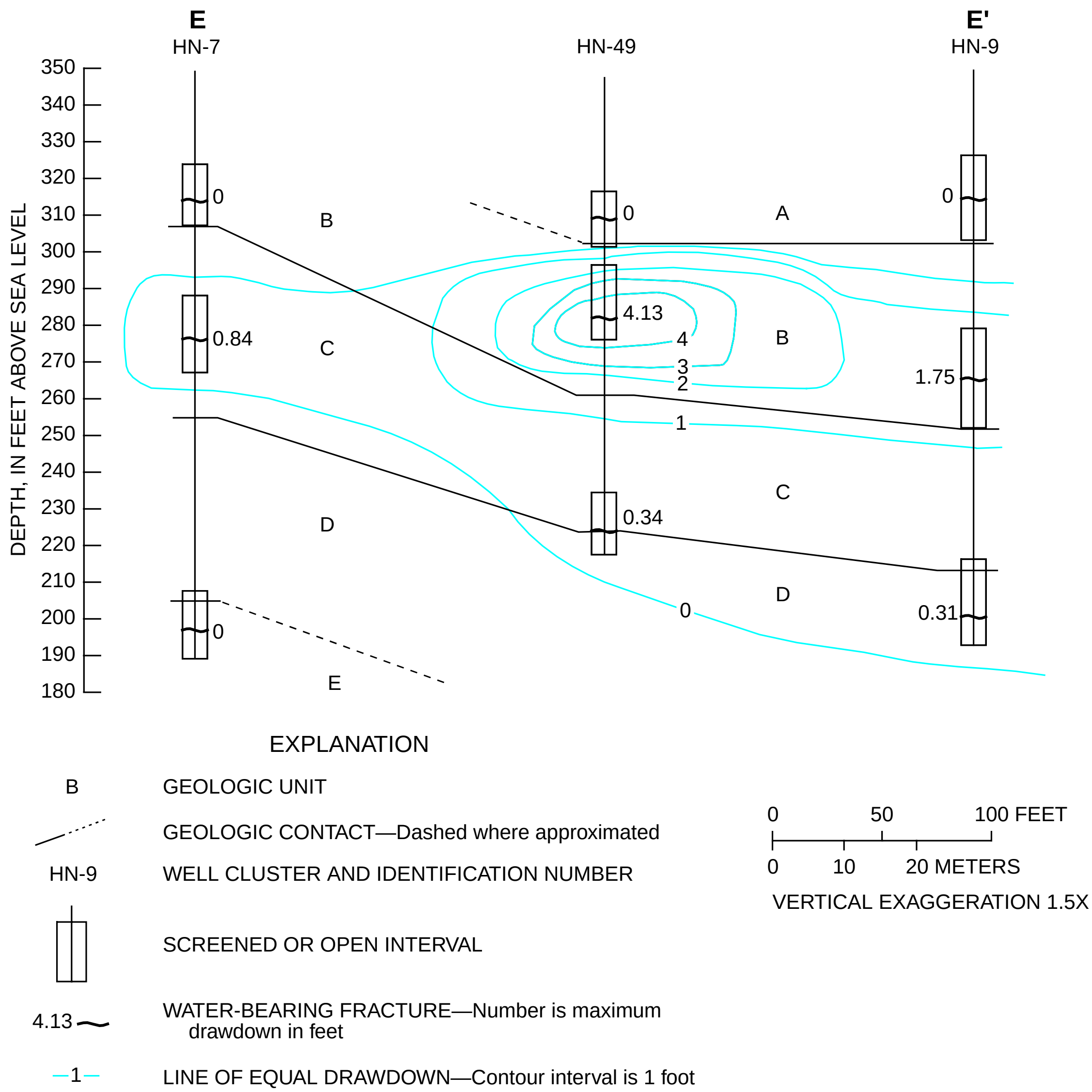
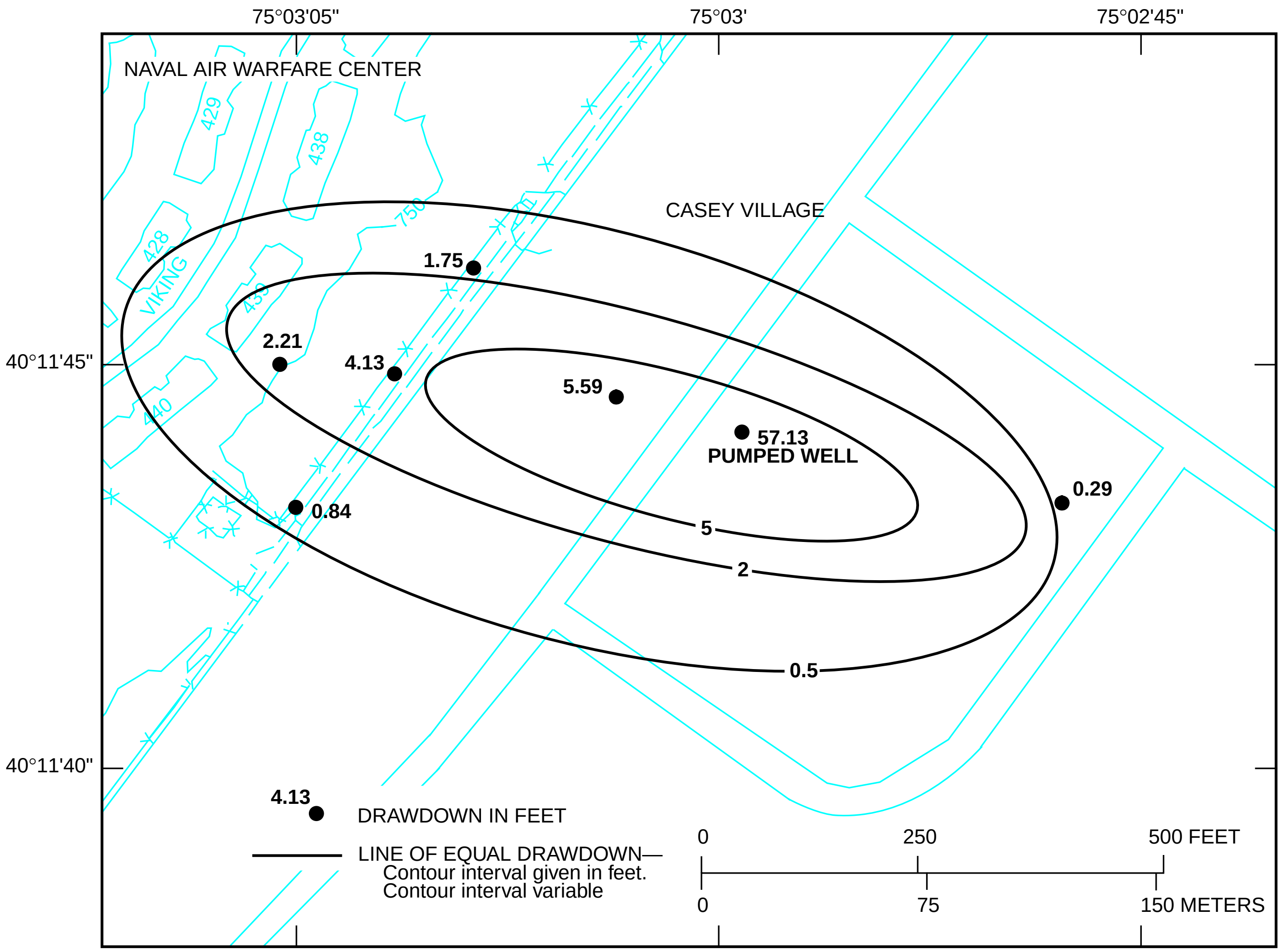


Figure 35. Generalized cross-section E-E' showing maximum drawdowns in observation wells during the aquifer test of well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania. (The location of the cross-section is shown on figure 33.)



Base provided by Brown and Root Environmental, Inc.

Figure 36. Drawdown measured in observation wells screened between 55 and 106 feet below land surface caused by pumping well BK-2799, October 28, 1996, Casey Village area, Bucks County, Pennsylvania.

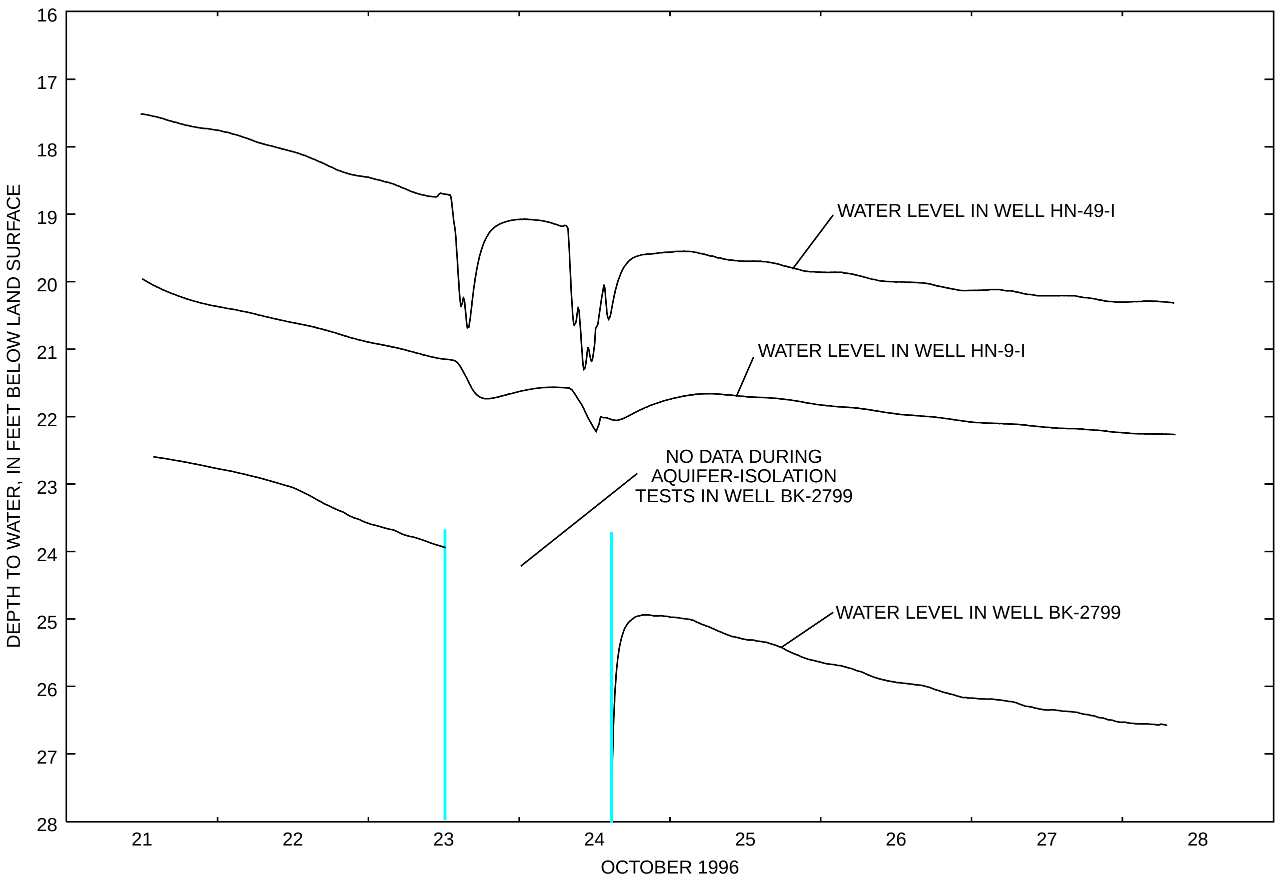


Figure 37. Water levels in wells BK-2799, HN-49-I, and HN-9-I, October 21-28, 1996, Casey Village area, Bucks County, Pennsylvania.

DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER

The primary VOC's of interest in ground water in the Casey Village area are trichloroethylene (TCE) and tetrachloroethylene (PCE). For this study, water samples were collected for laboratory analysis from 14 wells in Casey Village and 18 wells at the NAWC in February-March 1996 and from 14 wells in Casey Village and 2 wells at the NAWC in October 1996. Water samples were analyzed for physical properties (pH, temperature, and specific conductance) in the field and for VOC's in the laboratory. Complete results of laboratory chemical analyses are given in Appendix 2. A summary of compounds detected is given in table 3.

Spatial Distribution

As part of a hydrologic study performed by the U.S. Navy, water samples were collected from wells within 3,000 ft of the NAWC in May-July 1993. TCE and PCE concentrations in water samples collected by the U.S. Navy (written commun., 1997) are shown on figures 38 and 39, respectively. The highest detected concentration of TCE was 1,200 µg/L, in water from well BK-2799, and the highest concentration of PCE was 720 µg/L, in water from well BK-2769.

TCE and PCE concentrations in water samples collected by the USGS in 1996 are shown on figures 40 and 41, respectively. Fewer wells were available for sampling in 1996 because most domestic wells were destroyed when the residences in Casey Village were connected to public water. The highest concentrations of TCE were 450 and 140 µg/L in water from well BK-2799 in March and October, respectively. The highest concentrations of PCE were 690 and 630 µg/L in water from well BK-2769 in February and October, respectively.

The distribution of TCE and PCE in ground water indicates the presence of separate PCE and TCE plumes, each with a different source area. It is not possible to draw the boundaries of the plumes because of limited spatial data. The PCE plume (fig. 41) is located to the southeast of the TCE plume (fig. 40). Analytical results (table 3) do not show elevated concentrations of both TCE and PCE in water samples from the same well, which indicates that the PCE source is separate from the TCE sources. TCE detected in water samples from wells BK-2769, BK-2788, and BK-2789 probably is a breakdown product of PCE. The concentration of TCE in water samples from these wells is approximately 1 percent of the PCE concentrations.

The highest concentration of PCE was detected in water samples from well BK-2769 (fig. 41). The source area for the PCE plume is not known but probably is somewhere in the vicinity of well BK-2769. Sampling by the U.S. Navy did not show elevated concentrations of PCE upgradient from well BK-2769 (fig. 39). PCE concentrations decrease downgradient from well BK-2769 to the northeast (fig. 41).

The highest concentration of TCE in Casey Village was detected in water samples from well BK-2799 (table 3). The primary source area for the TCE plume in Casey Village probably is near and possibly downgradient from well BK-2799. Other sources, however, may be present in the area. The concentration of TCE in water samples from well BK-2799 has decreased since residential pumping was curtailed in 1993; however, the concentration of TCE increased when the well was pumped during the aquifer test (Appendix 2). This may indicate that the source is nearby. The source may be the former septic system and drain field; testing would be required to confirm this. A former owner of the property where well BK-2799 is located operated a septic tank and grease trap cleaning business, which may have used TCE, out of the residence for 14 years in the 1960's and 1970's (testimony from Douglas Martin, et. al. vs. United States of America, Civil Action No. 95-2543, United States District Court for the Eastern District of Pennsylvania, June 17, 1996).

The TCE plume appears to be moving in two directions away from the ground-water divide area. The residence where well BK-2799 is located was connected to public water on October 2, 1987, and the well was rarely used after that date. The pumping of well BK-2767 may have caused TCE migration into the ground-water divide area. From the divide area, the TCE plume appears to be moving both to the east and the west under the natural hydraulic gradient. In Casey Village, concentrations of TCE decrease from the area of well BK-2799 downgradient to the northeast. On the other side of the ground-water divide on the NAWC, concentrations of TCE decrease from the area of well HN-49-I downgradient to the west and southwest.

Trichlorofluoromethane (Freon-11), which was used as a refrigerant, polyurethane foaming agent, solvent, degreaser, and fire extinguishing agent, is associated with part of the TCE plume in the divide area. Trichlorofluoromethane was detected in water from one well in Casey Village, well BK-2767 (2.7 µg/L), and in water from two wells on the NAWC, well HN-49-I (3.7 µg/L) and well HN-61-S (2.8 µg/L).

Vertical movement of TCE and PCE may have taken place through the open-hole domestic wells in Casey Village prior to the installation of the public water distribution system and the reconstruction of most of the remaining domestic wells as monitor wells. Borehole geophysical logging and heatpulse-flow-meter measurements show upward or downward flow in open-hole wells under nonpumping conditions. Sloto, Macchiaroli, and Towle (1996) demonstrated that open boreholes in the Stockton Formation can serve as conduits for the vertical transport of contaminants.

Table 3. *Summary of concentrations of selected volatile organic compounds in ground water, Casey Village area, Bucks County, Pennsylvania*

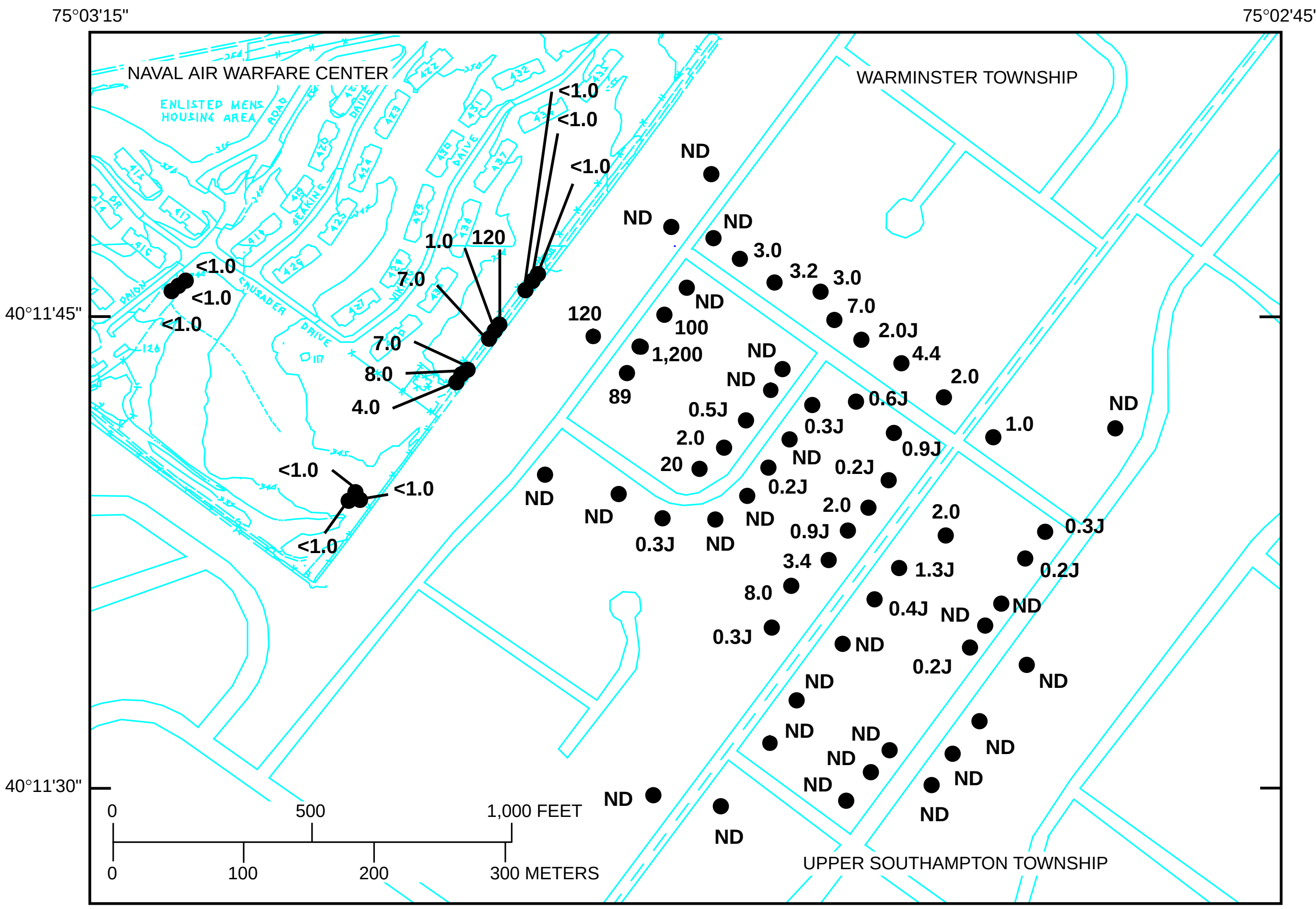
[Concentrations in micrograms per liter; <, less than; ND, not detected, detection limit not known; --, no data; Notes: 1, Data from U.S. Navy (written commun., 1997); 2, Data from Haliburton NUS Corporation (1995), date of sample collection unknown; 3, data collected by the U.S. Geological Survey; J, concentrations are estimated; Jt, detected concentrations are estimated, sample receipt temperature colder than criteria; Js, detected concentrations are estimated, laboratory surrogate spike failure]

Well identification number	Date	Notes	Carbon tetra-chloride	1,1-Di-chloro-ethylene	1,2-Di-chloro-ethylene, total	Tetra-chloro-ethylene	Tri-chloro-ethylene	1,1,1-Trichloro-ethane	Trichloro-fluoro-methane
BK-1021	5-18-93	1	1.5	ND	2.8	ND	0.1	ND	--
	2-14-96	3	< 1.0	< 1.0	6.2	< 1.0	5.8	< 1.0	< 1.0
	10-04-96	3	< 1.0	< 1.0	7.5	< 1.0	8.8	< 1.0	< 1.0
BK-2767	6-08-93	1	ND	ND	36	ND	120	ND	--
	2-15-96	3	< 1.0	< 1.0	22	< 1.0	70	< 1.0	2.7
	10-07-96	3	< 2.0	< 2.0	22	< 2.0	67	< 2.0	< 2.0
BK-2768	2-20-96	3, Jt	< 1.0	< 1.0	1.8	< 1.0	3.5	< 1.0	< 1.0
	10-04-96	3	< 1.0	< 1.0	< 1.0	< 1.0	2.8	< 1.0	< 1.0
BK-2769	7-14-93	1	ND	21	2.0	720	8	33	--
	2-20-96	3, Jt	< 1.0	13	2.0	690	5.4	22	< 1.0
	10-09-96	3	< 25	< 25	< 25	630	< 25	< 25	< 25
BK-2770	6-09-93	1	ND	ND	ND	ND	ND	ND	--
	2-21-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
	10-02-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
BK-2788	6-07-93	1	ND	5.4	.6 J	440	2.0	16	--
	2-20-96	3, Jt	< 1.0	4.8	1.0	370	2.3	13	< 1.0
	10-09-96	3	< 12	< 12	< 12	330	< 12	< 12	< 12
BK-2789	5-18-93	1	ND	1.5	.4 J	57	.9 J	1.0	--
	2-15-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
	10-02-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
BK-2795	2-15-96	3	< 1.0	< 1.0	26	< 1.0	80	< 1.0	< 1.0
	10-07-96	3	< 2.0	< 2.0	27	< 2.0	75	< 2.0	< 2.0
BK-2796	5-17-93	1	ND	ND	3.0	ND	3.9	ND	--
	2-14-96	3	< 1.0	< 1.0	2.5	< 1.0	3.0	< 1.0	< 1.0
	10-03-96	3	< 1.0	< 1.0	2.1	< 1.0	2.8	< 1.0	< 1.0
BK-2797	6-21-93	1	ND	1.0	ND	ND	ND	2.0	--
BK-2797	2-13-96	3	< 1.0	3.5	< 1.0	< 1.0	< 1.0	1.5	< 1.0
	10-03-96	3	< 1.0	5.7	< 1.0	< 1.0	< 1.0	1.5	< 1.0
BK-2798	5-18-93	1	ND	ND	35	.1 J	8.9	.2 J	--
	2-13-96	3	< 1.0	< 1.0	25	< 1.0	56	< 1.0	< 1.0
	10-07-96	3	< 1.0	< 1.0	28	< 1.0	61	< 1.0	< 1.0
BK-2799	6-24-93	3	ND	ND	ND	1.0	1,200	ND	--
	3-1-96	3	< 25	< 25	190	< 25	450	< 25	< 25
	10-09-96	3	< 4.2	< 4.2	70	< 5.0	140	< 4.2	< 4.2

Table 3. *Summary of concentrations of selected volatile organic compounds in ground water, Casey Village area, Bucks County, Pennsylvania—Continued*

[Concentrations in micrograms per liter; <, less than; ND, not detected, detection limit not known; --, no data; Notes: 1, Data from U.S. Navy (written commun., 1997); 2, Data from Haliburton NUS Corporation (1995), date of sample collection unknown; 3, data collected by the U.S. Geological Survey; J, concentrations are estimated; Jt, detected concentrations are estimated, sample receipt temperature colder than criteria; Js, detected concentrations are estimated, laboratory surrogate spike failure]

Well identification number	Date	Notes	Carbon tetra-chloride	1,1-Di-chloro-ethylene	1,2-Di-chloro-ethylene, total	Tetra-chloro-ethylene	Tri-chloro-ethylene	1,1,1-Trichloro-ethane	Trichloro-fluoro-methane
BK-2800	5-17-93	1	ND	ND	ND	ND	64	ND	--
	10-07-96	3, Js	< 1.0	< 1.0	24	< 1.0	43	< 1.0	< 1.0
	2-21-96	3	< 1.0	< 1.0	33	< 1.0	38	< 1.0	< 1.0
HN-5-S	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-21-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-5-I	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-13-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-5-D	1994	2	2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-23-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-6-S	1994	2	< 1.0	< 1.0	< 1.0	9	< 1.0	< 1.0	--
	2-22-96	3	< 1.0	2.0	< 1.0	< 1.0	16	< 1.0	< 1.0
HN-6-I	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-22-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-6-D	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-22-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-7-S	1994	2	< 1.0	< 1.0	2.0	< 1.0	7.0	< 1.0	--
	2-27-96	3	< 1.0	< 1.0	1.5	< 1.0	5.4	1.1	< 1.0
HN-7-I	1994	2	< 1.0	< 1.0	1.0	< 1.0	8.0	< 1.0	--
HN-7-I	2-27-96	3	< 1.0	< 1.0	1.9	< 1.0	9.2	< 1.0	< 1.0
HN-7-D	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	4.0	< 1.0	--
	2-22-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-9-S	1994	2	9	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-20-96	3, Jt	9.4	< 1.0	1.5	< 1.0	2.2	< 1.0	< 1.0
HN-9-I	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-20-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-9-D	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	--
	2-20-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-49-S	1994	2	< 1.0	< 1.0	< 1.0	< 1.0	1.0	< 1.0	--
	2-28-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-49-I	1994	2	< 1.0	< 1.0	30	< 1.0	120	< 1.0	--
	2-28-96	3	<6.2	<6.2	31	<6.2	120	<6.2	<6.2
	10-01-96	3, Jt	< 3.6	< 3.6	38	< 3.6	120	< 3.6	3.7
HN-49-D	1994	2	< 1.0	< 1.0	2.0	< 1.0	7.0	< 1.0	--
	2-28-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HN-61-S	2-28-96	3	< 2.5	< 2.5	12	< 2.5	49	< 2.5	< 2.5
	10-01-96	Jt	< 1.9	< 1.9	16 Jt	< 1.9	55	< 1.9	2.8
HN-61-I	10-01-96	3	< 1.0	< 1.0	1.1	< 1.0	2.3	< 1.0	< 1.0
HN-62-S	2-28-96	3	11	< 1.0	< 1.0	< 1.0	1.2	< 1.0	< 1.0
HN-62-I	2-27-96	3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

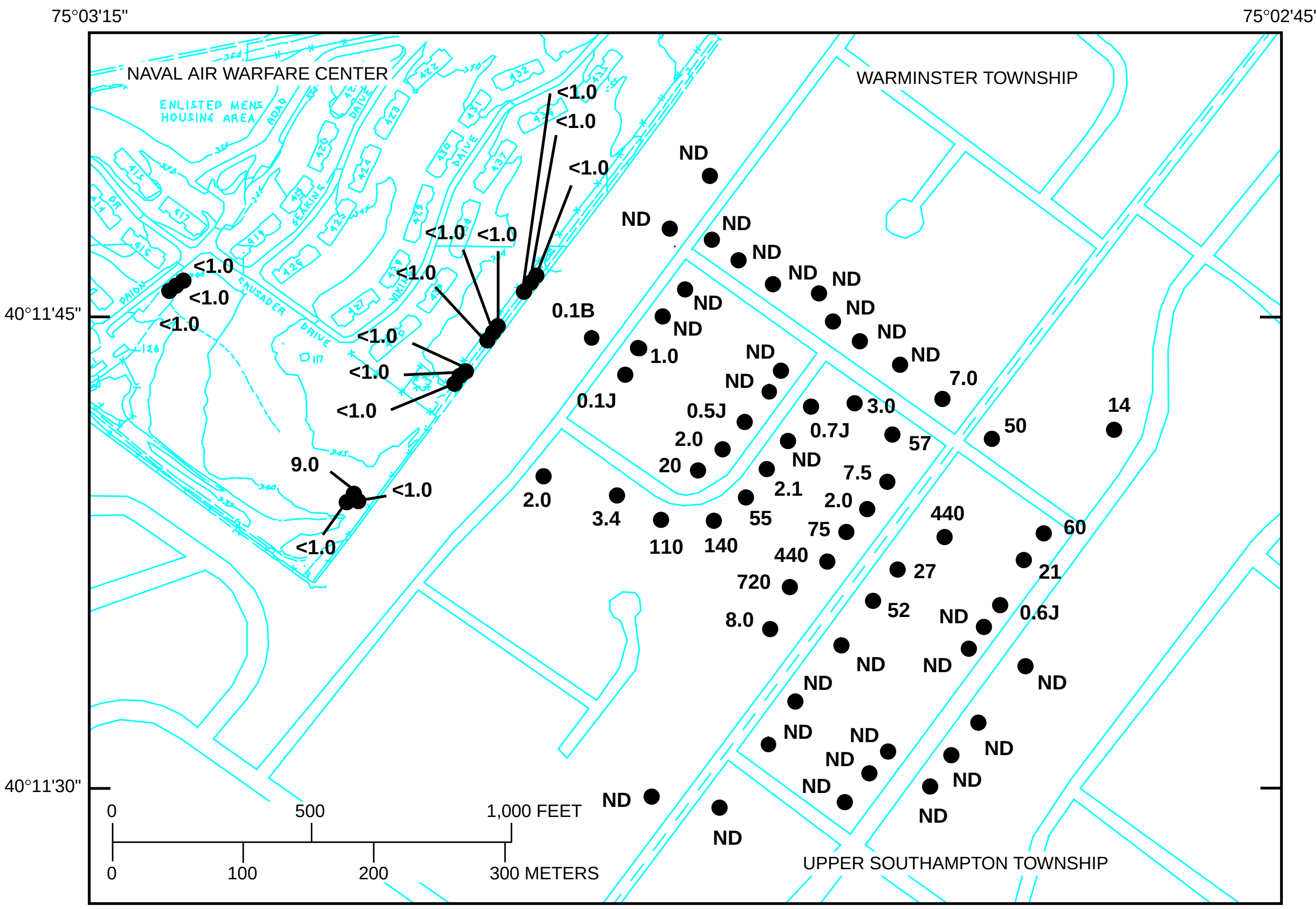


Base provided by Brown and Root Environmental, Inc.

EXPLANATION

● 89 WELL LOCATION AND CONCENTRATION OF TRICHLOROETHYLENE FOR MAY-JULY 1993 (CASEY VILLAGE) AND 1994 (NAWC)—Well locations are approximate. Concentrations in micrograms per liter. ND, not detected, detection limit not known; <, less than; J, estimated concentration

Figure 38. Concentrations of trichloroethylene in ground water, 1993-94, Casey Village area, Bucks County, Pennsylvania. Data from U.S. Navy (written commun., 1997) and Haliburton NUS Corporation (1995).

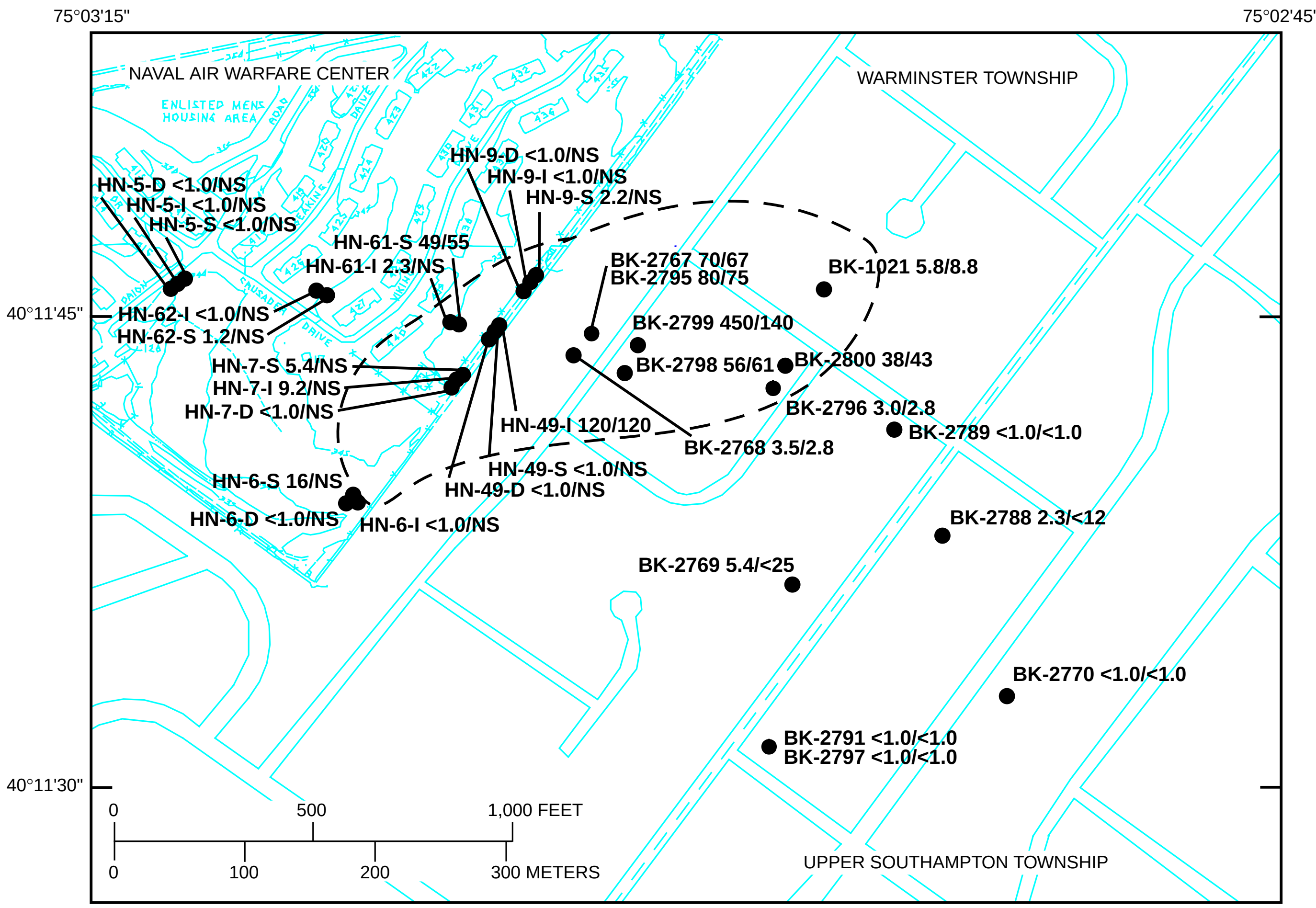


Base provided by Brown and Root Environmental, Inc.

EXPLANATION

● **720** WELL LOCATION AND CONCENTRATION OF TETRACHLOROETHYLENE FOR MAY-JULY 1993 (CASEY VILLAGE) AND 1994 (NAWC)—Well locations are approximate. Concentrations in micrograms per liter. ND, not detected, detection limit not known; <, less than; J, estimated concentration

Figure 39. Concentrations of tetrachloroethylene in ground water, 1993-94, Casey Village area, Bucks County, Pennsylvania. Data from U.S. Navy (written commun., 1997) and Haliburton NUS Corporation (1995).



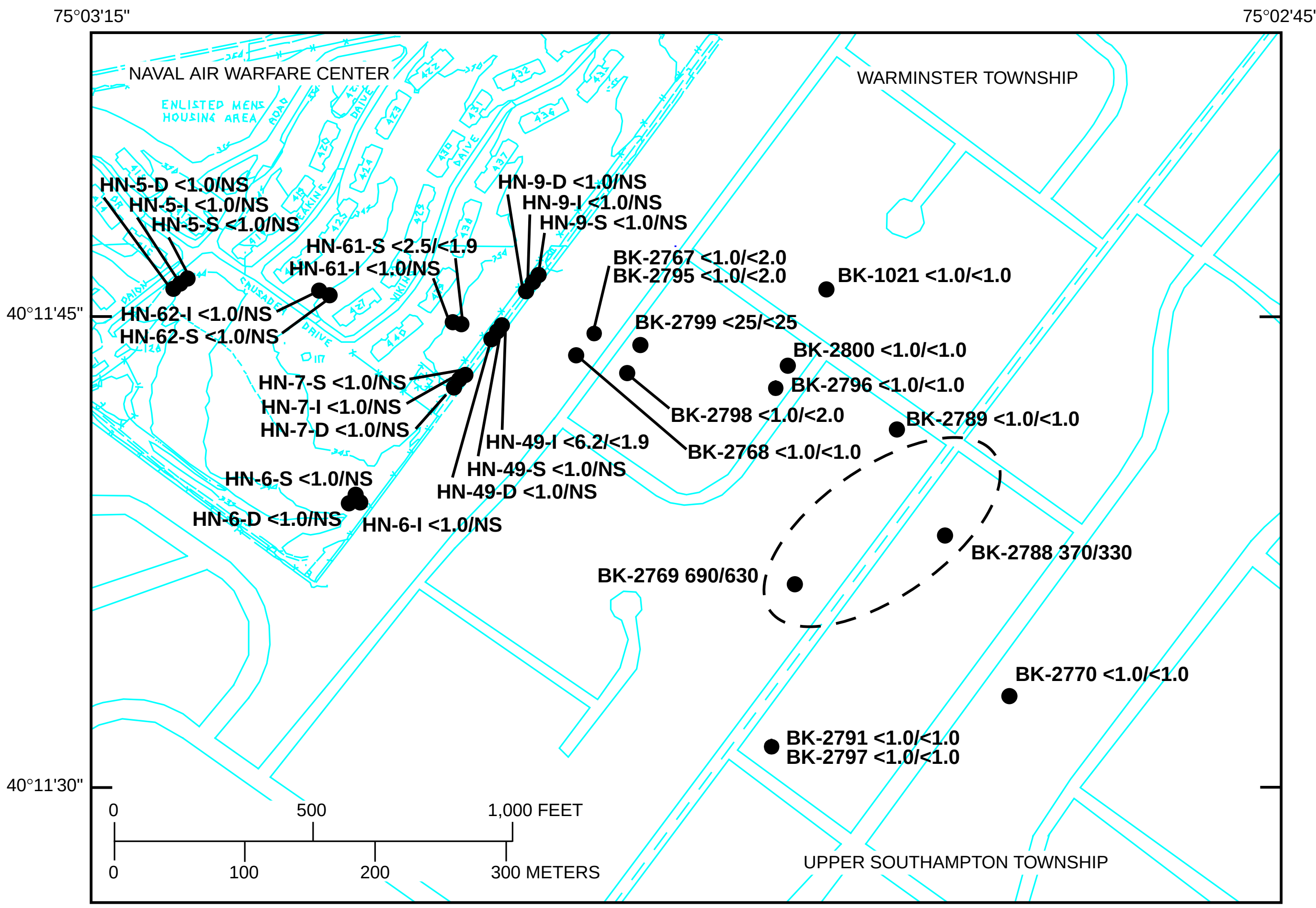
Base provided by Brown and Root Environmental, Inc.

EXPLANATION

BK-2800 38/43 ● WELL LOCATION AND CONCENTRATION OF TRICHLOROETHYLENE—First number is concentration for February-March 1996. Second number is concentration for October 1996. Concentrations in micrograms per liter. NS, not sampled in October 1996. <, less than

– — — – APPROXIMATE AREA OF ELEVATED TRICHLOROETHYLENE CONCENTRATIONS

Figure 40. Concentrations of trichloroethylene in ground water, February-March and October 1996, Casey Village area, Bucks County, Pennsylvania.



Base provided by Brown and Root Environmental, Inc.

EXPLANATION

BK-2769 690/630 ● WELL LOCATION AND CONCENTRATION OF TETRACHLOROETHYLENE—First number is concentrations for February-March 1996. Second number is concentration for October 1996. Concentrations in micrograms per liter. NS, not sampled in October 1996. <, less than

– — — – APPROXIMATE AREA OF ELEVATED TETRACHLOROETHYLENE CONCENTRATIONS

Figure 41. Concentrations of tetrachloroethylene in ground water, February-March and October 1996, Casey Village area, Bucks County, Pennsylvania.

Temporal Distribution

Between 1993 and 1996, the PCE concentration in water samples collected from wells in Casey Village decreased only slightly (table 3). Between June 1993 and October 1996, the concentration of PCE in water from wells BK-2769 and BK-2788 decreased from 720 to 630 µg/L and from 440 to 330 µg/L, respectively. Between June 1993 and October 1996, the concentration of PCE in water from well BK-2789 decreased from 57 µg/L to less than 1 µg/L; however, the decrease may be a consequence of well reconstruction. When well BK-2789 was reconstructed as a monitor well, the screened water-bearing fracture may not have been the one producing water with detectable concentrations of PCE.

Between 1993 and 1996, the TCE concentration in water samples collected from wells in Casey Village decreased (table 3). Water samples collected in Casey Village in 1993 mostly were from active domestic wells; in 1996, water samples were collected about 2 to 3 years after the cessation of pumping. This suggests that pumping of domestic wells may have contributed to TCE migration. The estimated ground-water pumpage for the 50 residences in Casey Village adjacent to the NAWC is 8,300 gal/d, assuming 2.9 people per house (Bucks County Planning Commission, 1993) and an average per capita water use of 57 gal/d (Bucks County Planning Commission, 1992).

The concentration of TCE in water from well BK-2799 decreased an order of magnitude, from 1,200 µg/L in June 1993 when domestic wells were pumping in Casey Village, to 140 µg/L in October 1996, approximately 3 years after cessation of domestic pumping. Concentrations of TCE in water from other wells decreased less dramatically from 1993 to 1996. Upward flow was measured in well BK-2799 during geophysical logging. If the primary source of TCE to the well was from shallow fractures, upward flow of less contaminated water could be flushing TCE from the immediate vicinity of well BK-2799.

Concentrations of TCE in water samples collected from wells in Casey Village in October 1996 were approximately the same as concentrations in water samples collected in February 1996. TCE concentrations in water samples collected from some wells decreased slightly, while TCE concentrations in water samples collected from other wells increased slightly (table 3).

Concentrations of TCE in water samples collected from wells on the adjoining part of the NAWC in 1994 and 1996 also were compared. The concentration of TCE in water samples from some wells increased, while the concentration in water samples from other wells decreased. Analyses of water from well HN-49-I by the USGS and the U.S. Navy show a consistent concentration of 120 µg/L in 1994 and 1996.

Change in Trichloroethylene Concentration with Pumping

On October 23-24, 1996, an aquifer-isolation test, commonly known as a packer test, was conducted in well BK-2799. The objective of the test was to isolate discrete fractures for collection of water samples for laboratory VOC analysis. Five intervals (table 4) were isolated by use of a straddle packer assembly (fig. 5).

Concentrations of TCE and 1,2-dichloroethylene (DCE) in water samples from the isolated intervals were similar (table 4). However, VOC concentrations were slightly lower in the deeper isolated zones (zones 1, 2, and 3) than in the shallower isolated zones (zones 4 and 5). The concentration of TCE in water samples from zones 1, 2, and 3 ranged from 88 to 120 µg/L; concentrations of TCE were 140 and 150 µg/L for zones 4 and 5, respectively (fig. 42). This may indicate a shallow source for TCE with upward flow of less

Table 4. *Intervals isolated in well BK-2799, Casey Village, Bucks County, Pennsylvania*

[--, no data, packer not inflated]

Zone	Depth of zone (feet below land surface)	Duration of pumping (minutes)	Average pumping rate (gallons per minute)	Maximum drawdown (feet)			Concentration (micrograms per liter)	
				Above isolated zone	In isolated zone	Below isolated zone	Trichloro-ethylene	1,2-Dichloro-ethylene
1	100-106	26	2.5	17.49	18.69	--	110	50
2	91-100.5	35	3.3	16.34	31.79	17.58	120	56
1 and 2	91-106	91	1.8	28.25	27.82	--	88	40
3	84-93.5	50	3.7	27.95	28.54	27.62	110	51
4	78-87.5	49	3.3	23.22	30.75	30.59	140	62
5	0-60	34	2.5	--	12.90	11.31	150	70

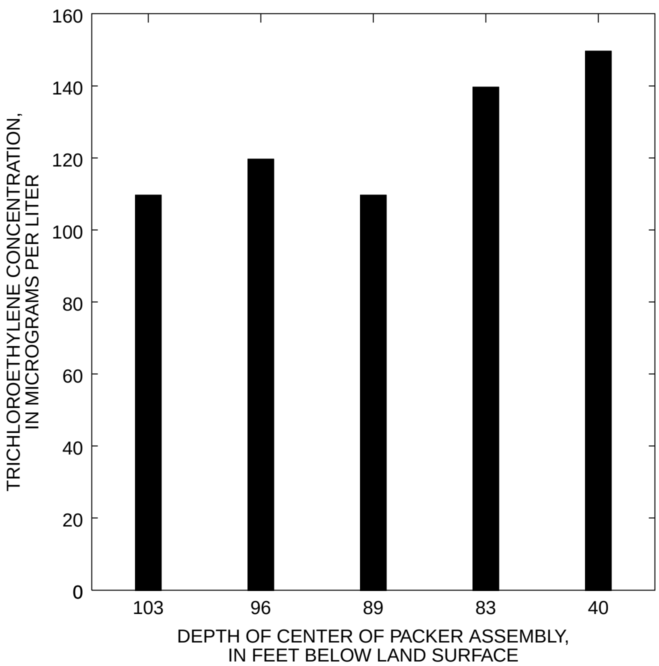


Figure 42. Concentration of trichloroethylene in water samples from well BK-2799 collected during aquifer-isolation tests, October 23-24, 1996, Casey Village, Bucks County, Pennsylvania.

contaminated water flushing TCE from the immediate vicinity of the well. This may help explain why the concentration of TCE in water from well BK-2799 decreased an order of magnitude between 1993 and 1996.

VOC concentrations increased with pumping time during the aquifer test, which was conducted 4 days after the aquifer-isolation test. Water samples were collected for VOC analysis after 1, 3, and 5 hours of pumping. The concentration of TCE increased from 120 µg/L after 1 hour of pumping to 180 µg/L after 5 hours of pumping (Appendix 2).

SUMMARY

Casey Village and the adjacent NAWC are underlain by the Stockton Formation. A generalized lithostratigraphic model of the Casey Village area developed from natural-gamma borehole geophysical logs shows that the area is underlain by an alternating series of siltstones and sandstones. Within the Stockton Formation, water moves through a network of interconnecting secondary openings—fractures, bedding planes, and joints. Nearly all deep, open-hole wells in the Stockton Formation are open to several water-bearing zones. Each water-bearing zone usually has a different hydraulic head. This causes water levels in adjacent wells completed at different depths to be different. Where differences in hydraulic head exist between water-bearing zones, water in the well bore flows vertically under nonpumping conditions in the direction of decreasing head. The direction of vertical ground-water gradients varies among well locations and sometimes with time. A consistent downward gradient was measured in seven wells or clusters, an upward gradient was measured in two wells, and both upward and downward gradients were measured in four well clusters. Vertical gradients can be substantial. Well pair BK-2791/BK-2797 screens water-bearing fractures at 20-22 and 52-54 ft bls, respectively. The difference in head was 7.1 ft over a 32-ft vertical section of the aquifer on February 15, 1996.

Potentiometric-surface maps were constructed for the Casey Village area for August 3, 1995, February 15, 1996, and October 7, 1996, to show horizontal ground-water-flow gradients. A ground-water divide that bisects the Casey Village area is evident on the potentiometric surface in wells screened between 18 and 64 ft bls. The ground-water divide coincides approximately with the surface-water drainage divide between Mill Creek and Southampton Creek. On the east side of the divide (towards Mill Creek), the general ground-water gradient is to the east and northeast. On the west side of the divide (towards Southampton Creek), the general ground-water gradient is to the southwest. The location of the ground-water divide on the potentiometric surface of wells screened between 48 and 106 ft bls is not obvious but is probably in nearly the same location as the shallower zone. On the east side of the divide (towards Mill Creek), the general ground-water gradient is to the northeast. On the west side of the divide (towards Southampton Creek), the general ground-water gradient is to the southwest and northwest.

An aquifer test showed that pumping well BK-2799 caused drawdown in wells on the opposite side of the ground-water divide on the NAWC. Drawdown measured in wells screened below 53 ft bls on the opposite side of the ground-water divide from the pumped well indicates that pumping shifted the ground-water divide in the deeper potentiometric surface to the west. No drawdown was measured in wells at the NAWC that were screened above 53 ft bls.

Drawdowns form an elliptical pattern indicating anisotropy; however, anisotropy is not aligned with strike or dip. Hydraulic stress caused by pumping crosses stratigraphic boundaries. In general, drawdown was greatest for wells screened in unit B;

however, drawdown also was greatest for wells screened in unit C where it is present at the same altitude as unit B. Wells screened between 55 and 106 ft bls fall in this horizon. When drawdown for these wells is plotted without regard to geologic unit, it forms an elliptical pattern oriented N. 75° W. It appears that the response to pumping is controlled as much or more by depth of water-bearing zones below land surface than by geologic unit.

Between 1993 and 1996, the concentration of TCE in water samples collected from wells in Casey Village decreased. The highest concentration of TCE in water samples collected by the U.S. Navy from Casey Village in 1993 was 1,200 µg/L in water from well BK-2799. The highest concentrations of TCE in water samples collected by the USGS in 1996 was 450 and 140 µg/L in water from well BK-2799 in March and October, respectively. Water samples collected in Casey Village in 1993 mostly were from active domestic wells; in 1996, water samples were collected about 2 to 3 years after the cessation of domestic pumping. This suggests that pumping of domestic wells may have contributed to TCE migration. Vertical movement of TCE and PCE also may have taken place through the open-hole domestic wells in Casey Village prior to the installation of public water.

Between 1993 and 1996, the PCE concentration in water samples collected from wells in Casey Village decreased only slightly. The highest concentration of PCE in water samples collected by the U.S. Navy from Casey Village in 1993 was 720 µg/L in water from well BK-2769. The highest concentrations of PCE in water samples collected by the USGS in 1996 were 690 and 630 µg/L in water from well BK-2769 in February and October, respectively.

The distribution of TCE and PCE in ground water indicates the presence of separate PCE and TCE plumes, each with a different source area. The TCE plume appears to be moving in two directions away from the ground-water divide area. The pumping of well BK-2767 may have caused TCE migration into the ground-water divide area. From the divide area, the TCE plume appears to be moving both to the east and the west under the natural hydraulic gradient.

Aquifer-isolation tests conducted in well BK-2799 isolated five intervals by use of a straddle packer assembly. Concentrations of TCE and DCE in water samples from the isolated intervals were similar; however, VOC concentrations were slightly lower in the deeper isolated zones than in the shallower isolated zones. Upward flow was measured in well BK-2977 during geophysical logging. If the source of TCE to the well was from shallow fractures, upward flow of less contaminated water could be flushing TCE from the immediate vicinity of well BK-2799.

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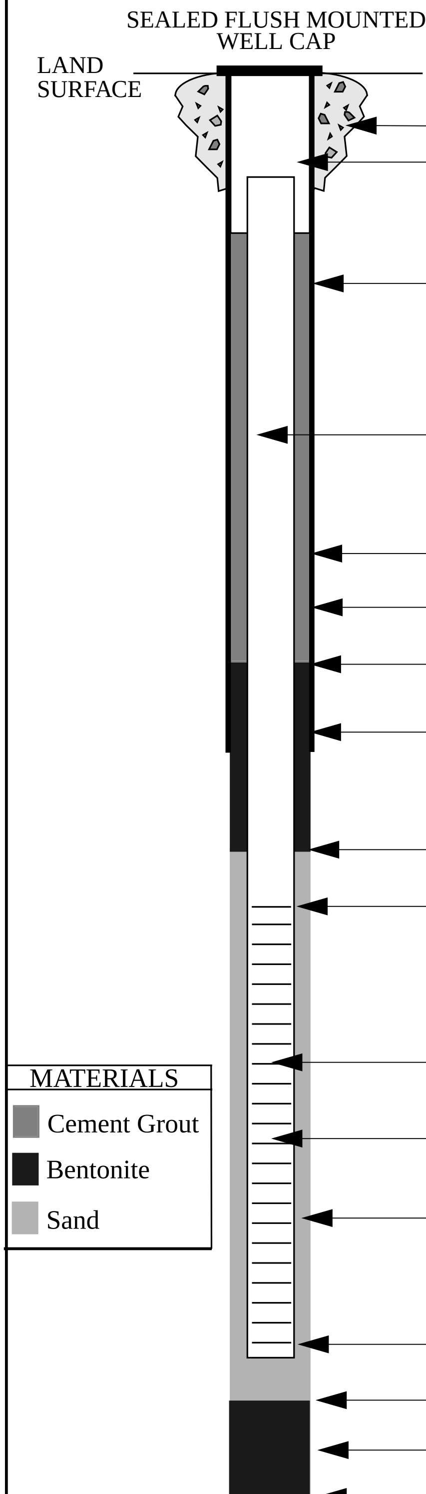
APPENDIX 1—CONSTRUCTION DIAGRAMS FOR MONITOR WELLS IN CASEY VILLAGE, BUCKS COUNTY, PENNSYLVANIA

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-1021
Date 6/8/95 **Hydrologist** Conger

ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE



TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	353.69
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	38’
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	50’
DEPTH OF SCREEN TOP	52’
LENGTH OF SCREEN	10’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	62’
DEPTH OF FILTER PACK BOTTOM	64’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	104’

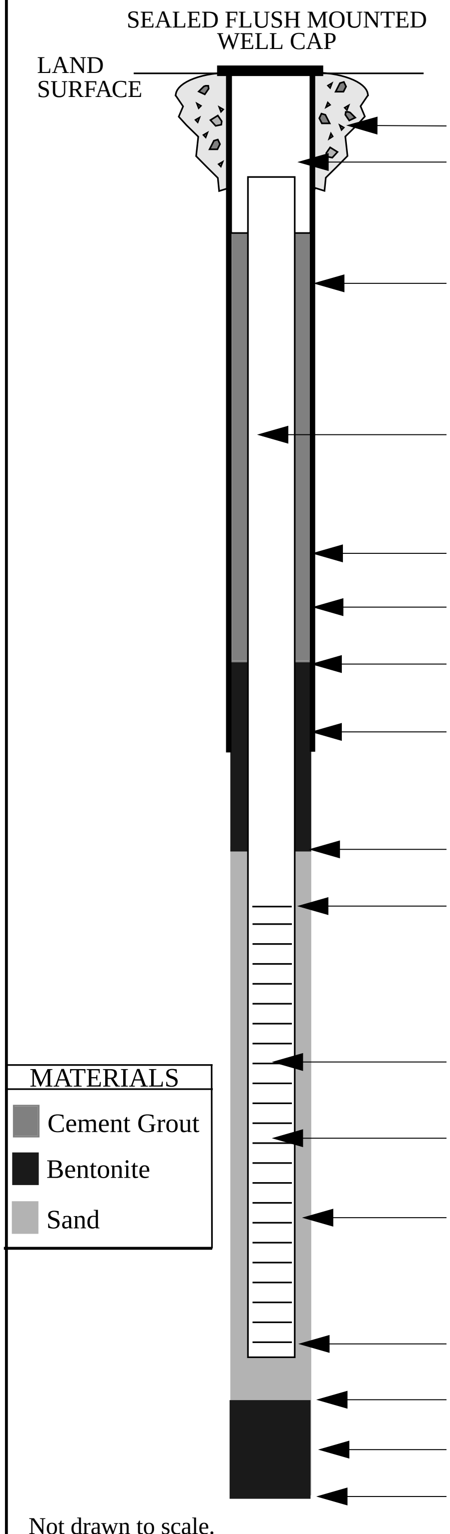
Not drawn to scale.

Figure 1. Construction diagram for monitor well BK-1021, Casey Village, Bucks County, Pennsylvania.

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-2768
Date 6/8/95 **Hydrologist** Conger

ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE



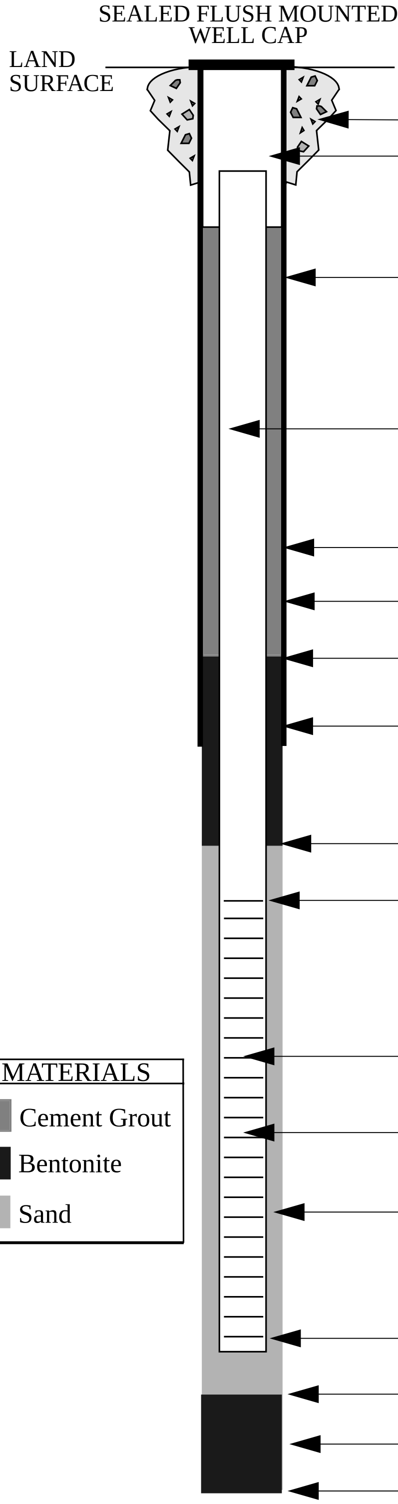
TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	354.68
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	23’
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	28’
DEPTH OF SCREEN TOP	30’
LENGTH OF SCREEN	10’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	40’
DEPTH OF FILTER PACK BOTTOM	42’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	111’

Figure 2. Construction diagram for monitor well BK-2768, Casey Village, Bucks County, Pennsylvania.

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-2769
Date 6/8/95 **Hydrologist** Conger

ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE



TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	355.19
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	35’
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	40’
DEPTH OF SCREEN TOP	42’
LENGTH OF SCREEN	15’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	57’
DEPTH OF FILTER PACK BOTTOM	59’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	89’

MATERIALS
- Cement Grout
- Bentonite
- Sand

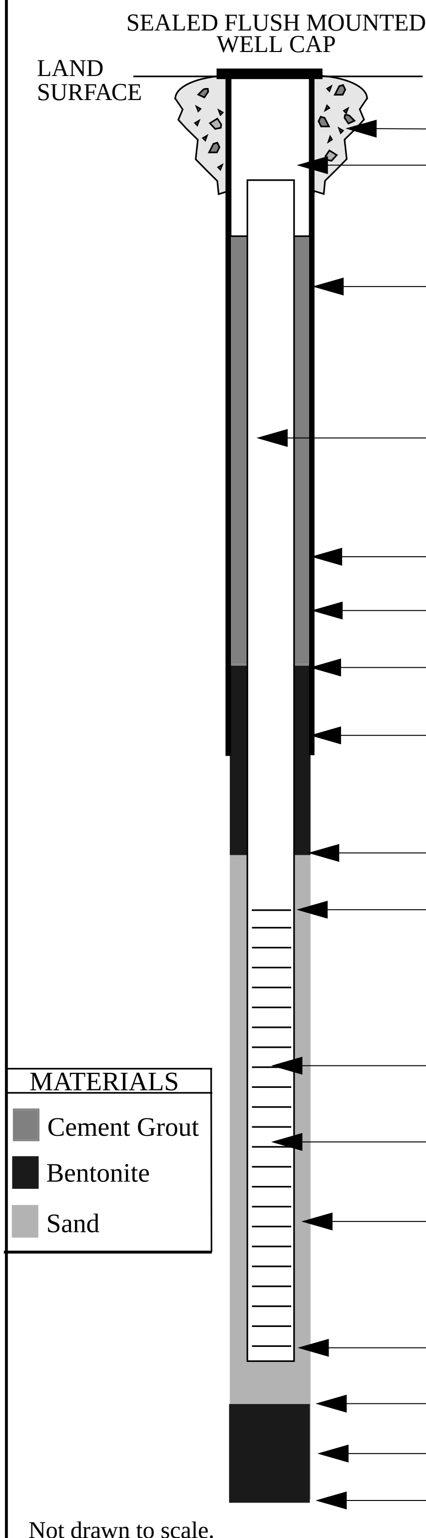
Not drawn to scale.

Figure 3. Construction diagram for monitor well BK-2769, Casey Village, Bucks County, Pennsylvania.

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-2770
Date 6/8/95 **Hydrologist** Conger

ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE



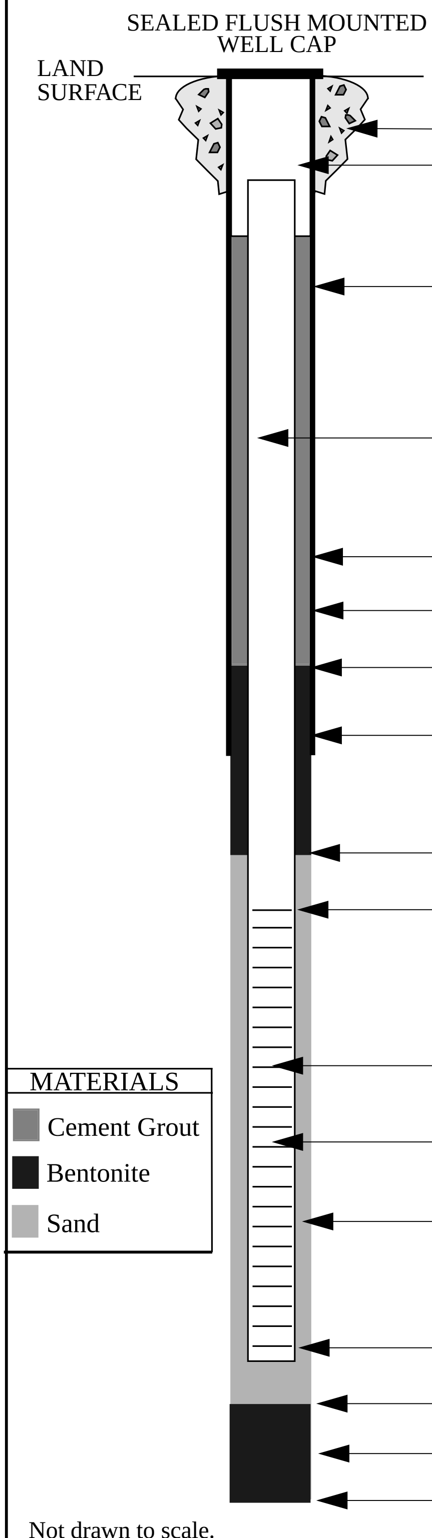
TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	359.25
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	21’
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	26’
DEPTH OF SCREEN TOP	28’
LENGTH OF SCREEN	10’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	38’
DEPTH OF FILTER PACK BOTTOM	39’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	40’

Figure 4. Construction diagram for monitor well BK-2770, Casey Village, Bucks County, Pennsylvania.

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-2788
Date 6/8/95 **Hydrologist** Conger

ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE

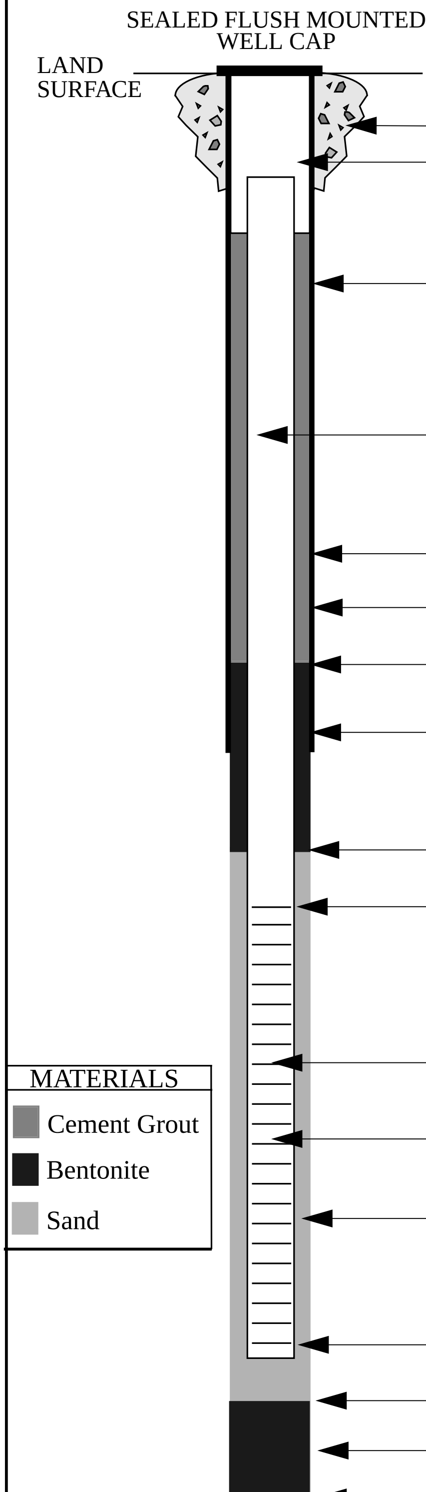


TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	347.15
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	13‘
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	18’
DEPTH OF SCREEN TOP	20’
LENGTH OF SCREEN	10’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	30’
DEPTH OF FILTER PACK BOTTOM	32’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	68’

Figure 5. Construction diagram for monitor well BK-2788, Casey Village, Bucks County, Pennsylvania.

U. S. Geological Survey
Monitor Well
Construction Diagram

Project Casey Village
Well Number: USGS BK-2789
Date 7/2/95 **Hydrologist** Conger



ALL DEPTHS GIVEN IN FEET BELOW LAND SURFACE

TYPE OF SURFACE SEAL	None
ELEVATION OF TOP OF RISER PIPE (MEASURING POINT)	344.36
SURFACE CASING DIAMETER	6”
TYPE OF SURFACE CASING	Steel
RISER PIPE DIAMETER	2”
RISER PIPE MATERIAL	PVC
BOREHOLE DIAMETER	6”
BACKFILL MATERIAL	Cement Grout
DEPTH OF TOP OF SEAL	25’
TYPE OF SEAL	Bentonite
DEPTH OF TOP OF FILTER PACK	30’
DEPTH OF SCREEN TOP	32’
LENGTH OF SCREEN	20’
TYPE OF SCREEN	Slotted PVC
SCREEN DIAMETER	2”
TYPE OF FILTER PACK	Sand
DEPTH OF SCREEN BOTTOM	52’
DEPTH OF FILTER PACK BOTTOM	54’
BACKFILL MATERIAL	Bentonite
DEPTH OF HOLE	78’

Not drawn to scale.

Figure 6. Construction diagram for monitor well BK-2789, Casey Village, Bucks County, Pennsylvania.

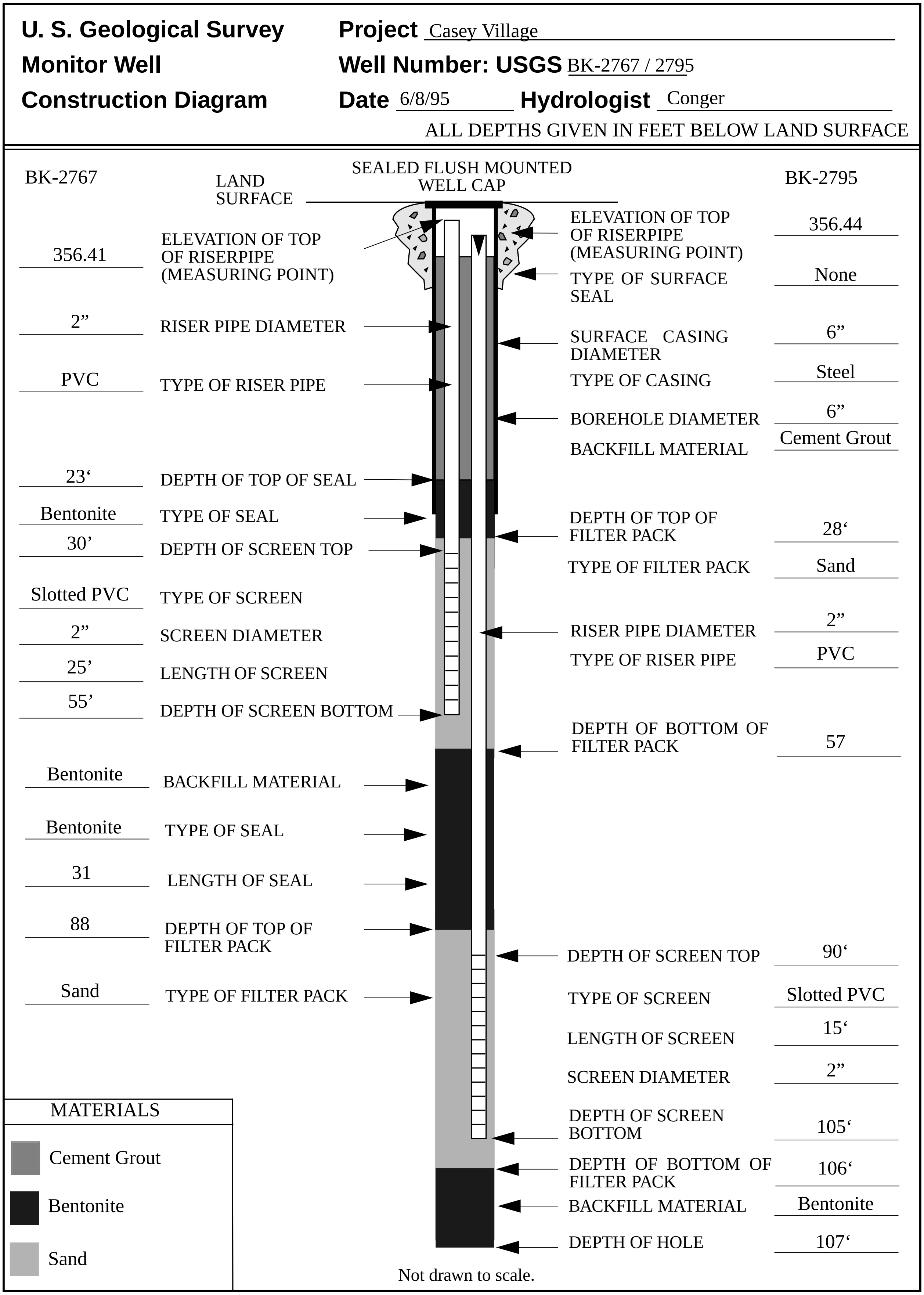


Figure 7. Construction diagram for monitor wells BK-2767 and BK-2795, Casey Village, Bucks County, Pennsylvania.

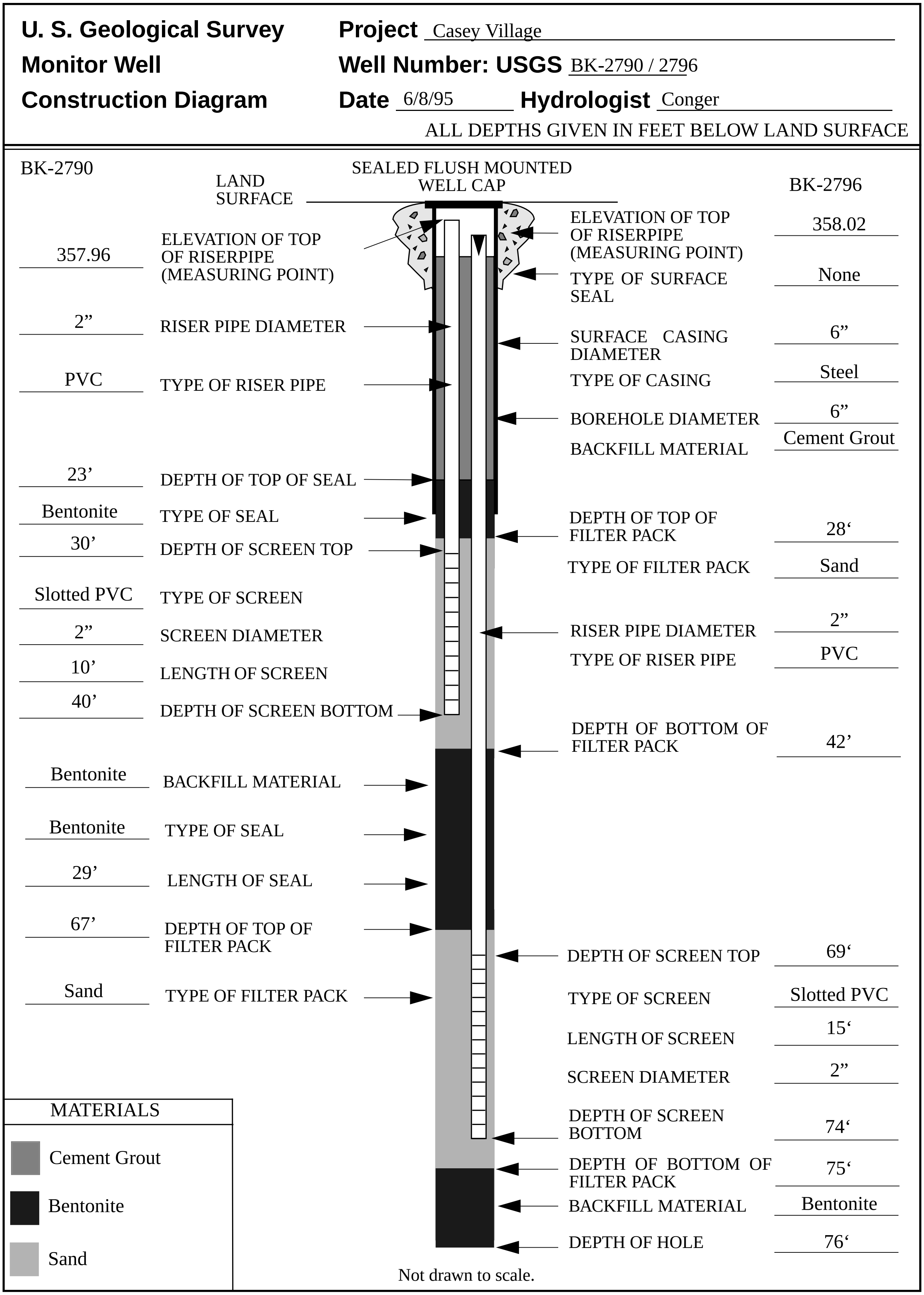


Figure 8. Construction diagram for monitor wells BK-2790 and BK-2796, Casey Village, Bucks County, Pennsylvania.

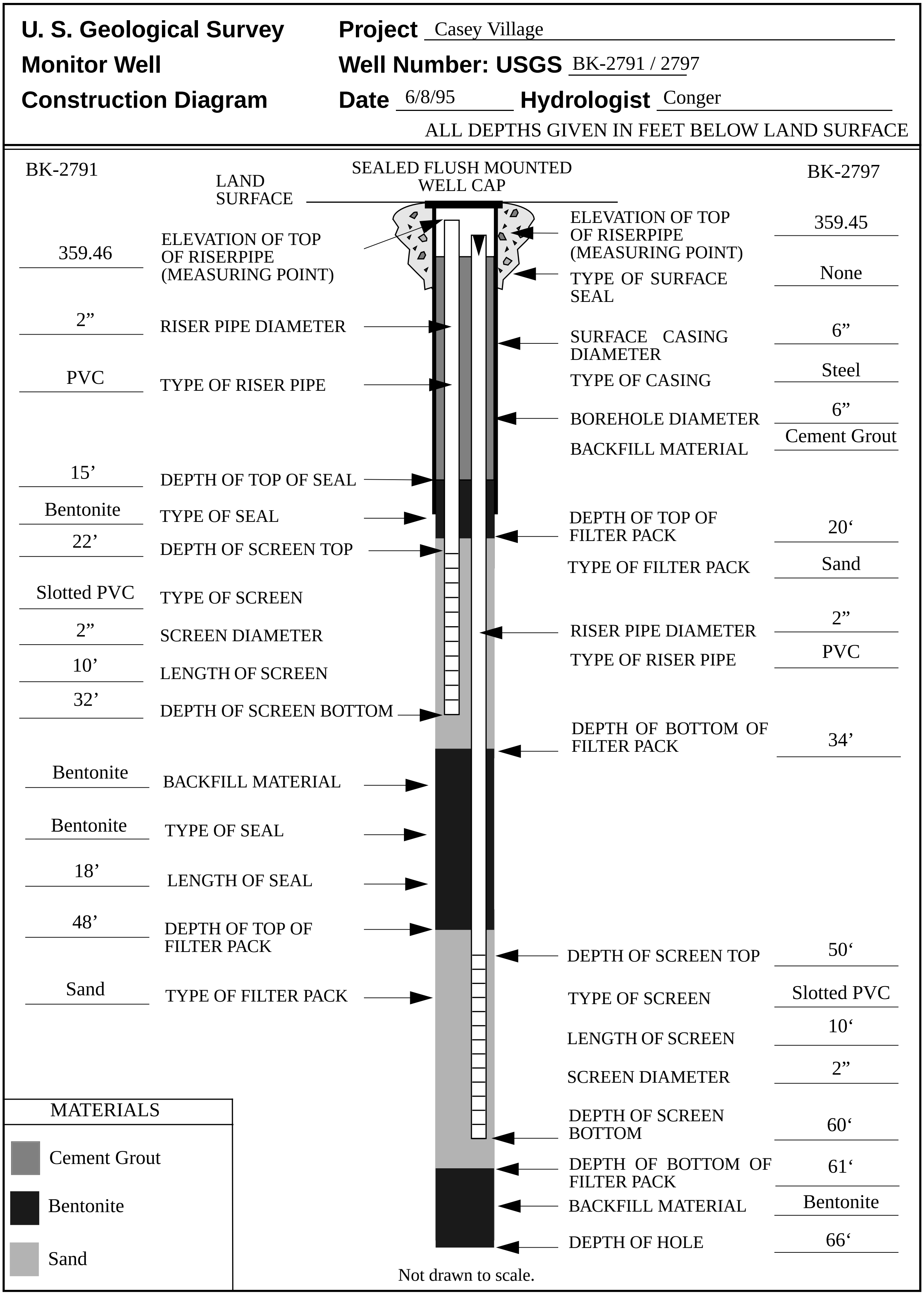


Figure 9. Construction diagram for monitor wells BK-2791 and BK-2797, Casey Village, Bucks County, Pennsylvania.

APPENDIX 2—RESULTS OF CHEMICAL ANALYSES FOR VOLATILE ORGANIC COMPOUNDS IN GROUND WATER, FEBRUARY AND OCTOBER 1996, CASEY VILLAGE AREA, BUCKS COUNTY, PENNSYLVANIA

[Concentrations given in micrograms per liter; < less than; UJ, compound not detected, detection limit may be inaccurate or imprecise, reason denoted by accompanying lowercase letter; J, estimated value, reason denoted by accompanying lowercase letter; R, value is qualitatively or quantitatively unreliable because of lab calibration problems; c, laboratory calibration failure; t, sample temperature upon receipt by laboratory less than 4 degrees Celsius; s, laboratory surrogate spike failure; y, lab blank contamination]

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Acetone	Benzene	Bromo-dichloro-methane	Bromo-form	Bromo-methane	2-Butanone	Carbon disulfide	Carbon tetra-chloride
BK-1021			2-14-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-04-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2767			2-15-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-07-96	<20 UJc	<2.0	<2.0	<2.0	<2.0	<20	<2.0	<2.0
BK-2768			2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 Rt	<1.0 UJt	<1.0 UJt
			10-04-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2769			2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 Rt	<1.0 UJt	<1.0 UJt
		Duplicate	2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 Rt	<1.0 UJt	<1.0 UJt
			10-09-96	<250 UJc	<25	<25	<25	<25	<250	<25	<25
		Duplicate	10-09-96	<250 UJc	<25	<25	<25	<25	<250	<25	<25
BK-2770			2-21-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-02-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2788			2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 Rt	<1.0 UJt	<1.0 UJt
			10-09-96	<120 UJc	<12	<12	<12	<12	<120	<12	<12
BK-2789			2-15-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-02-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2791			2-13-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-03-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2795			2-15-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-07-96	<20 UJc	<2.0	<2.0	<2.0	<2.0	<20	<2.0	<2.0
BK-2796			2-14-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-03-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2797			2-13-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-03-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2798			2-13-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
			10-07-96	<20 UJc	<2.0	<2.0	<2.0	<2.0	<20	<2.0	<2.0
BK-2799			3-01-96	<250	<25	<25	<25	<25	<250 R	<25	<25
		Duplicate	3-01-96	<250	<25	<25	<25	<25	<250 R	<25	<25
			10-09-96	<50 UJc	<5.0	<5.0	<5.0	<5.0	<50	<5.0	<5.0
		Duplicate	10-09-96	<50 UJc	<5.0	<5.0	<5.0	<5.0	<50	<5.0	<5.0
		Packer test zones 1 and 2	10-23-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 2	10-23-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 2 duplicate	10-23-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 3	10-24-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 4	10-24-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Acetone	Benzene	Bromo-dichloro-methane	Bromo-form	Bromo-methane	2-Butanone	Carbon disulfide	Carbon tetra-chloride
BK-2799		Packer test zone 5	10-24-96	<50	<5.0	<5.0	<5.0	<5.0	<50	<5.0	<5.0
		Packer test zone 1	10-24-96	<25	<2.5	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Aquifer test after 1 hour	10-28-96	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 3 hours	10-28-96	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 5 hours	10-28-96	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
BK-2800			2-21-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-07-96	<10 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<10 UJs	<1.0 UJs	<1.0 UJs
BK-2544	HN-5-S		2-21-96	<10 UJc	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2542	HN-5-I		2-13-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
BK-2543	HN-5-D		2-23-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2547	HN-6-S		2-22-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2546	HN-6-I		2-22-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2545	HN-6-D		2-22-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2550	HN-7-S		2-27-96	<10	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2544	HN-7-I		2-27-96	<10	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
		Duplicate	2-27-96	<10	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2548	HN-7-D		2-22-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2556	HN-9-S		2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 R	<1.0 UJt	9.4 Jt
BK-2555	HN-9-I		2-20-96	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 R	<1.0 UJt	<1.0 UJt
BK-2554	HN-9-D		2-23-96	<10 R	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2670	HN-49-S		2-28-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
BK-2671	HN-49-I		2-28-96	<62	<6.2	<6.2	<6.2	<6.2	<62 R	<6.2	<1.0
		Duplicate	2-28-96	<62	<6.2	<6.2	<6.2	<6.2	<62 R	<6.2	<1.0
			10-01-96	<36 UJc	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt
		Duplicate	10-01-96	<36 UJc	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt
BK-2672	HN-49-D		2-28-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
BK-2830	HN-61-S		2-28-96	<25	<2.5	<2.5	<2.5	<2.5	<25 R	<2.5	<2.5
			10-01-96	<19 UJc	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<19 UJt	<1.9 UJt	<1.9 UJt
BK-2831	HN-61-I		2-28-96	<10	<1.0	<1.0	<1.0	<1.0	<10 R	<1.0	<1.0
BK-2828	HN-62-S		2-27-96	<10	<1.0	<1.0	<1.0	<1.0	<10	<1.0	11
BK-2829	HN-62-I		2-27-96	<10	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Chloro-benzene	Chloro-ethane	2-Chloro-ethyl vinyl ether	Chloro-form	Chloro-methane	Dibromo-chloro-methane	1,2-Dichloro-benzene	1,3-Dichloro-benzene	1,4-Dichloro-benzene
BK-1021			2-14-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-04-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2767			2-15-96	<1.0	<1.0	<1.0 R	<0.5	<1.0	<1.0	<1.0	<1.0	<0.5
			10-07-96	<2.0	<2.0	<2.0 R	<1.0	<2.0	<2.0	<2.0	<2.0	<1.0
BK-2768			2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	<.5 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
			10-04-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2769			2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	<.5 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
		Duplicate	2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	<.5 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
			10-09-96	<25	<25	<25 R	<12	<25	<25	<25	<25	<12
		Duplicate	10-09-96	<25	<25	<25 R	<12	<25	<25	<25	<25	<12
BK-2770			2-21-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-02-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2788			2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	<.5 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
			10-09-96	<12	<12	<12 R	<6.2	<12	<12	<12	<12	<6.2
BK-2789			2-15-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-02-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2791			2-13-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-03-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2795			2-15-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-07-96	<2.0	<2.0	<2.0 R	<.5	<2.0	<2.0	<2.0	<2.0	<.5
BK-2796			2-14-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-03-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2797			2-13-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-03-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2798			2-13-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-07-96	<2.0	<2.0	<2.0 R	<1.0	<2.0	<2.0	<2.0	<2.0	<1.0
BK-2799			3-01-96	<25	<25	<25	<12	<25	<25	<25	<25	<12
		Duplicate	3-01-96	<25	<25	<25	<12	<25	<25	<25	<25	<12
			10-09-96	<5.0	<5.0	<5.0 R	<2.5	<5.0	<5.0	<5.0	<5.0	<2.5
		Duplicate	10-09-96	<4.2	<4.2	<4.2 R	<2.1	<4.2	<4.2	<4.2	<4.2	<2.1
		Packer test zones 1 and 2	10-23-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
		Packer test zone 2	10-23-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
		Packer test zone 2 duplicate	10-23-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
		Packer test zone 3	10-24-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
		Packer test zone 4	10-24-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Chloro-benzene	Chloro-ethane	2-Chloro-ethyl vinyl ether	Chloro-form	Chloro-methane	Dibromo-chloro-methane	1,2-Dichloro-benzene	1,3-Dichloro-benzene	1,4-Dichloro-benzene
BK-2799		Packer test zone 5	10-24-96	<5.0	<5.0	<5.0 R	<2.5	<5.0	<5.0	<5.0	<5.0	<2.5
		Packer test zone 1	10-24-96	<2.5	<2.5	<2.5 R	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
		Aquifer test after 1 hour	10-28-96	<5.0 UJt	<5.0 UJt	<5.0 R	<2.5 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<2.5 UJt
		Aquifer test after 3 hours	10-28-96	<5.0 UJt	<5.0 UJt	<5.0 R	<2.5 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<2.5 UJt
		Aquifer test after 5 hours	10-28-96	<5.0 UJt	<5.0 UJt	<5.0 R	<2.5 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<2.5 UJt
BK-2800			2-21-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
			10-07-96	<1.0 UJs	<1.0 UJs	<1.0 Rs	<.5 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<.5 UJs
BK-2544	HN-5-S		2-21-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2542	HN-5-I		2-13-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2543	HN-5-D		2-23-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2547	HN-6-S		2-22-96	<1.0 R	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2546	HN-6-I		2-22-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2545	HN-6-D		2-22-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2550	HN-7-S		2-27-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2544	HN-7-I		2-27-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
		Duplicate	2-27-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2548	HN-7-D		2-22-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2556	HN-9-S		2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	.83 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
BK-2555	HN-9-I		2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Rt	<.5 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<.5 UJt
BK-2554	HN-9-D		2-23-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2670	HN-49-S		2-28-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2671	HN-49-I		2-28-96	<6.2	<6.2	<6.2	<3.1	<6.2	<6.2	<6.2	<6.2	<3.1
		Duplicate	2-28-96	<6.2	<6.2	<6.2	<3.1	<6.2	<6.2	<6.2	<6.2	<3.1
			10-01-96	<3.6 UJt	<3.6 UJt	<3.6 R	<1.8 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<1.8 UJt
		Duplicate	10-01-96	<3.6 UJt	<3.6 UJt	<3.6 R	<1.8 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<1.8 UJt
BK-2672	HN-49-D		2-28-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2830	HN-61-S		2-28-96	<2.5	<2.5	<2.5	<1.2	<2.5	<2.5	<2.5	<2.5	<1.2
			10-01-96	<1.9 UJt	<1.9 UJt	<1.9 R	<.96 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<.96 UJt
BK-2831	HN-61-I		2-28-96	<1.0	<1.0	<1.0	<.5	<1.0	<1.0	<1.0	<1.0	<.5
BK-2828	HN-62-S		2-27-96	<1.0	<1.0	<1.0 R	.54	<1.0	<1.0	<1.0	<1.0	<.5
BK-2829	HN-62-I		2-27-96	<1.0	<1.0	<1.0 R	<.5	<1.0	<1.0	<1.0	<1.0	<.5

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	1,1-Dichloro-ethane	1,2-Dichloro-ethane	1,2-Dichloro-ethylene, total	1,1-Dichloro-ethylene	1,2-Dichloro-propane	cis-1,3-Dichloro-propene	trans-1,3-Dichloro-propene	1,2-Dibromo-methane
BK-1021			2-14-96	<1.0	<1.0	6.2	<1.0	<1.0	<1.0	<1.0	<1.0
			10-04-96	<1.0	<1.0	7.5	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2767			2-15-96	<1.0	<1.0	22	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<2.0	<2.0	22	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2768			2-20-96	<1.0 UJt	<1.0 UJt	1.8 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
			10-04-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2769			2-20-96	<1.0 UJt	<1.0 UJt	2.0 Jt	13 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
		Duplicate	2-20-96	<1.0 UJt	<1.0 UJt	2.0 Jt	14 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
			10-09-96	<25	<25	<25	<25	<25	<25	<25	<25
		Duplicate	10-09-96	<25	<25	<25	<25	<25	<25	<25	<25
BK-2770			2-21-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			10-02-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2788			2-20-96	<1.0 UJt	<1.0 UJt	<1.0 UJt	4.8 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
			10-09-96	<12	<12	<12	<12	<12	<12	<12	<12
BK-2789			2-15-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			10-02-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2791			2-13-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			10-03-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2795			2-15-96	<1.0	<1.0	26	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<2.0	<2.0	27	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2796			2-14-96	<1.0	<1.0	2.5	<1.0	<1.0	<1.0	<1.0	<1.0
			10-03-96	<1.0	<1.0	2.1	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2797			2-13-96	<1.0	<1.0	<1.0	3.5	<1.0	<1.0	<1.0	<1.0
			10-03-96	<1.0	<1.0	<1.0	5.7	<1.0	<1.0	<1.0	<1.0
BK-2798			2-13-96	<1.0	<1.0	25	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<2.0	<2.0	28	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2799			3-01-96	<25	<25	190	<25	<25	<25	<25	<25
		Duplicate	3-01-96	<25	<25	170	<25	<25	<25	<25	<25
			10-09-96	<5.0	<5.0	70	<5.0	<5.0	<5.0	<5.0	<5.0
		Duplicate	10-09-96	<4.2	<4.2	68	<4.2	<4.2	<4.2	<4.2	<4.2
		Packer test zones 1 and 2	10-23-96	<2.5	<2.5	40	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 2	10-23-96	<2.5	<2.5	56	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 2 duplicate	10-23-96	<2.5	<2.5	54	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 3	10-24-96	<2.5	<2.5	51	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 4	10-24-96	<2.5	<2.5	62	<2.5	<2.5	<2.5	<2.5	<2.5

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	1,1-Dichloro-ethane	1,2-Dichloro-ethane	1,2-Dichloro-ethylene, total	1,1-Dichloro-ethylene	1,2-Dichloro-propane	cis-1,3-Dichloro-propene	trans-1,3-Dichloro-propene	1,2-Dibromo-methane
BK-2799		Packer test zone 5	10-24-96	<5.0	<5.0	70	<5.0	<5.0	<5.0	<5.0	<5.0
		Packer test zone 1	10-24-96	<2.5	<2.5	50	<2.5	<2.5	<2.5	<2.5	<2.5
		Aquifer test after 1 hour	10-28-96	<5.0 UJt	<5.0 UJt	63 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 3 hours	10-28-96	<5.0 UJt	<5.0 UJt	80 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 5 hours	10-28-96	<5.0 UJt	<5.0 UJt	89 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
BK-2800			2-21-96	<1.0	<1.0	33	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<1.0 UJs	<1.0 UJs	24 Js	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs
BK-2544	HN-5-S		2-21-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2542	HN-5-I		2-13-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2543	HN-5-D		2-23-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2547	HN-6-S		2-22-96	2.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0	<1.0
BK-2546	HN-6-I		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2545	HN-6-D		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2550	HN-7-S		2-27-96	<1.0	<1.0	1.5	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2544	HN-7-I		2-27-96	<1.0	<1.0	1.9	<1.0	<1.0	<1.0	<1.0	<1.0
		Duplicate	2-27-96	<1.0	<1.0	1.8	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2548	HN-7-D		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2556	HN-9-S		2-20-96	<1.0 UJt	<1.0 UJt	1.5 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
BK-2555	HN-9-I		2-20-96	<1.0 UJt	<1.0 UJt	<1.0 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
BK-2554	HN-9-D		2-23-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2670	HN-49-S		2-28-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2671	HN-49-I		2-28-96	<6.2	<6.2	31	<6.2	<6.2	<6.2	<6.2	<6.2
		Duplicate	2-28-96	<6.2	<6.2	32	<6.2	<6.2	<6.2	<6.2	<6.2
			10-01-96	<3.6 UJt	<3.6 UJt	38 Jt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt
		Duplicate	10-01-96	<3.6 UJt	<3.6 UJt	35 Jt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt
BK-2672	HN-49-D		2-28-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2830	HN-61-S		2-28-96	<2.5	<2.5	12	<2.5	<2.5	<2.5	<2.5	<2.5
			10-01-96	<1.9 UJt	<1.9 UJt	16 Jt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt
BK-2831	HN-61-I		2-28-96	<1.0	<1.0	1.1	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2828	HN-62-S		2-27-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2829	HN-62-I		2-27-96	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Ethyl-benzene	2-Hex-anone	Methylene chloride	4-Methyl-2-pentanone	Styrene	1,1,1,2-Tetrachloro-ethane	1,1,2,2-Tetrachloro-ethane	Tetrachloro-ethylene	1,1,1-Trichloro-ethane
BK-1021			2-14-96	<1.0	<10 R	<1.0	<10	<1.0	<1.0	<1.0 UJc	<1.0	<1.0
			10-04-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2767			2-15-96	<1.0	<10 R	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<2.0	<20	<2.0	<20	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2768			2-20-96	<1.0	<10 R	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
			10-04-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2769			2-20-96	<1.0 UJt	<10 Rt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	690 Jt	22 Jt
		Duplicate	2-20-96	<1.0 UJt	<10 Rt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	710 Jt	23 Jt
			10-09-96	<25	<250	<25	<250	<25	<25	<25	630	<25
		Duplicate	10-09-96	<25	<250	<25	<250	<25	<25	<25	650	<25
BK-2770			2-21-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
			10-02-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2788			2-20-96	<1.0 UJt	<10 Rt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	370 Jt	<1.0 UJt
			10-09-96	<12	<120	<12	<120	<12	<12	<12	330	<12
BK-2789			2-15-96	<1.0	<10 R	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
			10-02-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2791			2-13-96	<1.0	<10	1.0 y	<10	<1.0	<1.0 R	<1.0	<1.0	<1.0
			10-03-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2795			2-15-96	<1.0	<10 R	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<2.0	<20	<2.0	<20	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2796			2-14-96	<1.0	<10 R	<1.0	<10	<1.0	<1.0	<1.0 UJc	<1.0	<1.0
			10-03-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2797			2-13-96	<1.0	<10	<1.0	<10	<1.0	<1.0 R	<1.0	<1.0	1.5
			10-03-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	1.5
BK-2798			2-13-96	<1.0	<10	1.0 y	<10	<1.0	<1.0 R	<1.0	<1.0	<1.0
			10-07-96	<2.0	<20	<2.0	<20	<2.0	<2.0	<2.0	<2.0	<2.0
BK-2799			3-01-96	<25	<250	<25	<25	<25	<25	<25	<25	<25
		Duplicate	3-01-96	<25	<250	<25	<25	<25	<25	<25	<25	<25
			10-09-96	<5.0	<50	<5.0	<50	<5.0	<5.0	<5.0	<5.0	<5.0
		Duplicate	10-09-96	<4.2	<42	<4.2	<42	<4.2	<4.2	<4.2	<4.2	<4.2
		Packer test zones 1 and 2	10-23-96	<2.5	<25	2.9	<25	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 2	10-23-96	<2.5	<25	2.9	<25	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 2 duplicate	10-23-96	<2.5	<25	<2.5	<25	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 3	10-24-96	<2.5	<25	<2.5	<25	<2.5	<2.5	<2.5	<2.5	<2.5
		Packer test zone 4	10-24-96	<2.5	<25	<2.5	<25	<2.5	<2.5	<2.5	<2.5	<2.5

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	Ethyl-benzene	2-Hex-anone	Methylene chloride	4-Methyl-2-pentanone	Styrene	1,1,1,2-Tetrachloro-ethane	1,1,2,2-Tetrachloro-ethane	Tetrachloro-ethylene	1,1,1-Trichloro-ethane
BK-2799		Packer test zone 5	10-24-96	<5.0	<50	<5.0	<50	<5.0	<5.0	<5.0	<5.0	<5.0
		Packer test zone 1	10-24-96	<2.5	<25	<2.5	<25	<2.5	<2.5	<2.5	<2.5	<2.5
		Aquifer test after 1 hour	10-28-96	<5.0 UJt	<50 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 3 hours	10-28-96	<5.0 UJt	<50 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 5 hours	10-28-96	<5.0 UJt	<50 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<5.0 UJt
BK-2800			2-21-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
			10-07-96	<1.0 UJs	<10 UJs	<1.0 UJs	<10 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs	<1.0 UJs
BK-2544	HN-5-S		2-21-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2542	HN-5-I		2-13-96	<1.0	<10	<1.0	<10	<1.0	<1.0 R	<1.0	<1.0	<1.0
BK-2543	HN-5-D		2-23-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2547	HN-6-S		2-22-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2546	HN-6-I		2-22-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2545	HN-6-D		2-22-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2550	HN-7-S		2-27-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	1.1
BK-2544	HN-7-I		2-27-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
		Duplicate	2-27-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2548	HN-7-D		2-22-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2556	HN-9-S		2-20-96	<1.0 UJt	<10 Rt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
BK-2555	HN-9-I		2-20-96	<1.0 UJt	<10 Rt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt
BK-2554	HN-9-D		2-23-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2670	HN-49-S		2-28-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2671	HN-49-I		2-28-96	<6.2	<62	<6.2	<62	<6.2	<6.2	<6.2	<6.2	<6.2
		Duplicate	2-28-96	<6.2	<62	<6.2	<62	<6.2	<6.2	<6.2	<6.2	<6.2
			10-01-96	<3.6 UJt	<36 UJt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt
		Duplicate	10-01-96	<3.6 UJt	<36 UJt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<3.6 UJt
BK-2672	HN-49-D		2-28-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2830	HN-61-S		2-28-96	<2.5	<25	<2.5	<25	<2.5	<2.5	<2.5	<2.5	<2.5
			10-01-96	<1.9 UJt	<19 UJt	<1.9 UJt	<19 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt	<1.9 UJt
BK-2831	HN-61-I		2-28-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2828	HN-62-S		2-27-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0
BK-2829	HN-62-I		2-27-96	<1.0	<10	<1.0	<10	<1.0	<1.0	<1.0	<1.0	<1.0

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	1,1,2-Trichloro-ethane	Trichloro-ethylene	Toluene	Trichloro-fluoro-methane	1,2,3-Trichloro-propane	Vinyl acetate	Vinyl chloride	Xylenes, total
BK-1021			2-14-96	<1.0	5.8	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-04-96	<1.0	8.8	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2767			2-15-96	<1.0	70	<1.0	2.7	<1.0	<10	<1.0	<1.0
			10-07-96	<2.0	67	<2.0	<2.0	<2.0	<10	<1.0	<1.0
BK-2768			2-20-96	<1.0 UJt	3.5 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
			10-04-96	<1.0	2.8	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2769			2-20-96	<1.0 UJt	5.4 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
		Duplicate	2-20-96	<1.0 UJt	5.5 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
			10-09-96	<25	<25	<25	<25	<25	<250	<25	<25
		Duplicate	10-09-96	<25	<25	<25	<25	<25	<250	<25	<25
BK-2770			2-21-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-02-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2788			2-20-96	<1.0 UJt	2.3 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
			10-09-96	<12	<12	<12	<12	<12	<120	<12	<12
BK-2789			2-15-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-02-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2791			2-13-96	<1.0	<1.0	<1.0	<1.0	<1.0 R	<10	<1.0	<1.0
			10-03-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2795			2-15-96	<1.0	80	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-07-96	<2.0	75	<2.0	<2.0	<2.0	<20	<2.0	<2.0
BK-2796			2-14-96	<1.0	3.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-03-96	<1.0	2.8	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2797			2-13-96	<1.0	<1.0	<1.0	<1.0	<1.0 R	<10	<1.0	<1.0
			10-03-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2798			2-13-96	<1.0	56	<1.0	<1.0	<1.0 R	<10	<1.0	<1.0
			10-07-96	<2.0	61	<2.0	<2.0	<2.0	<20	<2.0	<2.0
BK-2799			3-01-96	<25	450	<25	<25	<25	<250	<25	<25
		Duplicate	3-01-96	<25	410	<25	<25	<25	<250	<25	<25
			10-09-96	<5.0	140	<5.0	<5.0	<5.0	<50	<5.0	<5.0
		Duplicate	10-09-96	<4.2	150	<4.2	<4.2	<4.2	<42	<4.2	<4.2
		Packer test zones 1 and 2	10-23-96	<2.5	88	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 2	10-23-96	<2.5	120	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 2 duplicate	10-23-96	<2.5	110	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 3	10-24-96	<2.5	110	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Packer test zone 4	10-24-96	<2.5	140	<2.5	<2.5	<2.5	<25	<2.5	<2.5

Appendix 2. *Results of chemical analysis for volatile organic compounds in ground water, February and October 1996, Casey Village Area, Bucks County, Pennsylvania—Continued*

USGS well-identification number	Site well-identification number	Notes	Date	1,1,2-Trichloro-ethane	Trichloro-ethylene	Toluene	Trichloro-fluoro-methane	1,2,3-Trichloro-propane	Vinyl acetate	Vinyl chloride	Xylenes, total
BK-2799		Packer test zone 5	10-24-96	<5.0	150	<5.0	<5.0	<5.0	<50	<5.0	<5.0
		Packer test zone 1	10-24-96	<2.5	110	<2.5	<2.5	<2.5	<25	<2.5	<2.5
		Aquifer test after 1 hour	10-28-96	<5.0 UJt	120 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 3 hours	10-28-96	<5.0 UJt	160 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
		Aquifer test after 5 hours	10-28-96	<5.0 UJt	180 Jt	<5.0 UJt	<5.0 UJt	<5.0 UJt	<50 UJt	<5.0 UJt	<5.0 UJt
BK-2800			2-21-96	<1.0	38	<1.0	<1.0	<1.0	<10	<1.0	<1.0
			10-07-96	<1.0 UJs	43	<1.0 UJs	<1.0 UJs	<1.0 UJs	<10 UJs	<1.0 UJs	<1.0 UJs
BK-2544	HN-5-S		2-21-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2542	HN-5-I		2-13-96	<1.0	<1.0	<1.0	<1.0	<1.0 R	<10	<1.0	<1.0
BK-2543	HN-5-D		2-23-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2547	HN-6-S		2-22-96	<1.0	16	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2546	HN-6-I		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2545	HN-6-D		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2550	HN-7-S		2-27-96	<1.0	5.4	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2544	HN-7-I		2-27-96	<1.0	9.2	<1.0	<1.0	<1.0	<10	<1.0	<1.0
		Duplicate	2-27-96	<1.0	9.1	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2548	HN-7-D		2-22-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2556	HN-9-S		2-20-96	<1.0 UJt	2.2 Jt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
BK-2555	HN-9-I		2-20-96	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<1.0 UJt	<10 UJt	<1.0 UJt	<1.0 UJt
BK-2554	HN-9-D		2-23-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2670	HN-49-S		2-28-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2671	HN-49-I		2-28-96	<6.2	120	<6.2	<6.2	<6.2	<62	<6.2	<6.2
		Duplicate	2-28-96	<6.2	120	<6.2	<6.2	<6.2	<62	<6.2	<6.2
			10-01-96	<3.6 UJt	120 Jt	<3.6 UJt	3.7 Jt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt
		Duplicate	10-01-96	<3.6 UJt	110 Jt	<3.6 UJt	<3.6 UJt	<3.6 UJt	<36 UJt	<3.6 UJt	<3.6 UJt
BK-2672	HN-49-D		2-28-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2830	HN-61-S		2-28-96	<2.5	49	<2.5	<2.5	<2.5	<25	<2.5	<2.5
			10-01-96	<1.9 UJt	55 Jt	<1.9 UJt	2.8 Jt	<1.9 UJt	<19 UJt	<1.9 UJt	<1.9 UJt
BK-2831	HN-61-I		2-28-96	<1.0	2.3	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2828	HN-62-S		2-27-96	<1.0	1.2	<1.0	<1.0	<1.0	<10	<1.0	<1.0
BK-2829	HN-62-I		2-27-96	<1.0	<1.0	<1.0	<1.0	<1.0	<10	<1.0	<1.0