Borehole Geophysical Logging and Aquifer-Isolation Tests Conducted in Well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania

By Philip H. Bird

In cooperation with the
U.S. Environmental Protection Agency

Scientific Investigations Report 2006-5014

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

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

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia: 2006

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Suggested citation:
Bird, P.H., 2006, Borehole geophysical logging and aquifer-isolation tests conducted in well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2006-5014, 43 p.

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Volume		
gallon (gal)	3.785	liter (L)
Flow rate		
gallon per minute (gal/min)	0.06309	liter per second (L/s)
Specific capacity		
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s/m]

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

$$˚F = (1.8 \times ˚C) + 32$$

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

$$˚C = (˚F - 32) / 1.8$$

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

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

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

Borehole Geophysical Logging and Aquifer-Isolation Tests Conducted in Well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania

By Philip H. Bird

Abstract

Borehole geophysical logging and aquifer-isolation (packer) tests were conducted in well MG-1693 (NP-87) at the North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pa. Objectives of the study were to identify the depth and yield of water-bearing zones, occurrence of vertical borehole flow, and effects of pumping on water levels in nearby wells. Caliper, natural-gamma, single-point-resistance, fluid-temperature, fluid-resistivity, heatpulse-flowmeter, and borehole-video logs were collected. Vertical borehole-fluid movement direction and rate were measured under nonpumping conditions. The suite of logs was used to locate water-bearing fractures, determine zones of vertical borehole-fluid movement, and select depths to set packers. Aquifer-isolation tests were conducted to sample discrete intervals and to determine specific capacities of water-bearing zones and effects of pumping individual zones on water levels in two nearby monitor wells. Specific capacities of isolated zones during aquifer-isolation tests ranged from 0.03 to 3.09 (gal/min)/ft (gallons per minute per foot). Fractures identified by borehole geophysical methods as water-producing or water-receiving zones produced water when isolated and pumped.

Water enters the borehole primarily through high-angle fractures at 416 to 435 ft bls (feet below land surface) and 129 to 136 ft bls. Water exits the borehole through a high-angle fracture at 104 to 107 ft bls, a broken casing joint at 82 ft bls, and sometimes as artesian flow through the top of the well. Thirteen intervals were selected for aquifer-isolation testing, using a straddle-packer assembly. The specific capacity of interval 1 was 2.09 (gal/min)/ft. The specific capacities of intervals 2, 3, and 4 were similar—0.27, 0.30, and 0.29 (gal/min)/ft, respectively. The specific capacities of intervals 5, 6, 7, 8, and 10 were similar—0.03, 0.04, 0.09, 0.09, and 0.04 (gal/min)/ft, respectively. Intervals 9, 11, and 12 each showed a strong hydraulic connection outside the borehole with intervals above and below the isolated interval. The specific capacities of intervals 9, 11, 12, and 13 were similar—2.12, 2.17, 3.09, and 3.08 (gal/min)/ft, respectively.

The aquifer-isolation tests indicate that wells MG-1693 (NP-87) and MG-924 (NP-21) are connected primarily through the high-angle fracture from 416 to 435 ft bls. Pumping in either of these wells directly impacts the other well, allowing the pumped well to draw from water-bearing zones in the nonpumped well that are not present in or are not connected directly to the pumped well. The two boreholes act as a single, U-shaped well. The aquifer-isolation tests also show that the lower zones in well MG-1693 (NP-87) are a major source of hydraulic head in well MG-1661 (W-13) through the broken casing joint at 82 ft bls. Water moving upward from the lower intervals in well MG-1693 (NP-87) exits the borehole through the broken casing joint, moves upward outside the borehole, possibly around and (or) through a poor or damaged casing seal, and through the weathered zone above bedrock to well MG-1661 (W-13).

Samples for volatile organic compounds (VOCs) were collected in nine isolated intervals. Six compounds were detected (1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethene, toluene, 1,1,1-trichloroethane, and trichloroethene (TCE)), and TCE was found in all nine isolated intervals. Intervals 4 (124-149 ft bls) and 6 (277-302 ft bls) had the highest total concentration of VOCs (6.66 and 6.2 micrograms per liter, respectively). Intervals 1 (68-93 ft bls) and 4 each had five compounds detected, which was the highest number of compounds detected. Interval 5 (252-277 ft bls) had the lowest total concentration of VOCs (0.08 microgram per liter) and the least number of VOCs detected (one). Detected compounds were not evenly distributed throughout the intervals. Contaminants were found in shallow, intermediate, and deep intervals and were associated with high-angle fractures and rough areas that showed no distinct fractures.

Introduction

Well MG-1693 (owner designation NP-87) is in a wellfield at the northwest end of Crystal Lane near Colmar, Montgomery County, Pa. (fig. 1). The depth of well MG-1693 at the time of geophysical logging (July 1998) was 476 ft below land surface (bls). The well is 30 ft west-northwest of a wellhouse containing former production well MG-924 (owner designation NP-21) (fig. 2), and is 97 ft west-southwest of monitor well

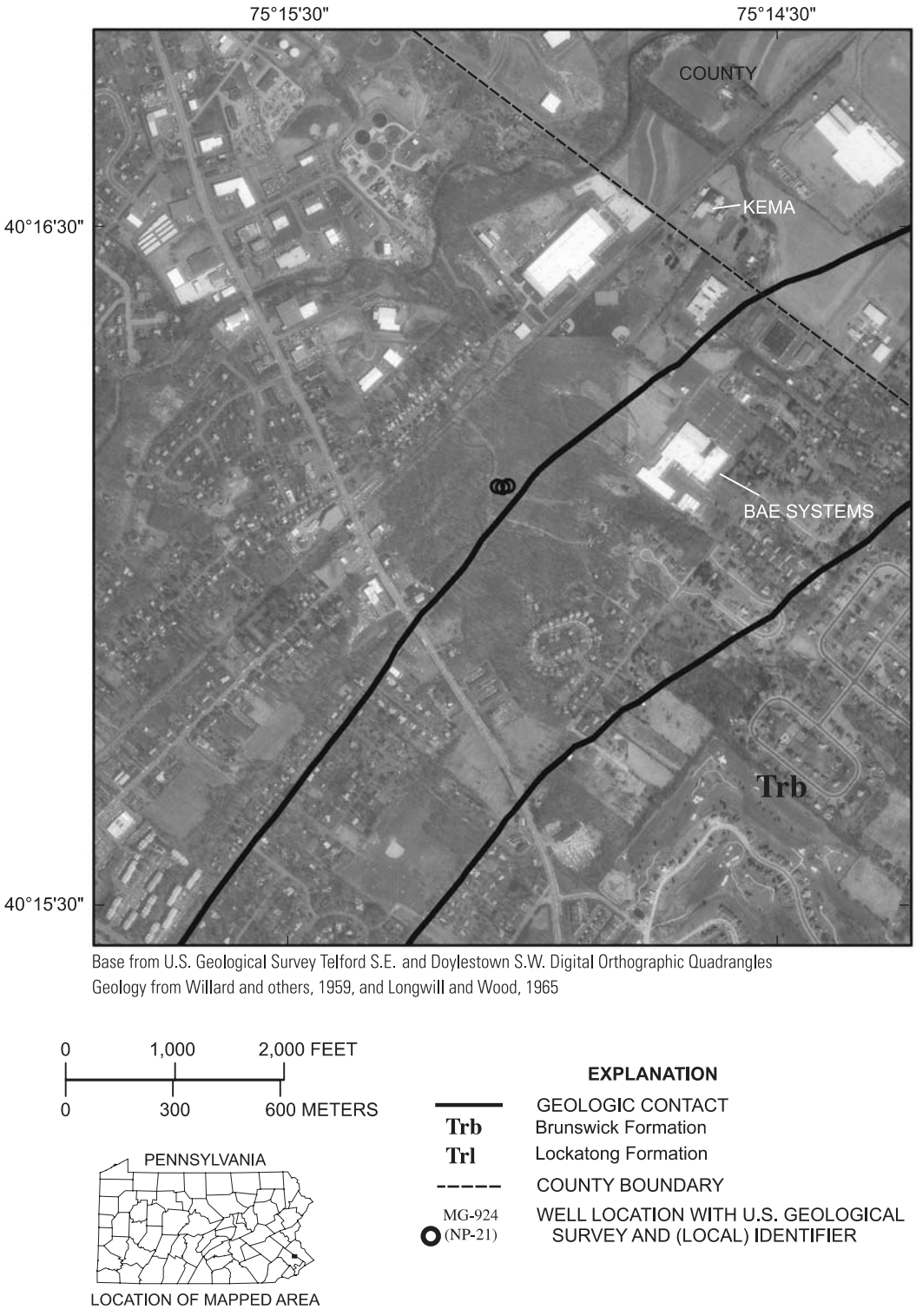

Figure 1. Geology and location of wells at the North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Figure 2. Well MG-1693 (NP-87) set up for aquifer test in May 2002, at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania. [Well house contains former production well MG-924 (NP-21). View is to the north.]

MG-1661 (owner designation W-13). These wells are within the North Penn Area 5 Superfund Site.

The North Penn Area 5 Superfund Site is in Montgomery and Bucks Counties, Pa. In August 1979, the North Penn Water Authority (NPWA) detected trichloroethene (TCE) in ground-water samples collected from municipal-supply well MG-924 adjacent to well MG-1693; this well was then removed from service. Subsequently, American Electronics Laboratory (AEL), now BAE Systems (BAE), discovered leakage from its underground spent solvent tank, which contained, in part, TCE (Earth Technology Corporation, 1993). AEL removed the underground tank in June 1980, aerated the associated contaminated soil, and returned it to the excavated hole. In April 1981, AEL signed a Consent Order and Agreement with the Pennsylvania Department of Environmental Resources (PADER), now known as the Pennsylvania Department of Environmental Protection (PADEP). As part of the Agreement, AEL installed monitor and recovery wells and a treatment system for contaminated ground water. In 1985, TCE and similar compounds were detected in several NPWA wells on the North Penn Area 5 Superfund Site, and, as a result, the site was proposed for the National Priorities List (NPL) in January 1987. The site was added to the NPL in March 1989.

Subsequent ground-water sampling indicated the contaminant plume was migrating away from the original spill area at AEL (Earth Technology Corporation, 1993). The highest concentrations were at the northern boundary of the AEL property, suggesting that sources outside the AEL property also may be contributing to ground-water contamination. From February through May 1990, KEMA-Powertest conducted ground-water sampling at the property on County Line Road that it later purchased in June 1990. Elevated concentrations of 1,1,1-trichloroethane (TCA) were detected in one shallow monitor well (Earth Technology Corporation, 1993). TCA is not a breakdown product of TCE. This suggests an additional source of ground-water contamination. The North Penn Area 5 Superfund Site now includes the properties where contamination was found and surrounding areas.

Contaminants of concern detected at the site include TCE, TCA, and tetrachloroethene (PCE). Affected environmental media include soil and ground water. Primary exposure routes to contaminants include ingestion of ground water through drinking, inhalation of ground water used for sanitary purposes, and contact during recreational activities with ground water that has discharged to streams.

Aquifer tests were run in well MG-924 (NP-21) in June 2000 and in well MG-1693 (NP-87) in May 2002 (Risser and Bird, 2003). The aquifer-isolation tests described in this report were conducted at the request of the U.S. Environmental Protection Agency (USEPA) in conjunction with other studies done at the North Penn Area 5 Superfund Site.

Purpose and Scope

This report describes the results of borehole geophysical logging and aquifer-isolation (packer) tests in well MG-1693 (NP-87) at the North Penn Area 5 Superfund Site. Objectives of the study were to identify the depth and yield of water-bearing zones, occurrence of vertical borehole flow, and effects of pumping on water levels in nearby wells. Caliper, natural-gamma, single-point-resistance, fluid-resistivity, fluid-temperature, borehole-video, and heatpulse-flowmeter logs were collected in the borehole. Vertical borehole-fluid movement direction and rate were measured under nonpumping conditions. The suite of logs was used to locate water-bearing fractures, determine zones of vertical borehole-fluid movement, and select depths to set packers. Aquifer-isolation tests were conducted to sample discrete intervals and to determine specific capacities of water-bearing zones and effects of pumping individual zones on water levels in two nearby monitor wells. Aquifer-isolation tests were performed on 13 intervals, based on interpretation of the geophysical and borehole-video logs. Samples for water-quality analyses for volatile organic compounds (VOCs) from discrete zones were collected by TetraTech, Inc., from nine intervals to determine distribution of contamination. Results from that investigation are included in this report.

Geohydrologic Setting

The North Penn Area 5 Superfund Site is in the Piedmont Physiographic Province and is underlain by Triassic-age sediments of the Newark Supergroup. The terrain varies from flat to low rolling hills and is drained by the West Branch Neshaminy Creek and two unnamed tributaries to the West Branch Neshaminy Creek. Well MG-1693 is near the mapped contact of the Brunswick and Lockatong Formations (fig. 1).

Brunswick and Lockatong Formations

The Brunswick Formation underlies the northwestern part of the study area. The Brunswick interfingers laterally with the Lockatong Formation. The contact between the Brunswick and the Lockatong generally is placed where the thickness of red beds of the Brunswick equals the thickness of gray and black beds of the Lockatong. The lower part of the Brunswick Formation consists of homogeneous, soft, red to reddish-brown and gray to greenish-gray mudstones and shales that crumble easily. The bedding is irregular, wavy, and sometimes micaceous. Interbedded shales and siltstones are fairly well sorted. Conglomerate and fine-grained sandstone are found in the upper part of the formation. Mudcracks, ripple marks, crossbeds, and burrows are found in all of the beds (Drake and others, 1967). The Brunswick Formation contains detrital cycles of medium to dark gray and olive to greenish-gray, thin-bedded and evenly bedded shale and siltstone; these are similar to the rocks of the underlying Lockatong Formation (Lyttle and Epstein, 1987). These units are not as continuous as those in the Lockatong Formation. Higher parts of the formation have gray beds that are softer and are largely mud- and silt-shale and siltstone. The interfingered thin beds that underlie the southeastern part of the site were mapped as the Lockatong Formation by Willard and others (1959) but are considered the lower beds of the Brunswick Formation by Lyttle and Epstein (1987). The contact of the Brunswick Formation with the Lockatong Formation is gradational over about 1,640 ft (Lyttle and Epstein, 1987). The lower contact of the Brunswick can be either conformable and gradational to older rocks of the Newark Supergroup or unconformable on basement rocks. The thickness of the formation is estimated to be 3,420 ft (Drake and others, 1967). The mean strike of the Brunswick Formation, interpreted from the acoustic televiewer logs, at the North Penn Area 5 Superfund Site is N. 62˚ E. (dip azimuth 332˚), and the dip is 31˚ NW.

The Lockatong Formation underlies the southeastern part of the site. It underlies and interfingers laterally with the Brunswick Formation. The lithology of the Lockatong Formation is fairly homogenous and includes detrital and chemical-lacustrine sediments. The detrital rocks are dark gray to black, calcareous, pyritic siltstone and shale in the lower part overlain by dark gray, calcareous siltstone and fine-grained sandstone (Van Houten, 1962). The chemical-lacustrine rocks are dark gray to black, dolomitic siltstone and marlstone with lenses of pyritic limestone in the lower part, overlain by red or gray analcime- and carbonate-rich siltstone. These rocks are nonfissile and are very resistant to weathering. Willard and others (1959) refer to these rocks as argillite, a term meaning a tough, firmly cemented, nonfissile, argillaceous (composed of clay or clay-sized particles) rock. Dark red shale, siltstone, and marlstone interfinger with gray beds, especially in the upper and western parts, but differ from the gray beds mainly in color. Pyrite and calcite crystals up to 1/4-in. long are scattered throughout the beds. Rock containing sufficient calcite to be considered an argillaceous limestone occurs in beds up to a few feet thick (Willard and others, 1959). The rocks contain shrinkage cracks, mudcracks, ripple marks, root disruptions, and burrows. Bedding is generally even and commonly about a foot thick, although some beds may be massive. In some places, the contact between red and gray beds is sharp; in most others, there is a brownish- to purplish-gray transition rock, which is a few inches to a few feet thick. Where the contact is sharp, the gray is commonly suncracked, and the cracks are filled with red sediment (Willard and others, 1959). The maximum thickness of the formation is estimated to be 3,900 ft (Lyttle and Epstein, 1987). The mean strike of the Lockatong Formation, interpreted from the acoustic televiewer logs, at the North Penn Area 5 Superfund Site is N. 67˚ E. (dip azimuth 337˚), and the dip is 19˚ NW.

Ground-Water-Flow System

Ground water at the North Penn Area 5 Superfund Site originates from infiltration of local precipitation and discharges to streams, artesian wells, and pumping wells. After infiltrating through soil and saprolite, ground water moves through vertical and horizontal fractures in the shale and siltstones. Primary porosity is very low or nonexistent. Permeability and storage are very low. Ground water in rocks of the Brunswick Formation and Lockatong Formation may be under confined, unconfined, or perched conditions. Ground water in the upper part of the aquifer generally is under unconfined (water-table) conditions; ground water in the deeper part of the aquifer may be confined or partially confined, resulting in local artesian conditions.

Shallow and deep ground-water-flow systems may exist at the site. Ground-water levels fluctuate with pumping and seasonal variations in recharge. Water from the upper system may drain locally to streams and may leak downward to a deeper ground-water-flow system. Wells constructed as open boreholes may penetrate both systems, and water levels measured in these wells represent composite heads. Where differences in potentiometric head are present, water in the borehole flows from zones of higher head to zones of lower head. Shallow ground water generally flows in a direction similar to the topographic gradient. The natural direction of flow can be altered by pumping. In the rocks of the Brunswick and Lockatong Formations, cones of depression caused by pumping tend to extend along strike or fracture orientation (Longwill and Wood, 1965). Pumping from deep zones also may induce downward flow from shallow zones.

The configuration of the water table commonly is similar to topography in the Triassic rocks, and depth to water commonly is greater beneath ridge tops than hillsides or valleys. Available data indicate the depth to water in wells in the vicinity of the site ranges from above land surface (artesian/flowing, fig. 3) to 35 ft bls.

Figure 3. Well MG-1693 (NP-87) in artesian conditions, flowing at an estimated 4 gallons per minute prior to the start of aquifer-isolation testing in June 2002 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Previous Investigations

A study of ground water in the Brunswick Formation was conducted by Longwill and Wood (1965). Regional geologic mapping was compiled by Lyttle and Epstein (1987). Rima (1955), Longwill and Wood (1965), and Newport (1971) provide well and ground-water-quality data and a description of the ground-water resources in Montgomery County, Pa., including the area approximately 1 mi west of the North Penn Area 5 Superfund Site. Longwill and Wood (1965) compiled a geologic map, which, in the study area, was based almost entirely on unpublished manuscripts by Dean B. McLaughlin. Lyttle and Epstein (1987) compiled a geologic map of the Newark 1° x 2° quadrangle that updated and revised the geologic nomenclature for the area. Biesecker and others (1968) described the water resources of the Schuylkill River Basin, which drains part of the study area. Senior and Goode (1999) described the ground-water system and effect of pumping on ground-water flow in the area near Colmar, Pa. Bird and Conger (2002) described the geophysical-logging results, aquifer-isolation tests, contaminant distribution, and water-level measurements at the North Penn Area 5 Superfund Site. Risser and Bird (2003) presented aquifer-test results and ground-water-flow simulations for the North Penn Area 5 Superfund Site.

Well-Numbering System

Well-identification numbers used in this report consist of a county-abbreviation prefix preceding a sequentially assigned well number. The prefix MG denotes a well in Montgomery County. Other well-identification numbers are assigned by well owners or contractors and are presented here for correlation purposes. Well locations are shown in figure 1. A record of wells is provided in table 1.

Methods of Investigation

Borehole geophysical logs, borehole-video logs, and heat-pulse-flowmeter measurements were used in the investigation to characterize the geohydrologic framework near well MG-1693 (NP-87). Interpretive results from the geophysical logs and borehole-video logs were used to select depth intervals to perform aquifer-isolation tests. Aquifer-isolation tests were done to determine hydraulic properties of discrete fractures and to collect water-quality samples for VOC analyses.

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

Table 1. Record of selected wells at North Penn Area 5 Superfund Site, Montgomery County, Pennsylvania.

[NGVD 29, National Geodetic Vertical Datum of 1929]

U.S. Geological Survey borehole-identification number	Site identification number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Land-surface elevation (feet above NGVD 29)	Total depth (feet below land surface)	Well diameter (inches)	Length of casing (feet below land surface)
MG-924	NP-21	40 16 06.38	75 15 01.48	288.41	500	12	51.0
MG-1693	NP-87	40 16 06.46	75 15 01.98	287.06	476	12	104
MG-1661	W-13	40 16 06.56	75 15 00.76	288.29	46.0	3.5	10.0

Borehole Geophysical Logs

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

The natural-gamma or gamma log measures the intensity of natural-gamma radiation emitted from rocks penetrated by the borehole. The most common emitters of gamma radiation are uranium-238, thorium-232, their daughter elements, and potassium-40. These radioactive elements are concentrated in clays by adsorption, precipitation, and ion exchange. Fine-grained sediments, such as in shale or siltstone, usually emit more gamma radiation than sandstone, limestone, or dolomite. Geophysical logging with a gamma probe can be conducted in the fluid-filled, dry, cased, or uncased parts of a borehole. However, casing, especially metal, reduces the gamma response. The gamma log is also used to correlate geologic units between wells (Keys, 1990).

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

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

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

Borehole-Video Logs

Borehole-video logs were made by lowering a waterproof camera down the borehole and recording a wide-angle color image on both VHS and 8 millimeter (mm) video tape. The video logs allow for direct viewing of fractures, bedding planes, etc., and are used to locate smooth sections of the borehole that aid in setting of packers. The camera lighthead (a black rectangle) and the compass (a disk) are sometimes visible in the video images. The depth indicated on the borehole video logs may not correspond precisely to the geophysical logs because of some minor slippage of the television cable.

Heatpulse Flowmeter

The direction and rate of borehole-water movement was determined by the use of a heatpulse flowmeter. The heatpulse flowmeter operates by heating a small sheet of water between two sensitive thermistors (heat sensors). A measurement of direction and rate is computed when a peak temperature is recorded by one of the thermistors. The range of flow measurement is about 0.01-1.5 gal/min in a 2- to 10-in. diameter borehole (Conger, 1996).

Some heatpulse-flowmeter measurements may be influenced by (1) poor seal integrity between the borehole wall and heatpulse flowmeter and (2) contributions of water from storage within the borehole. If the seal between the borehole wall and flowmeter is not complete, some water can bypass the flowmeter, resulting in measurements of flow that are less than the actual rate. Although the heatpulse flowmeter is a calibrated probe, the data are used primarily as a relative indicator to identify water-producing zones.

Aquifer-Isolation Tests

Aquifer-isolation tests, commonly called packer tests, were conducted in well MG-1693. Because ground water moves though discrete fractures or fracture zones, the hydraulic properties and water quality of individual fractures or fracture zones can differ. The properties of individual fractures and zones can be obtained by isolating them with a straddle-packer assembly. The straddle-packer assembly consists of two inflatable bladders (packers) separated by a length of perforated pipe in which a pump is set (figs. 4 and 5). The perforated pipe length is adjusted to cover the vertical length of the fracture or fracture zone to be tested. In this packer test, the perforated pipe length is fixed for the entire test. Installed transducers allow the water level below the bottom packer and above the upper packer to be recorded concurrently with the isolated fracture or fracture zone.

Three wells were monitored during the aquifer-isolation test. Well MG-1693 (NP-87) is a 12-in. diameter borehole originally drilled to 500 ft bls and is cased to 104 ft bls. The depth determined during the logging of well MG-1693 was 476 ft bls. Although intended to replace nearby production well MG-924

(NP-21), it was never put into service. Well MG-924 (NP-21) is a former production well that was taken out of service. It is a 12-in. diameter borehole to a depth of 252 ft bls and a 6-in. diameter borehole from 252 ft bls to the bottom. The borehole is cased to 50 ft bls. The original drilled depth was 500 ft bls, but current maximum depth is unknown because pipes and cabling obstruct the borehole below 300 ft bls. Well MG-924 was monitored to observe pumping influence in the bedrock. Well MG-1661 (W-13) is a 3.5-in. PVC-screened shallow observation well. Total depth of this well is 46 ft bls, and the screened interval is 10 to 45 ft bls. Well MG-1661 was monitored to observe pumping influence in the weathered rock zone just above bedrock.

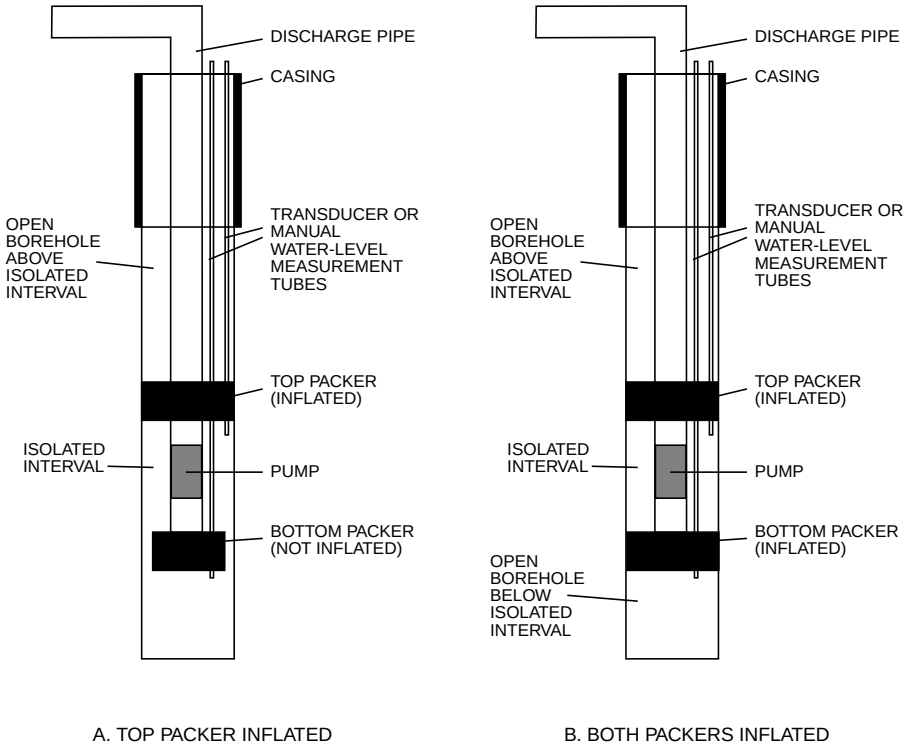

Figure 4. Generalized sketch of packer configurations used in aquifer-isolation test of well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania (Sloto and others, 1995).

Figure 5. Packer rig and packer assembly over well MG-1693 prior to start of aquifer-isolation testing in June 2002 (Lower packer is in borehole).

Results of Borehole Geophysical Logging

Borehole geophysical logs were collected in well MG-1693 (NP-87). The reference measuring point for all logs is land surface. Depth of well, casing length, and water levels at the time of logging are given in feet below land surface or feet above land surface (ft als).

The caliper log shows the total depth of the borehole is 476 ft and it is cased with 12-in.-diameter casing to 104 ft bls (fig. 6). The caliper log shows major fractures at 104-107, 116, 129-136, 260-270, 297-301, 416-435, and 457-459 ft bls. The caliper log also shows rough zones from 304 to 325 ft bls and 391 to 397 ft bls and an anomaly in the casing at 82 ft bls. The natural-gamma log shows shale units with elevated gamma readings at 110-114, 350-352, 441-444, and 462-470 ft bls (fig. 6). The log correlates well with well MG-924 (NP-21) down to 252 ft bls with exception of a large natural-gamma reading at 238 ft bls in MG-924 that is not apparent in MG-1693 (fig. 7). The single-point-resistance log shows coarser-grained units at 127-135, 143-147, 172-182, 188-210, 236-250, 328-350, 414-438, and 448-460 ft bls. The fluid-resistivity and fluid-temperature logs show changes in slope at 282, 286, 313, 315, 317, 350-367, 375, 386-398, 430-440, and 445-474 ft bls that suggest possible water-bearing zones (fig. 6). The geophysical logs indicate water probably enters the borehole through fractures at 130, 390, and 426 ft bls, moves upward, and exits the borehole through a fracture at 104 ft bls (the bottom of casing), a broken casing joint weld at 82 ft bls, and occasional artesian flow (fig. 6). This well remains an unused open borehole.

The borehole-video log shows major high-angle fractures at 104-107, 129-136, 260-270, 416-435, and 457-459 ft bls and rough zones with possible high-angle fractures from 304 to 325 ft bls and 391 to 397 ft bls and a broken casing joint at 82 ft bls. Water was visibly entering the borehole at 130 and 420 ft bls, indicating water-bearing zones. An earlier borehole-video log taken in well MG-1693 (NP-87) during the June 2000 aquifer test of well MG-924 showed an estimated downward flow of 100 gal/min. This flow entered the borehole primarily at the casing break at 82 ft bls (fig. 8), the high-angle fracture from 104 to 107 ft bls, and the high-angle fracture from 129 to 136 ft bls and exited the borehole through the high-angle fracture from 416 to 435 ft bls (fig. 9). The flow rate was estimated by trolling the camera down the borehole at a rate equal to the smallest visible particulates in the water. Because the surface/volume ratio of particles increases with decreasing size, thus increasing drag on the particle as it attempts to settle to the bottom of the well, it was assumed that the downward velocity of the smallest visible particle would be derived primarily from downward flow, rather than from gravitational settling.

The heatpulse-flowmeter measurements (table 2) showed most water enters the borehole through the high-angle fracture from 416 to 435 ft bls, moves upward, and exits the borehole through the high-angle fracture from 104 to 107 ft bls and the broken casing joint at 82 ft bls. Between the high-angle fracture from 416 to 435 ft bls and the high-angle fracture from 104 to 107 ft bls, the upward flow was more than the maximum measurable by the heatpulse flowmeter, and contributions from water-bearing zones between these two fractures were not detectable.

The gamma-log correlation for wells MG-1693 (NP-87) and MG-924 (NP-21) is shown in figure 7. Well MG-924 (NP-21) is approximately 36 ft, 55° east of south from well MG-1693 (NP-87), with a land-surface elevation 1.4 ft higher. The gamma-log correlation (fig. 7) shows continuous features occur at nearly equal elevations (or depths, if surface elevations are similar); well MG-1693 (NP-87) is approximately 4 ft downdip of well MG-924 (NP-21).

Table 2. Summary of heatpulse-flowmeter measurements for borehole MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

[gal/min, gallons per minute]

Depth (feet below land surface)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions
20	no flow	
60	no flow	
90	1.2	up
113	1.5	up
123	1.5	up
143	1.5	up
220	1.5	up
320	1.5	up
380	1.5	up
400	1.24	up
443	.1	up
464	no flow	

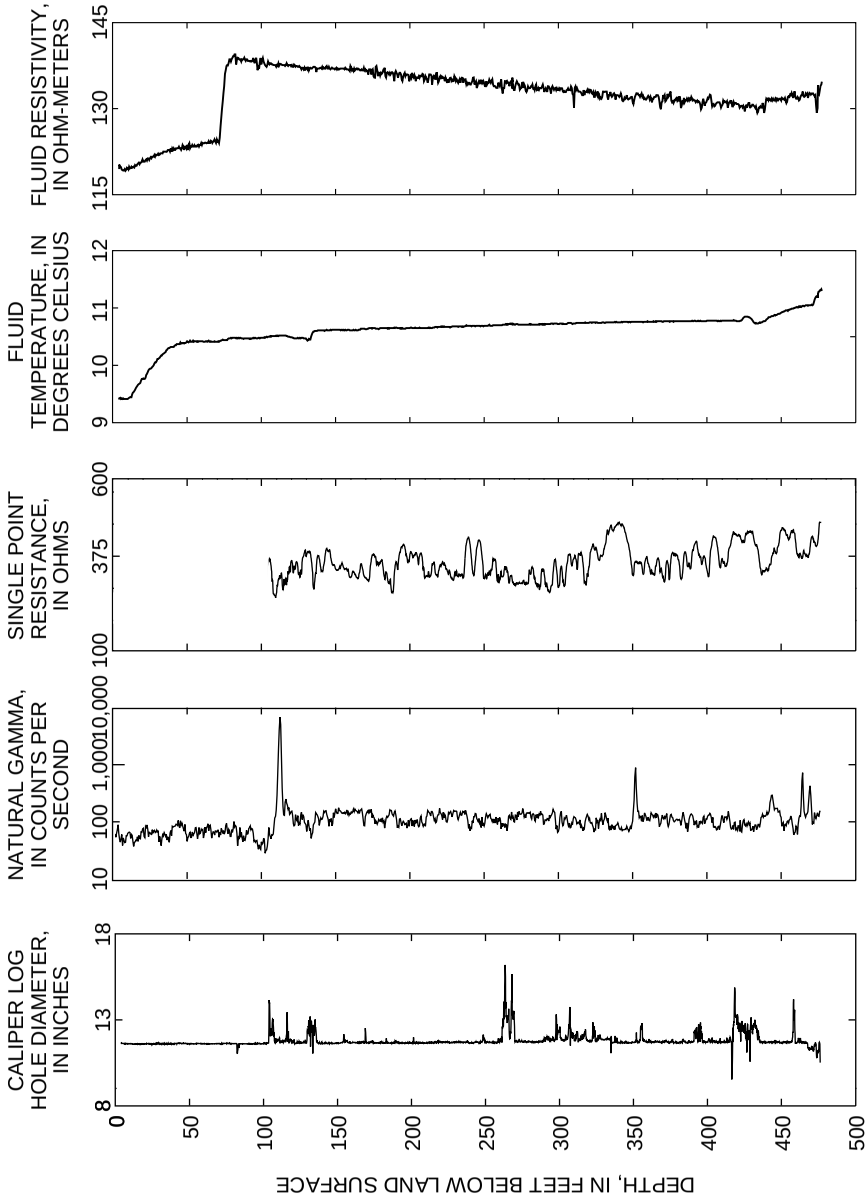

Figure 6. Borehole geophysical logs from well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

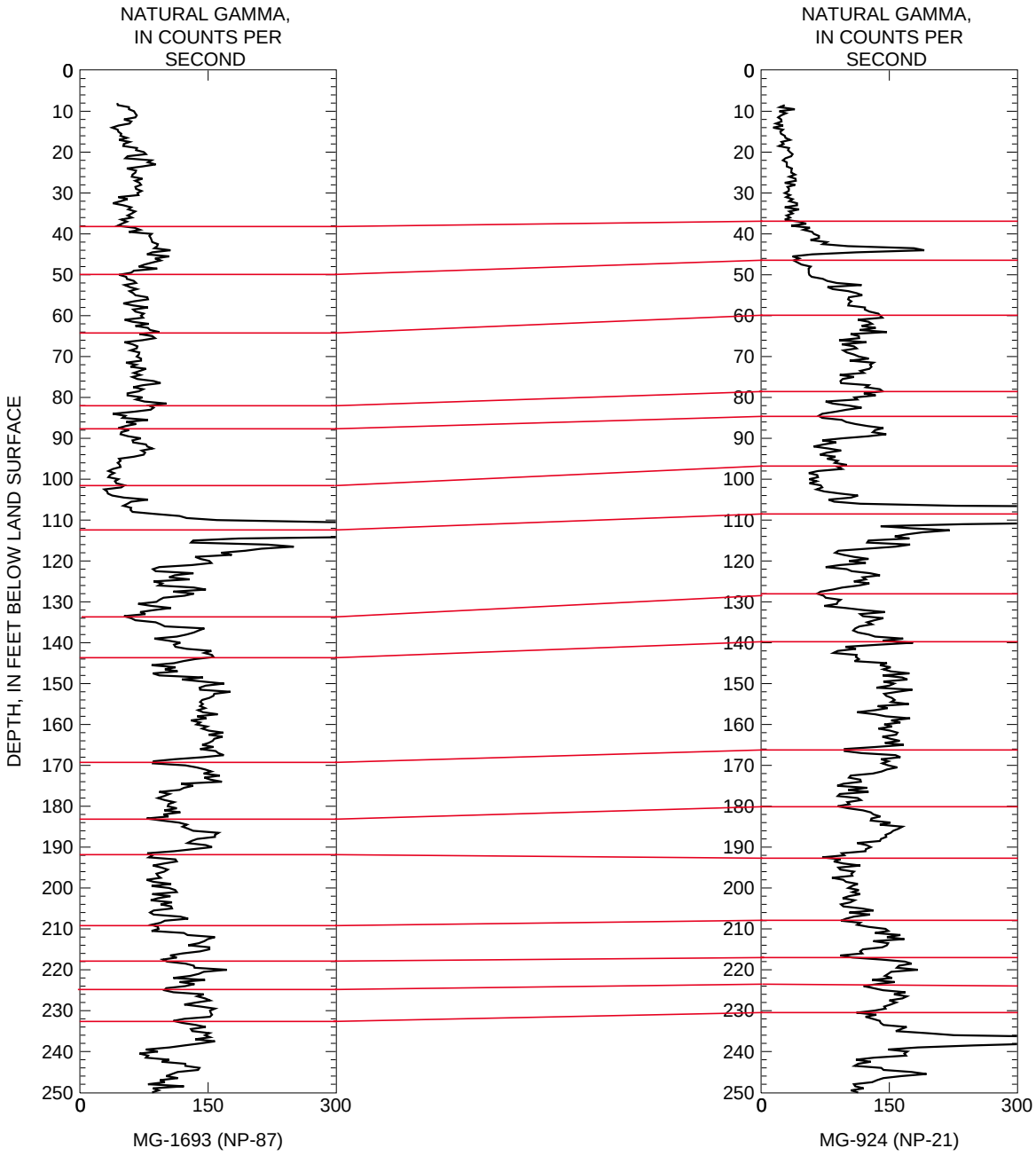

Figure 7. Natural-gamma-log correlation of lithology in wells MG-1693 (NP-87) and MG-924 (NP-21) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

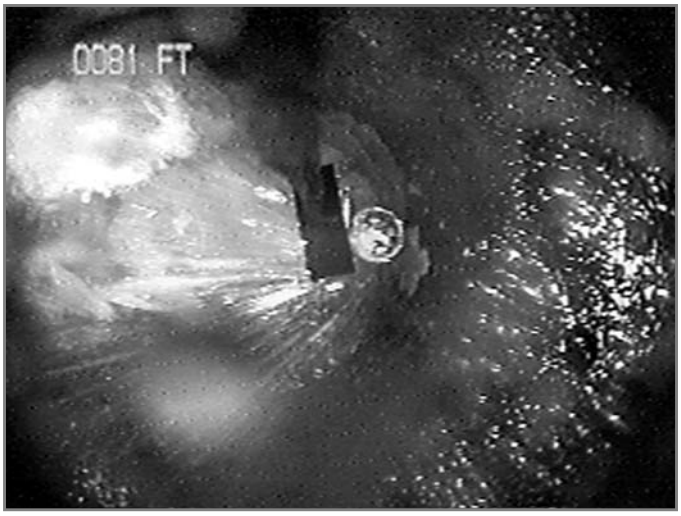

Figure 8. Borehole video still picture showing water entering through broken casing joint at 82 feet below land surface in well MG-1693 (NP-87) during June 2000 aquifer test of well MG-924 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

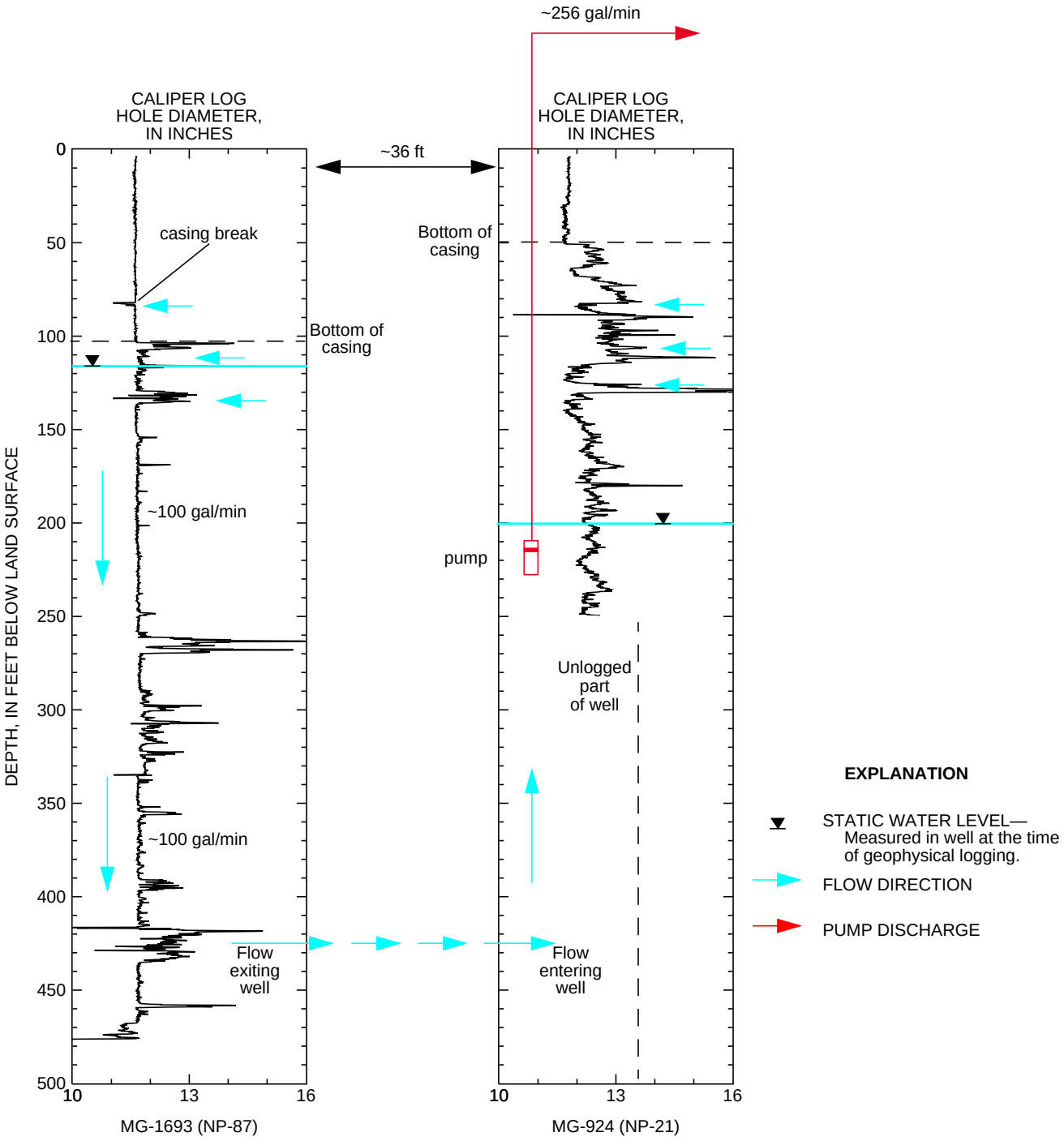

Figure 9. Generalized schematic of flow connection between wells MG-1693 (NP-87) and MG-924 (NP-21) during June 2000 aquifer test at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania. Location of wells is shown on figure 1.

Results of Aquifer-Isolation Tests

Aquifer-isolation tests were conducted using a straddle-packer assembly to isolate discrete intervals to determine specific capacities and to obtain depth-specific water samples. The straddle-packer ("packer") assembly consists of two inflatable packers separated by 2-in. perforated pipe, in which a pump is set for the isolated interval. Tubes to the surface from the isolated and lower intervals were used for manual and transducer water-level measurements. The interval span was 25 ft, measured from the center of the upper packer to the center of the lower packer. The packer assembly was lowered to the selected interval depth and the packers were then inflated individually. For consistency throughout the isolation tests, it was predetermined the lower packer would be inflated first. The packers were inflated with pressurized nitrogen gas. The maximum inflation pressure was 383 pound per square inch for the lower packer when inflated at 461 ft bls. Pressure was monitored and maintained at levels appropriate for the interval depths. Interval depth selection was based on locations of water-bearing zones determined from geophysical log interpretation, and the packers are set at areas of the borehole determined to be relatively smooth from the caliper and borehole-video logs. Interval depth settings given in this report were from center of the upper packer to center of the lower packer. Water levels were monitored continuously and recorded during the tests with pressure transducers set in the upper, isolated, and lower intervals and in nearby wells MG-924 (NP-21) and MG-1661 (W-13). Periodically, water levels were checked manually with electric water-level tapes to verify transducer measurements. Water samples were collected and sent for analysis by TetraTech, Inc., using USEPA standards, and the results are presented in this report. Specific capacities of the isolated intervals were determined by dividing the pumping rate for the interval by the drawdown in the interval just prior to pump shutdown.

On the basis of the borehole geophysical logs and heat-pulse-flowmeter measurements, 13 intervals were selected for aquifer-isolation testing (table 3 and fig. 10). For intervals 9 and 12, only the upper packer was inflated (fig. 4A); for all other intervals, both packers were inflated (fig. 4B).

Water-level recording was started prior to packer inflation. After inflation, water levels were allowed to (roughly) stabilize prior to pumping. After water-level stabilization, the isolated interval was pumped at the maximum rate that allowed continuous measurement of the water level in that interval. Once the pumping water level in the isolated interval stabilized, the pump was shut off. Water levels were then allowed to recover to stabilized or near-stabilized levels in all three intervals before the packers were deflated. Intervals 1, 2, 5, 6, and 10 were redone to use a single pumping rate; the inflation and pumping hydrographs for these intervals have different start times for each test. The isolated intervals, quantity of water pumped, and specific capacity of each interval are summarized in table 3.

Table 3. Summary of intervals isolated during aquifer-isolation tests for well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

[TD, total depth of well]

Interval	Isolated depth interval (feet below land surface)	Description and reason for selection	Total water pumped (gallons)	Specific capacity (gallons per minute per foot)
1	68-93	Broken casing joint, water-receiving	2,060	2.09
2	87-112	High-angle fracture, water-receiving	2,925	.27
3	99-124	Low-angle fracture at 116 ft bls	1,303	.30
4	124-149	High-angle fracture, water-producing	1,479	.29
5	252-277	High-angle fracture, possibly water-bearing	406	.03
6	277-302	High-angle fracture, possibly water-bearing	154	.04
7	302-327	Rough zone, possibly water-bearing	610	.09
8	339-364	High-angle fracture, possibly water-bearing	101	.09
9	362-TD	All borehole below interval 8	2,184	2.12
10	382-407	Broken zone, possibly water-bearing	97	.04
11	412-437	Extended high-angle fracture, water-producing	2,160	2.17
12	436-TD	All borehole below interval 11	1,311	3.09
13	436-461	High-angle fracture, possibly water-bearing	1,257	3.08

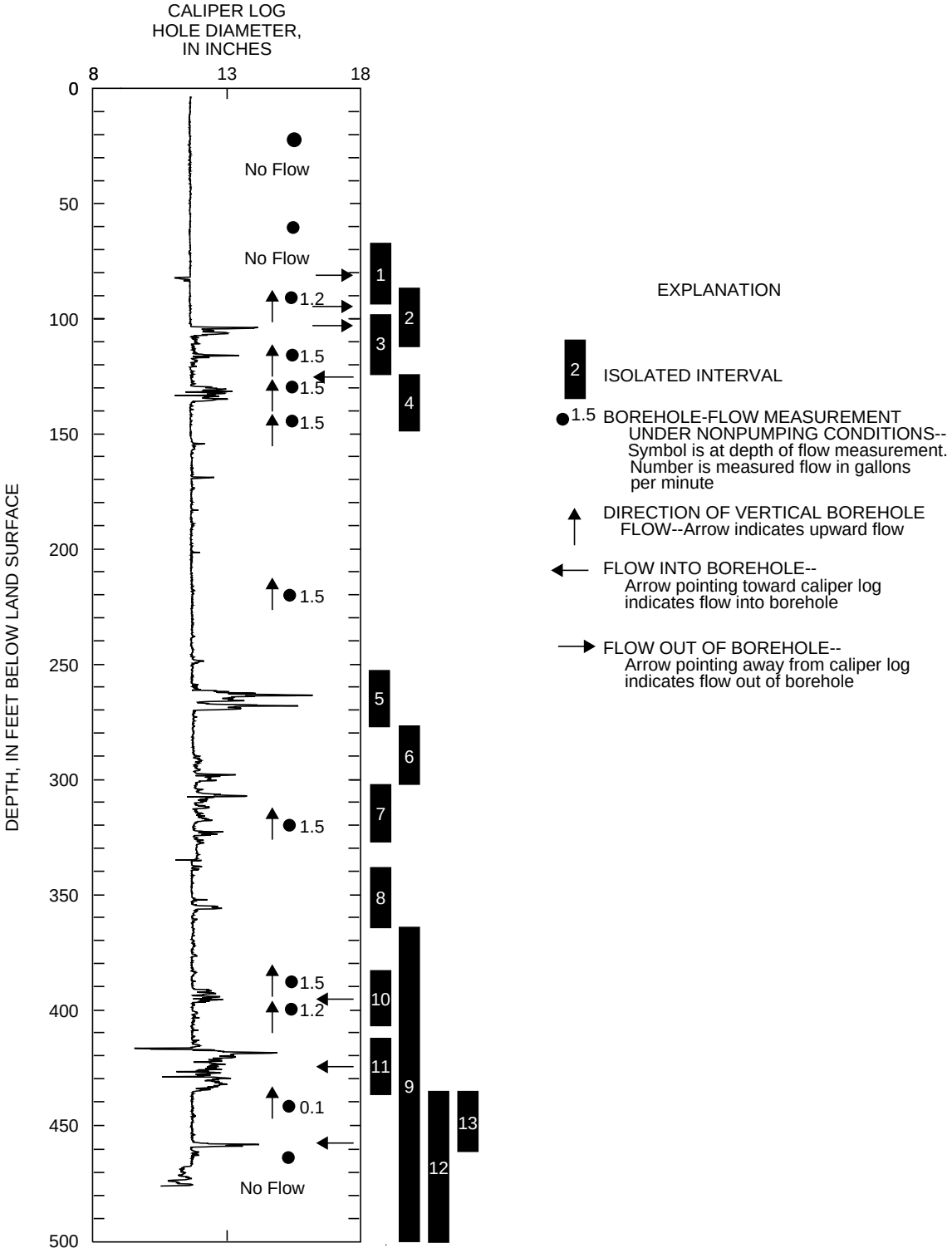

Figure 10. Caliper log, borehole-flow measurements, and isolated intervals in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 1 (68-93 Feet Below Land Surface)

Interval 1 isolated a broken casing joint at 82 ft bls (fig. 11). The center of the top packer was placed at 68 ft bls and the center of the bottom packer was placed at 93 ft bls. The static water level in the open borehole prior to inflation was 1.06 ft als. Fifty-four minutes after start of lower-packer inflation, the water level was 0.94 ft als in the upper interval, 4.42 ft als in the lower interval, 3.91 ft bls in the isolated interval, and 2.81 ft als in well MG-924 (NP-21) (fig. 12). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated interval had a lower head than the water-producing fractures below it. The inflation hydrograph showed the connection with well MG-924 (NP-21) through lower intervals. This is consistent with the results of the aquifer test of June 2000, which indicated a very strong hydraulic connection between well MG-924 (NP-21) and well MG-1693 (NP-87) through the extended high-angle fracture from 416 to 435 ft bls (Risser and Bird, 2003).

The isolated interval was pumped at 22.8 gal/min for 90 minutes. Drawdown was 10.9 ft in the isolated interval (fig. 13). The water level in the upper interval dropped 0.10 ft. The water level rose 0.13 ft in the lower interval and 0.11 ft in well MG-924 (NP-21). The drawdowns indicated interval 1 was isolated from the rest of the borehole. The specific capacity of the isolated interval was 2.09 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.36 ft after packer inflation, indicating hydraulic head in this well was partially influenced through the broken casing joint in well MG-1693 (NP-87) by intervals in well MG-1693 below the casing (fig. 14). Drawdown in well MG-1661 (W-13) was 1.43 ft during pumping of well MG-1693 (NP-87). This supports the conclusion that this well was hydraulically connected to well MG-1693 through the broken casing joint in well MG-1693 at 82 ft bls.

Figure 11. Borehole video still picture showing broken casing joint at 82 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

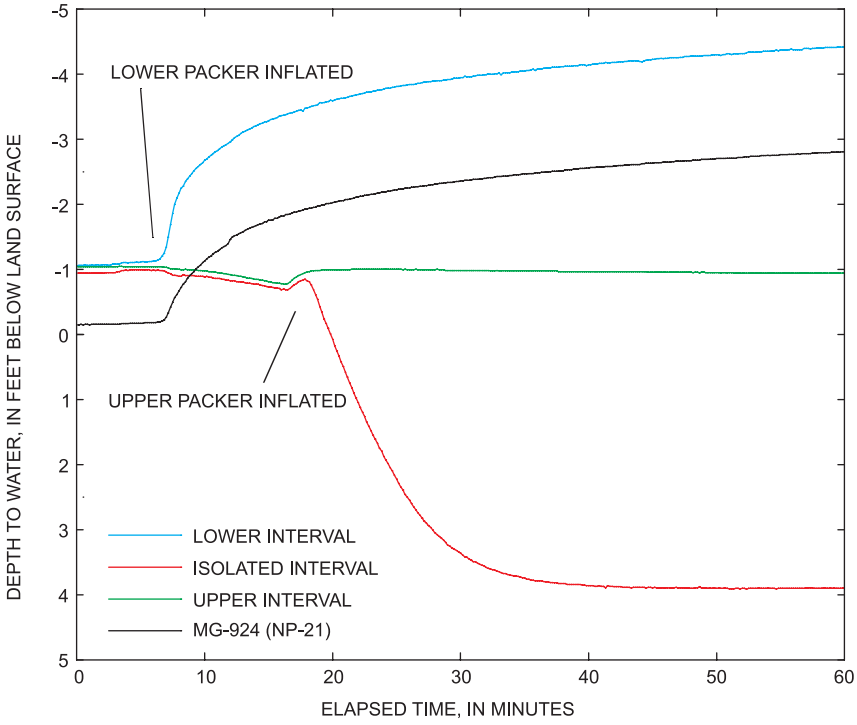

Figure 12. Hydrographs from packer inflation of interval 1 (68 to 93 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

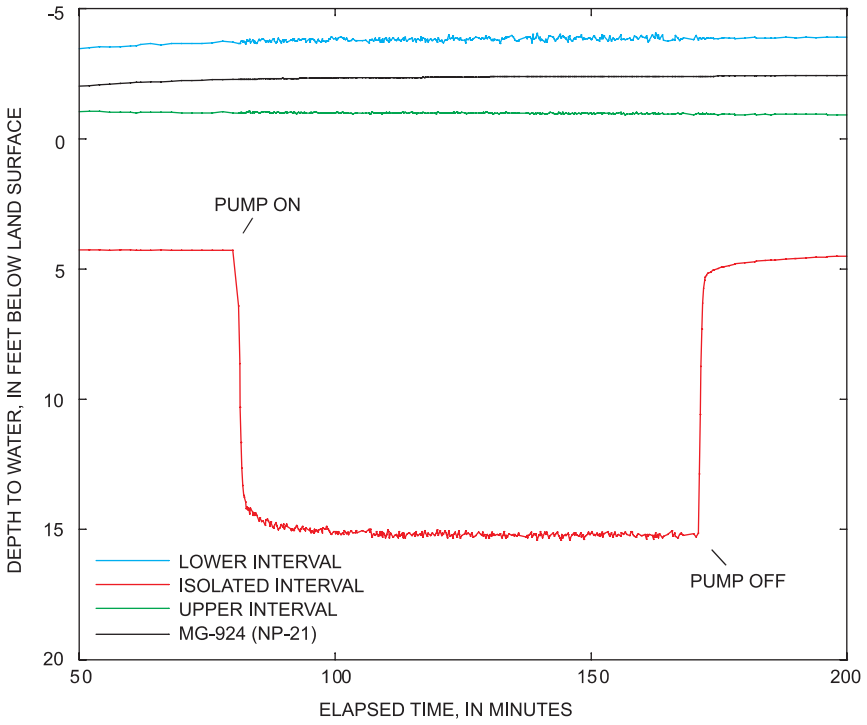

Figure 13. Hydrographs from aquifer-isolation test of interval 1 (68 to 93 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

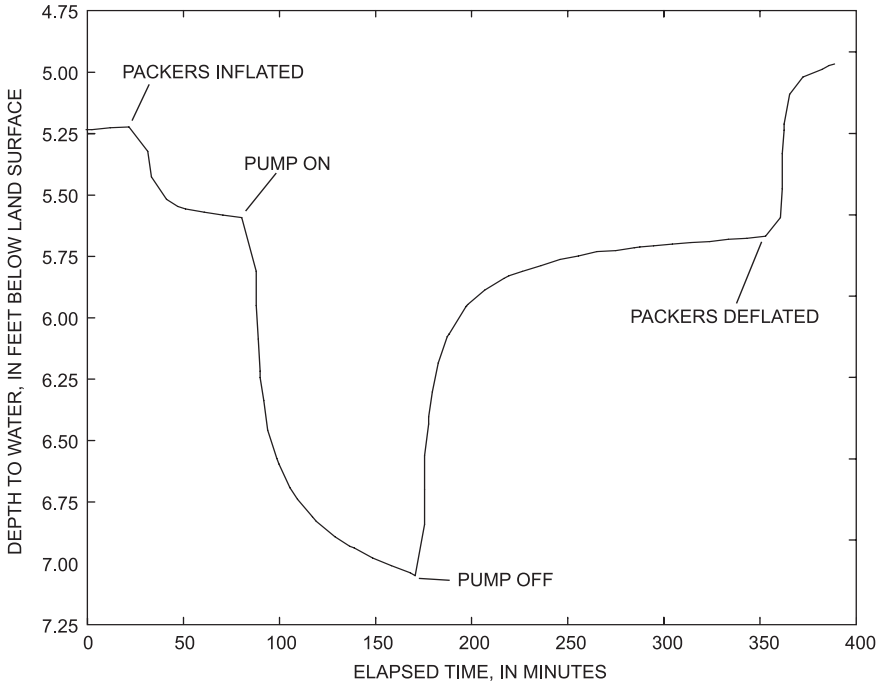

Figure 14. Hydrograph of well MG-1661 (W-13) during aquifer-isolation test of interval 1 (68 to 93 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 2 (87-112 Feet Below Land Surface)

Interval 2 isolated a high-angle fracture from 104 ft (bottom of casing) to 107 ft bls (fig. 15). The center of the top packer was placed at 87 ft bls, just below the broken casing joint at 82 ft bls, and the center of the bottom packer was placed at 112 ft bls. The static water level in the open borehole prior to inflation was 1.03 ft als. Eighty-six minutes after start of lower-packer inflation, the water level was 4.26 ft bls in the upper interval, 1.70 ft bls in the isolated interval, 5.68 ft als in the lower interval, and 4.39 ft als in well MG-924 (NP-21) (fig. 16). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the lower interval had a higher hydraulic head than the isolated and upper intervals. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

The isolated interval was pumped at 19.5 gal/min for 150 minutes (fig. 17). Drawdown was 71.8 ft in the isolated interval, 0.31 ft in the upper interval, and 0.01 ft in well MG-924 (NP-21). The water level rose 0.40 ft in the lower interval. The drawdowns indicated little hydraulic connection among the three intervals. The specific capacity of the isolated interval was 0.27 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.48 ft after packer inflation (fig. 18). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.20 ft during pumping of well MG-1693 (NP-87). This drawdown indicated a slight hydraulic connection between well MG-1661 (W-13) and the high-angle fracture at 104 to 107 ft bls in well MG-1693 (NP-87).

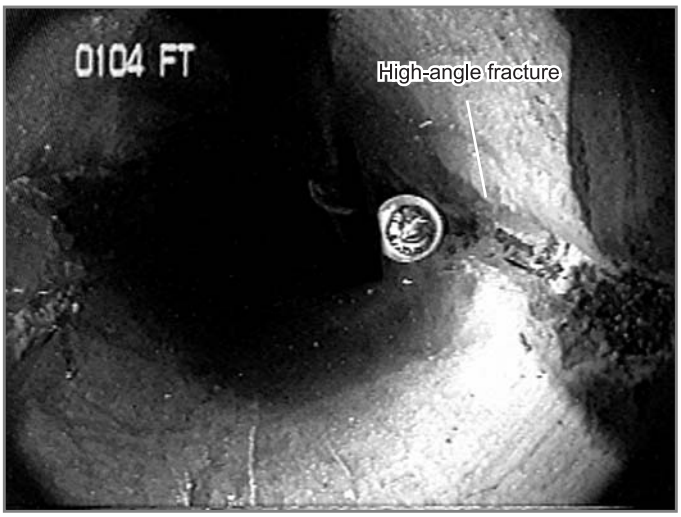

Figure 15. Borehole video still picture showing high-angle fracture at 104 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

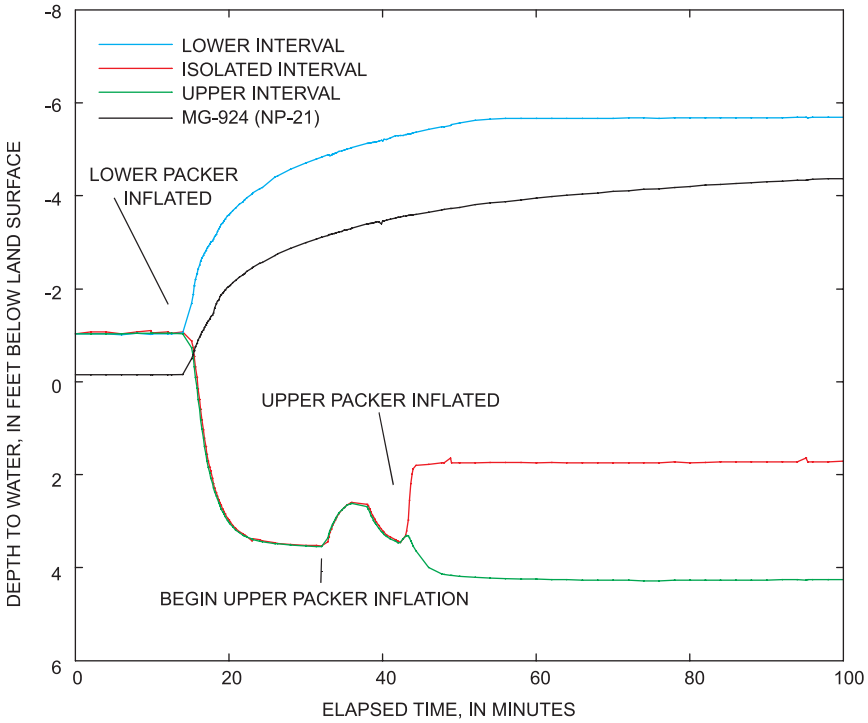

Figure 16. Hydrographs from packer inflation of interval 2 (87 to 112 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

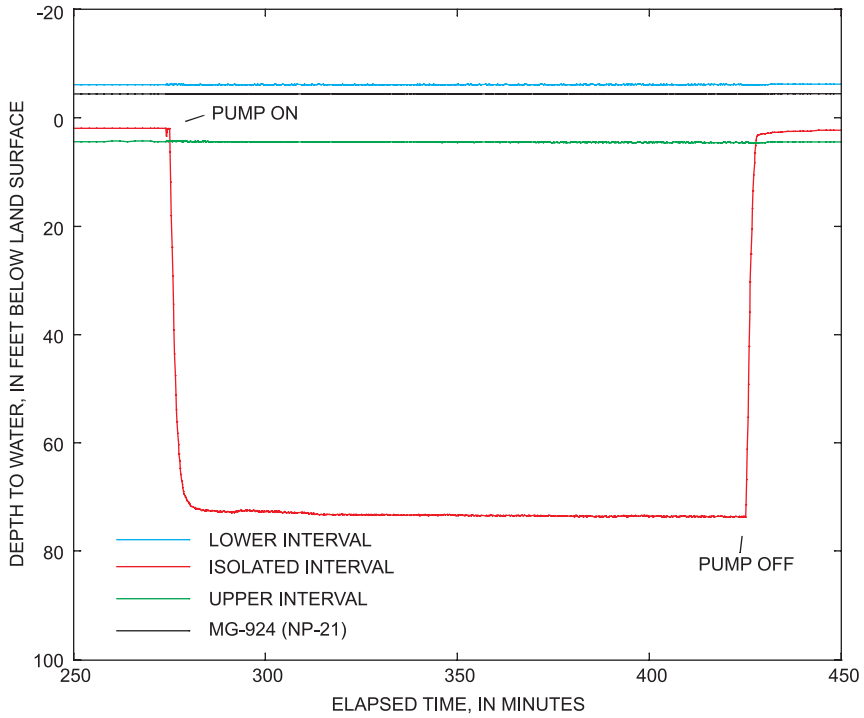

Figure 17. Hydrographs from aquifer-isolation test of interval 2 (87 to 112 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

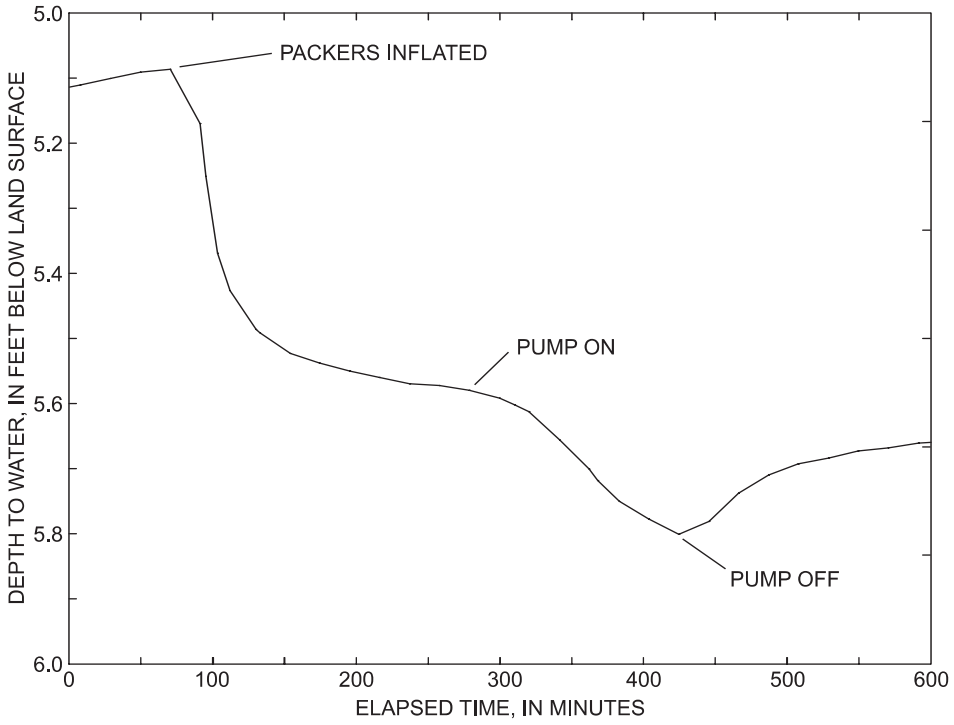

Figure 18. Hydrograph of well MG-1661 (W-13) during aquifer-isolation test of interval 2 (87 to 112 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 3 (99-124 Feet Below Land Surface)

Interval 3 isolated the high-angle fracture at 104 to 107 ft bls from interval 2 and also included a low-angle fracture at 116 ft bls (fig. 19). The center of the top packer was placed at 99 ft bls and the center of the bottom packer was placed at 124 ft bls. The static water levels prior to inflation were 1.07 ft als in the open borehole and 0.19 ft als in well MG-924 (NP-21). Ninety-nine minutes after start of lower-packer inflation, the water level was 1.82 ft bls in the isolated interval, 4.21 ft bls in the upper interval, 6.07 ft als in the lower interval, and 4.38 ft als in well MG-924 (NP-21) (fig. 20). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the lower interval had a higher head than the isolated and upper intervals. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

After packer inflation, a short pump test was run to determine an appropriate pumping rate. The pump was then turned off and the well was allowed to recover for 37 hours while the packers remained inflated. The full pump test was then run (fig. 21).

The isolated interval was pumped at 21.7 gal/min for 60 minutes (fig. 21). Drawdown was 72.75 ft in the isolated interval and 0.10 ft in the upper interval. The water level rose 0.12 ft in the lower interval and 0.07 ft in well MG-924 (NP-21). Drawdowns in the upper interval and water-level increases in the lower interval and well MG-924 (NP-21) indicated little hydraulic connection between MG-924 and the isolated interval and little water was contributed by the low-angle fracture at 116 ft bls. The specific capacity of the isolated interval was 0.30 (gal/min)/ft.

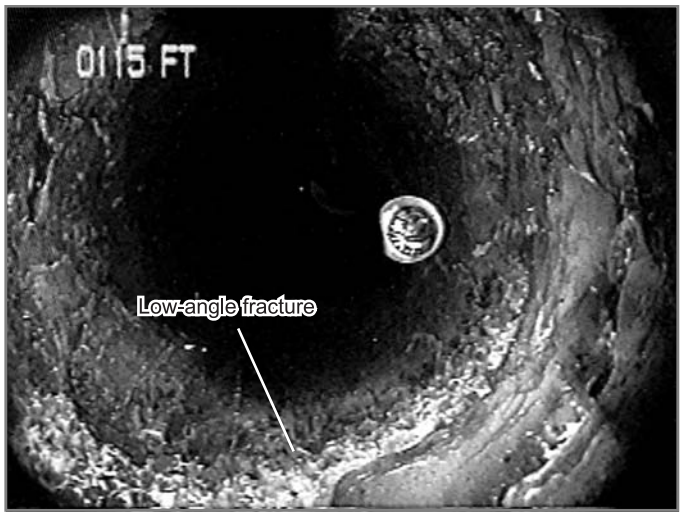

Figure 19. Borehole video still picture showing low-angle fracture at 116 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

The water level in well MG-1661 (W-13) dropped 0.30 ft after packer inflation (fig. 22). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.23 ft during pumping of well MG-1693 (NP-87). The drawdown during pumping indicated a slight hydraulic connection between well MG-1661 (W-13) and isolated interval 3 in well MG-1693 (NP-87). The hydrograph for well MG-1661 (W-13) shows the packer inflations and the pump-rate test (fig. 22).

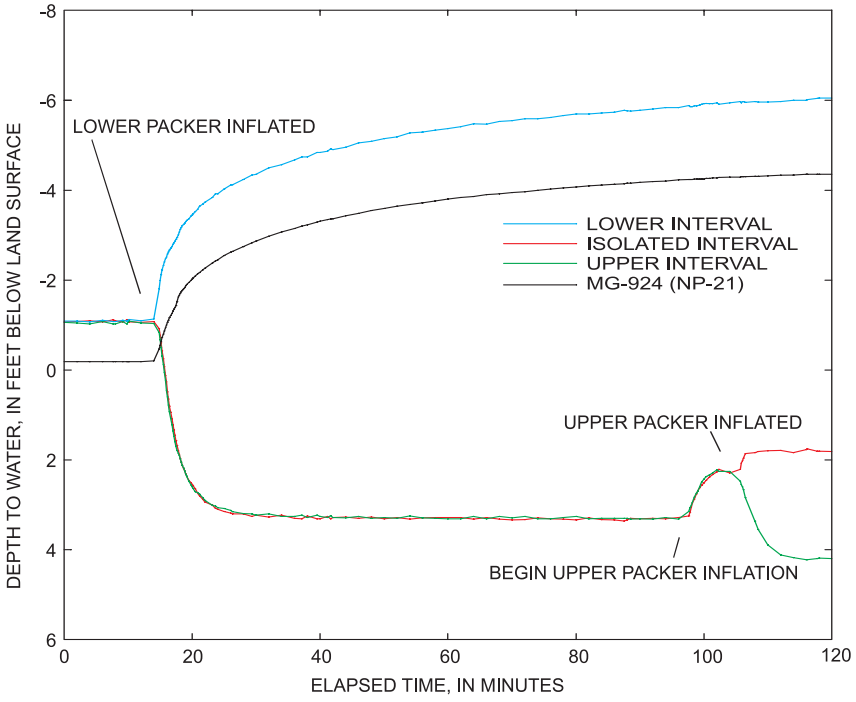

Figure 20. Hydrographs from packer inflation of interval 3 (99 to 124 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

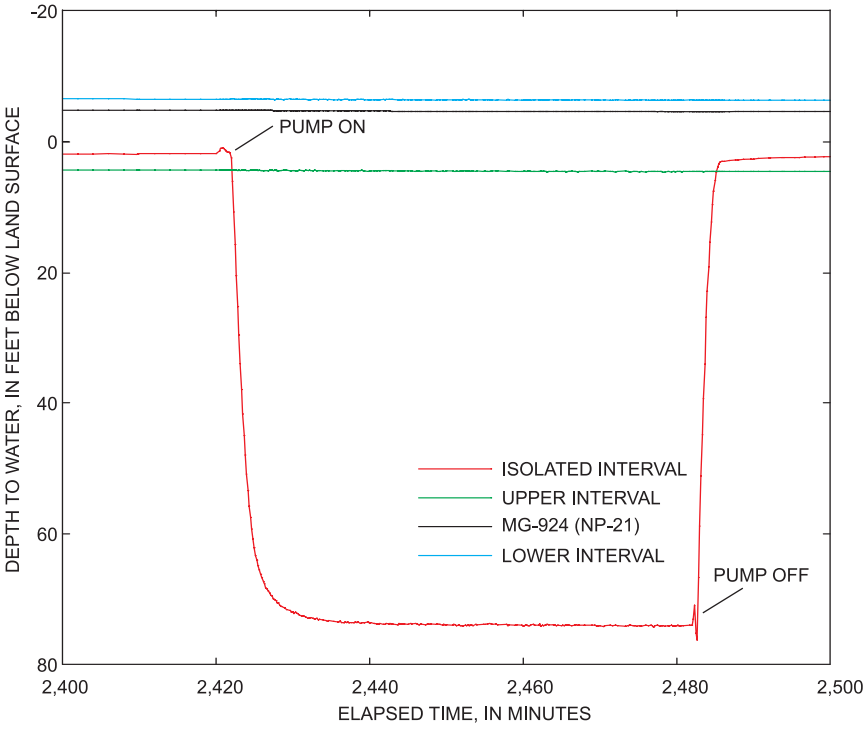

Figure 21. Hydrographs from aquifer-isolation test of interval 3 (99 to 124 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

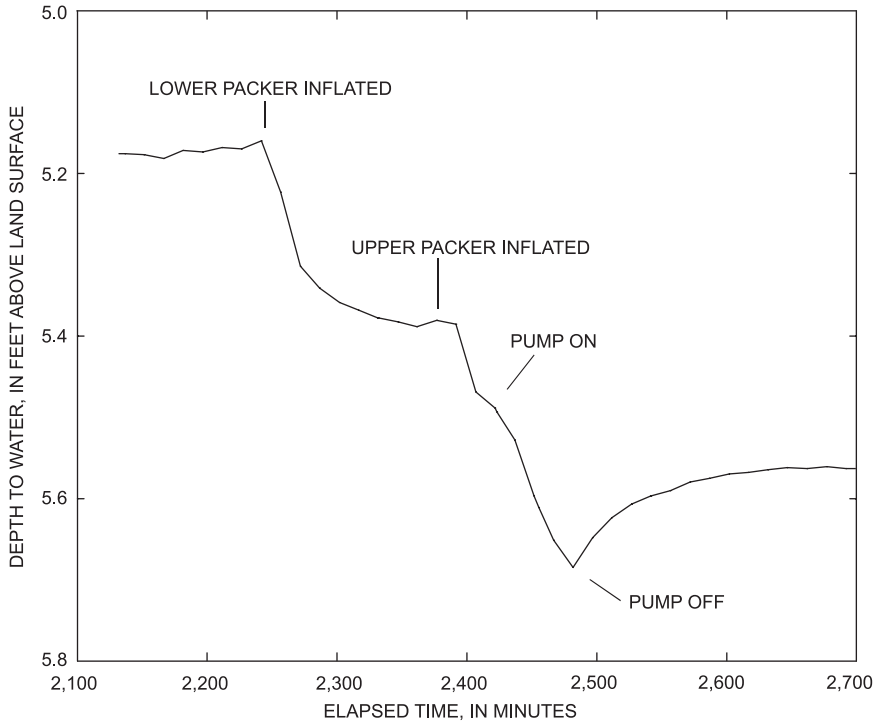

Figure 22. Hydrograph in well MG-1661 (W-13) during pump-rate test of interval 3 (99 to 124 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 4 (124-149 Feet Below Land Surface)

Interval 4 isolated a high-angle fracture from 129 to 136 ft bls (fig. 23). The center of the top packer was placed at 124 ft bls and the center of the bottom packer was placed at 149 ft bls. The static water level in the open borehole prior to inflation was 1.02 ft als. Fifty-two minutes after start of lower-packer inflation, the water level was 5.14 ft als in the isolated interval, 3.39 ft bls in the upper interval, 5.75 ft als in the lower interval, and 4.21 ft als in well MG-924 (NP-21) (fig. 24). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the lower and isolated intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through the lower intervals.

The isolated interval was pumped at 19.72 gal/min for 40 minutes (fig. 25). Drawdown was 68.29 ft in the isolated interval, 0.05 ft in the upper interval, 3.12 ft in the lower interval, and 2.76 ft in well MG-924 (NP-21). Drawdown in the lower interval indicated some hydraulic connection between the isolated and lower intervals. Drawdown in well MG-924 (NP-21) was similar in magnitude to drawdown in the lower interval and indicated a hydraulic connection between MG-924 (NP-21) and the lower interval. The specific capacity of the isolated interval was 0.29 (gal/min)/ft.

No data was collected in well MG-1661 (W-13) for isolated interval 4 in well MG-924 (NP-87) because of transducer failure.

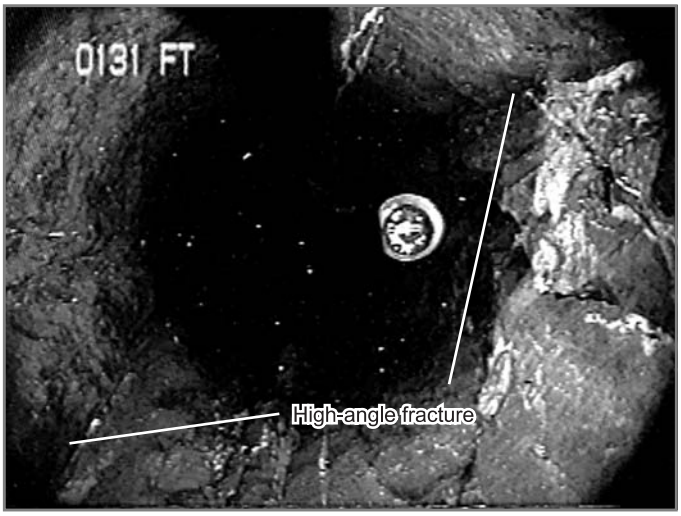

Figure 23. Borehole video still picture showing high-angle fracture at 131 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

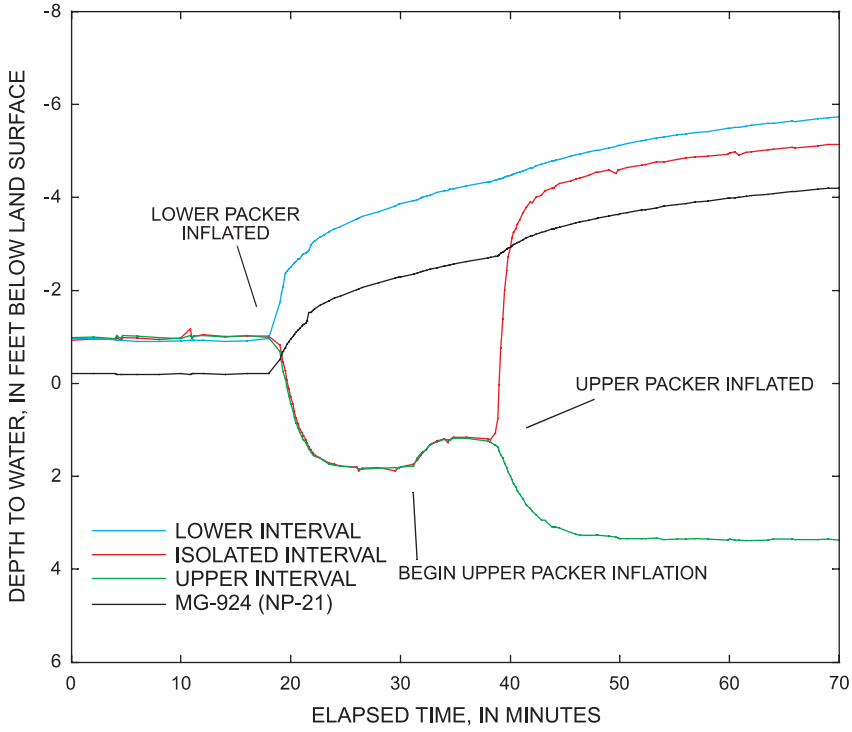

Figure 24. Hydrographs from packer inflation of interval 4 (124 to 149 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

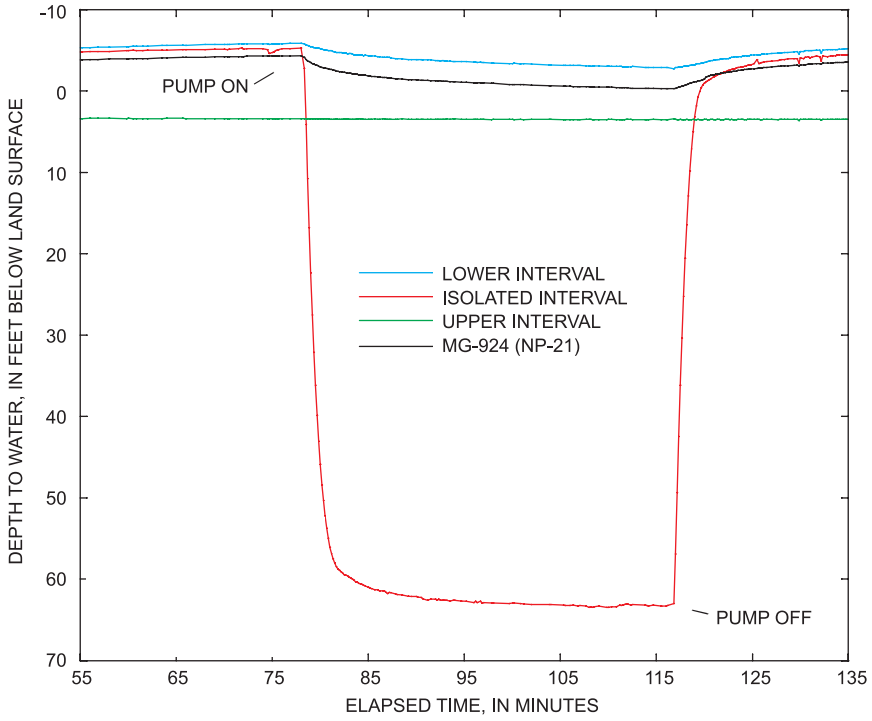

Figure 25. Hydrographs from aquifer-isolation test of interval 4 (124 to 149 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 5 (252-277 Feet Below Land Surface)

Interval 5 isolated a high-angle fracture from 260 to 270 ft bls (fig. 26). The center of the top packer was placed at 252 ft bls and the center of the bottom packer was placed at 277 ft bls. The static water level in the open borehole prior to inflation was 1.08 ft als. Forty-eight minutes after start of lower-packer inflation, the water level was 5.49 ft als in the isolated interval, 1.86 ft bls in the upper interval, 4.33 ft als in the lower interval, and 2.79 ft als in well MG-924 (NP-21) (fig. 27). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated and lower intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

The isolated interval was pumped at 3.4 gal/min for 121 minutes (fig. 28). Drawdown was 108.9 ft in the isolated interval, 0.06 ft in the upper interval, 0.48 ft in the lower interval, and 0.34 ft in well MG-924 (NP-21). Drawdown in the lower interval indicated a slight hydraulic connection between the isolated and lower intervals and between the isolated interval and well MG-924 (NP-21). The specific capacity of the isolated interval was 0.03 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.18 ft after packer inflation (fig. 29). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.02 ft during pumping of well MG-1693 (NP-87). This drawdown indicated no connection between well MG-1661 (W-13) and the high-angle fracture at 260 to 270 ft bls in well MG-1693 (NP-87).

Figure 26. Borehole video still picture showing high-angle fracture at 264 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

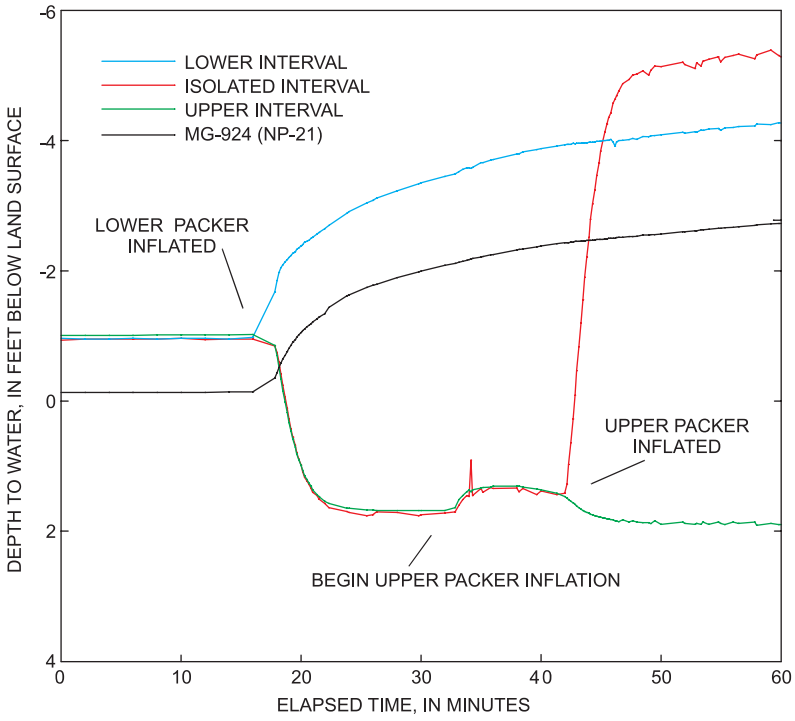

Figure 27. Hydrographs from packer inflation of interval 5 (252 to 277 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

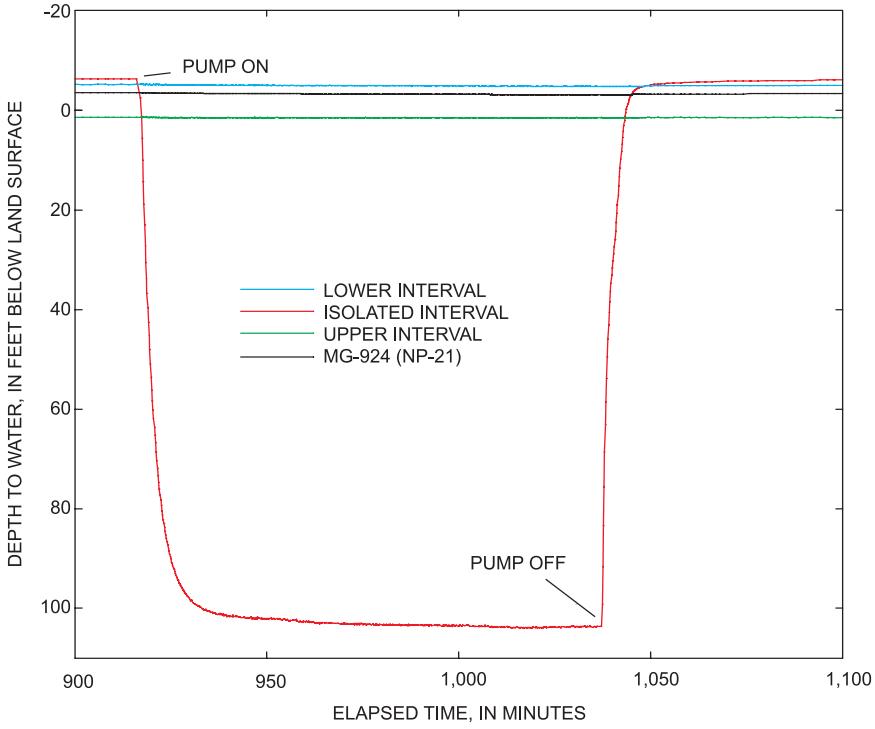

Figure 28. Hydrographs from aquifer-isolation test of interval 5 (252 to 277 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

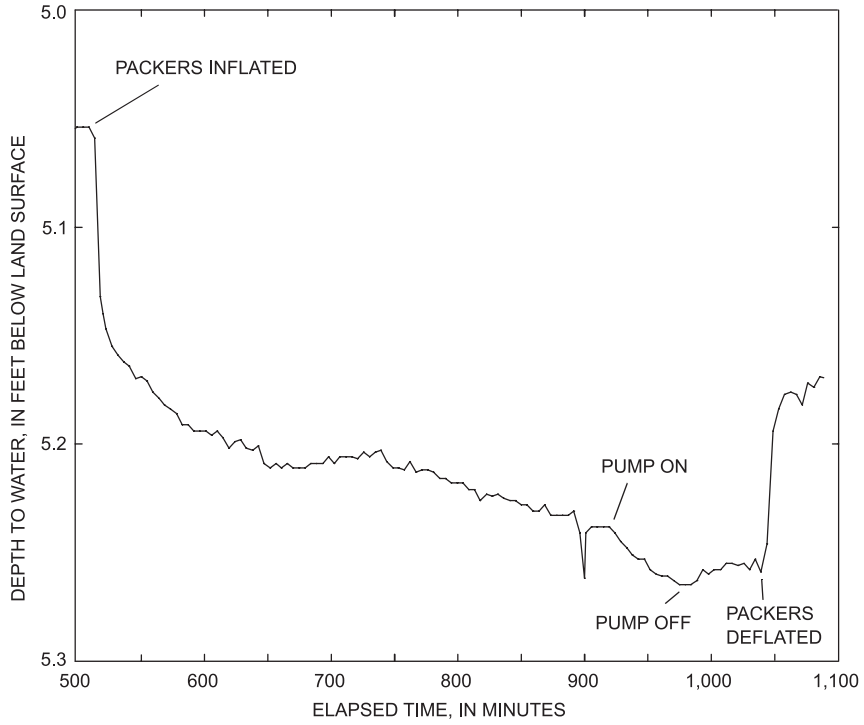

Figure 29. Hydrograph of well MG-1661 (W-13) during aquifer-isolation test of interval 5 (252 to 277 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 6 (277-302 Feet Below Land Surface)

Interval 6 isolated a high-angle fracture zone from 297 to 301 ft bls (fig. 30). The center of the top packer was placed at 277 ft bls and the center of the bottom packer was placed at 302 ft bls. The static water level in the open borehole prior to inflation was 1.06 ft als. One-hundred twenty-seven minutes after start of lower-packer inflation, the water level was 5.42 ft als in the isolated interval, 1.60 ft bls in the upper interval, 5.18 ft als in the lower interval, and 3.46 ft als in well MG-924 (NP-21) (fig. 31). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated and lower intervals have a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

The isolated interval was pumped at 3.4 gal/min for 45 minutes (fig. 32). Drawdown was 90.3 ft in the isolated interval, 0.12 ft in the upper interval, 1.92 ft in the lower interval, and 0.51 ft in well MG-924 (NP-21). Drawdown in the lower interval indicated a slight hydraulic connection between the isolated and lower intervals. Drawdown in well MG-924 (NP-21) indicated negligible hydraulic connection with the isolated interval. The specific capacity of the isolated interval was 0.04 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.12 ft after packer inflation (fig. 33). The drop was probably the result of the isolation of the broken casing joint from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.03 ft during pumping of well MG-1693 (NP-87). This drawdown indicated no connection between well MG-1661 (W-13) and the high-angle fracture zone at 297 to 301 ft bls in well MG-1693 (NP-87).

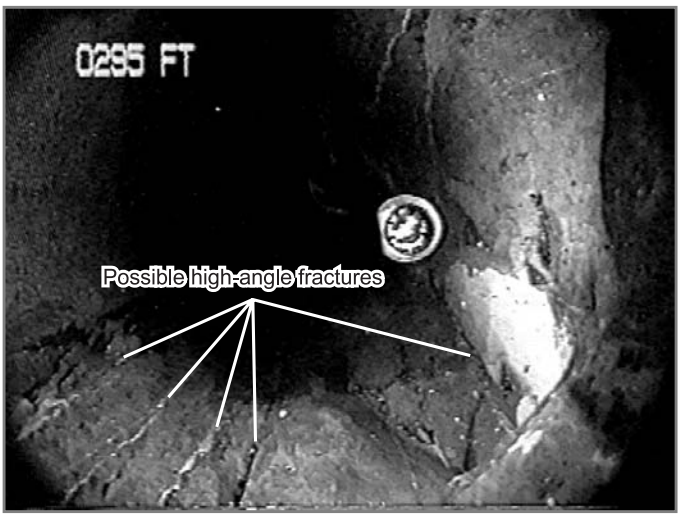

Figure 30. Borehole video still picture showing possible high-angle fractures at 295 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

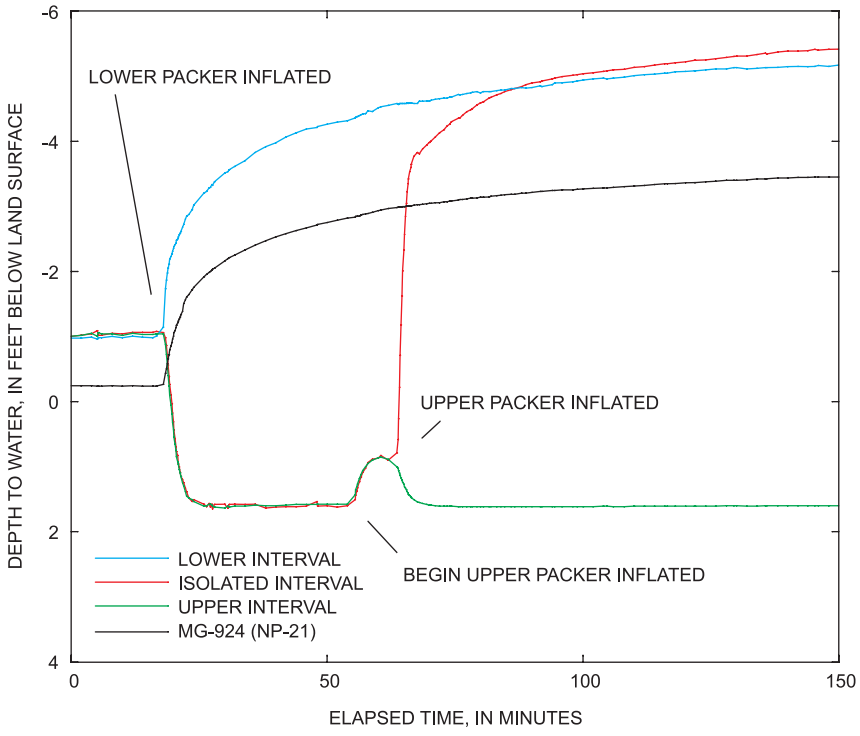

Figure 31. Hydrographs from packer inflation of interval 6 (277 to 302 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

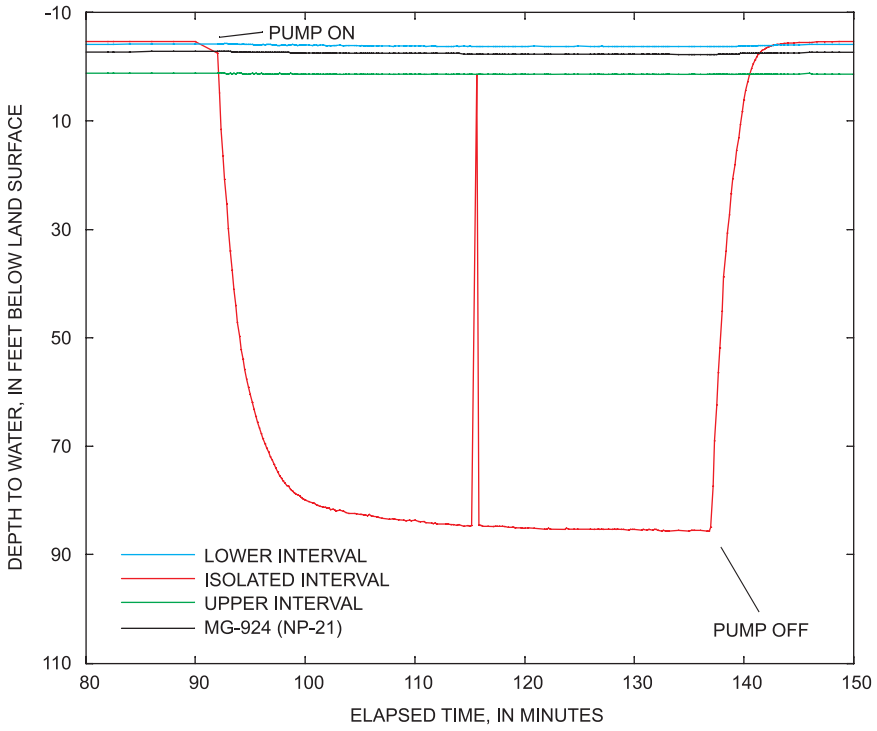

Figure 32. Hydrographs from aquifer-isolation test of interval 6 (277 to 302 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

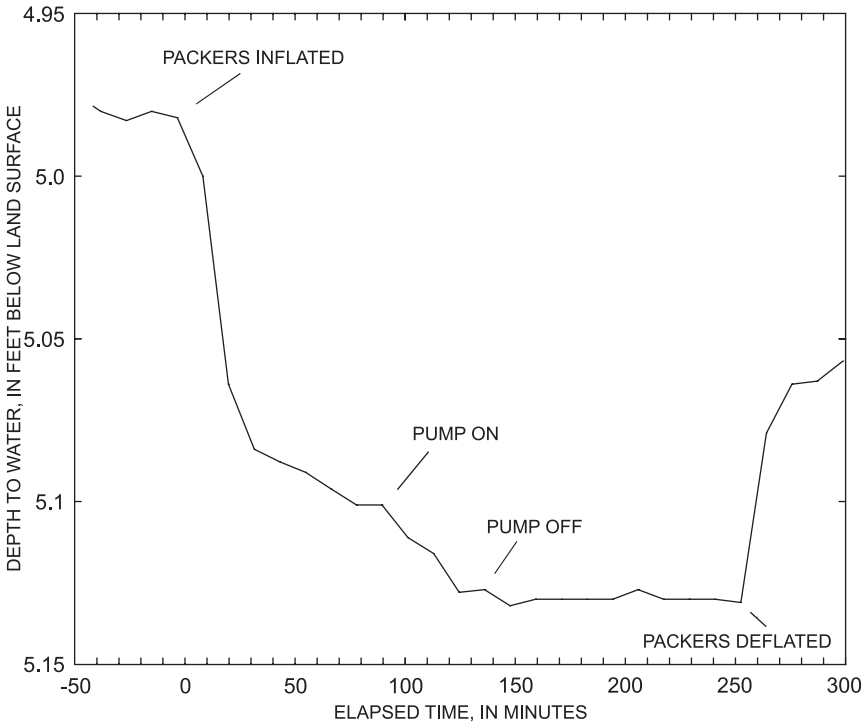

Figure 33. Hydrograph of well MG-1661 (W-13) during aquifer-isolation test of interval 6 (277 to 302 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

An initial test to determine the maximum pumping rate for interval 6 resulted in unexpected water-level changes in the isolated interval (fig. 34). Outgassing from the interval was noted after the inflation of the lower packer and prior to the inflation of the upper packer. Because there was no loss of pressure, this outgassing was not leakage from the lower packer. The initial pumping rate of 17.6 gal/min drew the water level down below the transducer at 115 ft bls. The pump was shut off after 3 minutes, and the water level rose rapidly. Two minutes after pump shut-off, water erupted briefly from the isolated-interval monitoring tube. Following this eruption, the water level dropped rapidly, then rebounded along a more gentle recovery curve (fig. 34). No further eruptive behavior was observed during water-level recovery. This pump-rate test was repeated twice, with eruptions occurring 2 minutes after pump shutoff in each case. The lower packer was deflated first, then the upper packer was deflated. Upon deflation of the upper packer, well MG-1693 (NP-87) began artesian flow. Three minutes after the well began to flow, heavy outgassing was observed at the surface for 2 minutes (fig. 35). The water level dropped rapidly upon cessation of outgassing, then recovered more slowly to artesian-flow conditions. The eruptions were probably driven by outgassing, which may be the cause of the sharp spike in the pumping hydrograph (fig. 32).

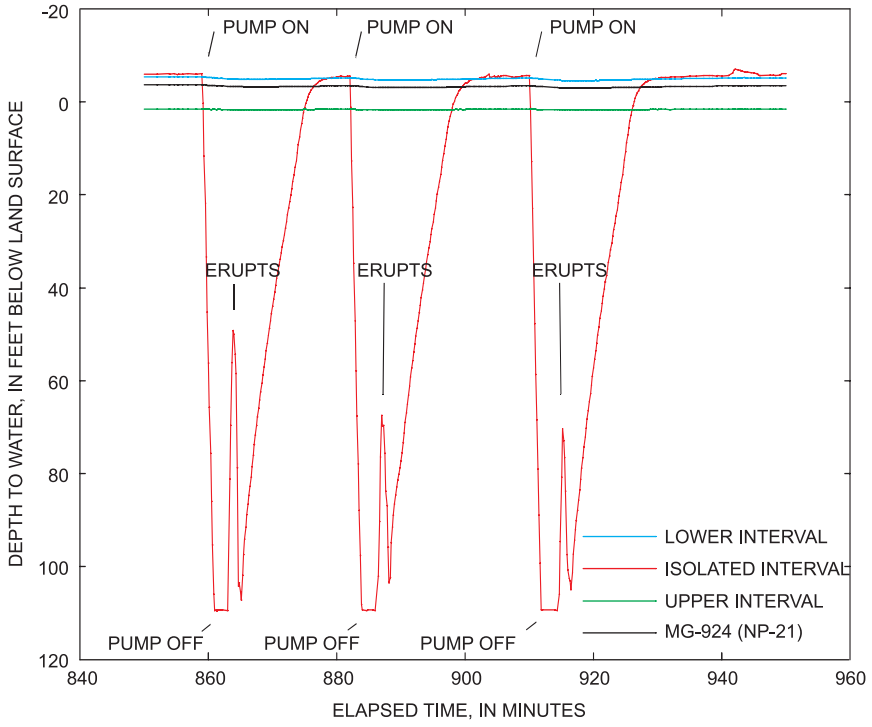

Figure 34. Hydrographs in well MG-1693 (NP-87) from aquifer-isolation test of interval 6 (277 to 302 feet below land surface) in well MG-924 (NP-21) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Figure 35. Well MG-1693 (NP-87) outgassing after packer deflation following interval 6 aquifer-isolation test at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania, June 2002.

Interval 7 (302-327 Feet Below Land Surface)

Interval 7 isolated a rough zone with possible high-angle fractures from 304 to 325 ft bls (fig. 36). The center of the top packer was placed at 302 ft bls and the center of the bottom packer was placed at 327 ft bls. The static water level in the open borehole prior to inflation was 1.02 ft als. Forty-six minutes after start of lower-packer inflation, the water level was 5.19 ft als in the isolated interval, 1.40 ft bls in the upper interval, 4.33 ft als in the lower interval, and 3.07 ft als in well MG-924 (NP-21) (fig. 37). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated and lower intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

After packer inflation, a short pump test was run to determine an appropriate pumping rate. The pump was then turned off and the well allowed to recover overnight while the packers remained inflated. The full pump test was run the next day (fig. 38).

The isolated interval was pumped at 8.7 gal/min for 70 minutes (fig. 38). Drawdown was 93.9 ft in the isolated interval, 0.44 ft in the upper interval, 2.29 ft in the lower interval, and 1.65 ft in well MG-924 (NP-21). Drawdown in the lower interval indicated some hydraulic connection between the isolated and lower intervals. Drawdown in well MG-924 (NP-21) was similar in magnitude to drawdown in the lower interval and indicated a hydraulic connection between well MG-924 (NP-21) and the lower interval. The specific capacity of the isolated interval was 0.09 (gal/min)/ft.

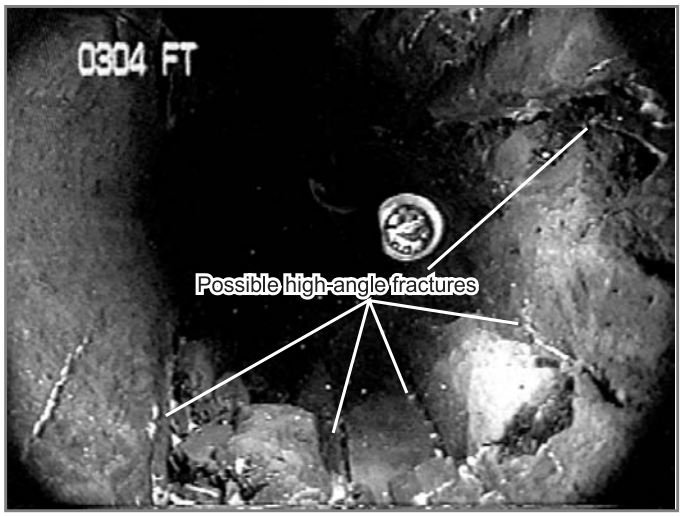

Figure 36. Borehole video still picture showing possible high-angle fractures at 304 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

The water level in well MG-1661 (W-13) dropped 0.09 ft after lower packer inflation (fig. 39). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.04 ft during pumping of well MG-1693 (NP-87). This drawdown indicated no connection between well MG-1661 (W-13) and the rough zone fractures at 304 to 327 ft bls in well MG-1693 (NP-87).

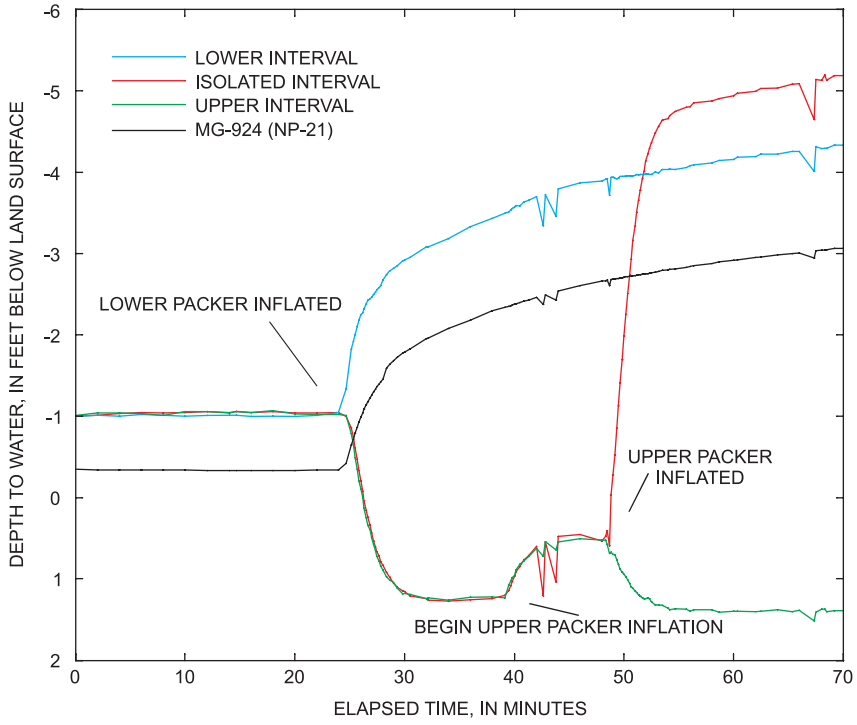

Figure 37. Hydrographs from packer inflation of interval 7 (302 to 327 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

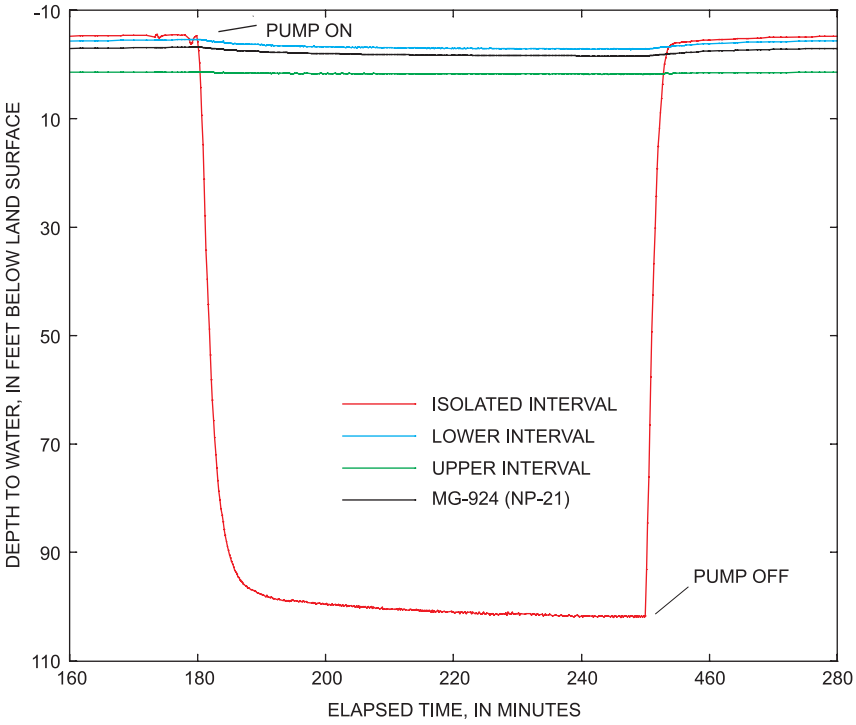

Figure 38. Hydrographs from aquifer-isolation test of interval 7 (302 to 327 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

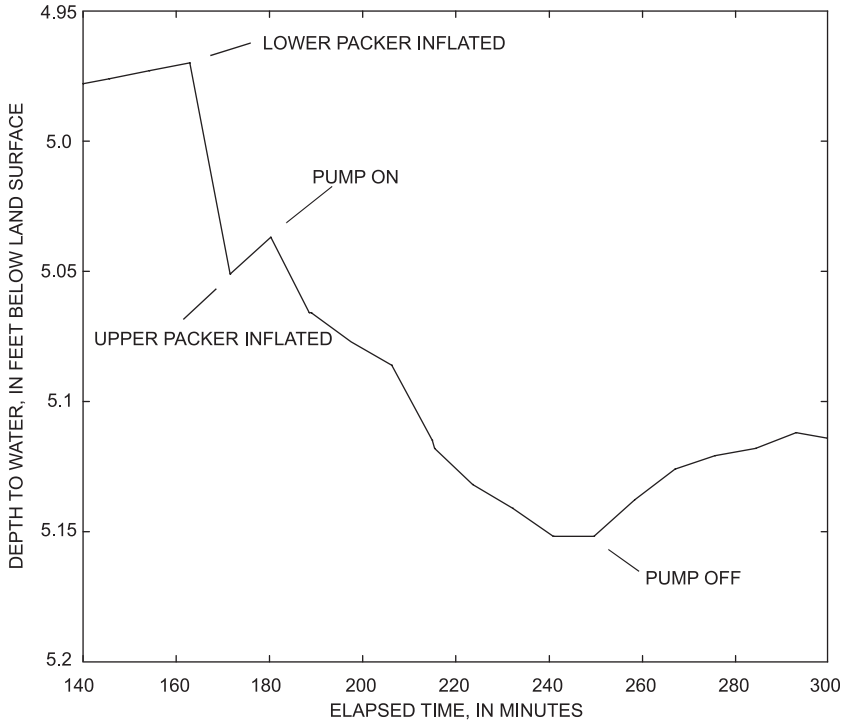

Figure 39. Hydrograph of well MG-1661 (W-13) during aquifer-isolation test of interval 7 (302 to 327 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 8 (339-364 Feet Below Land Surface)

Interval 8 isolated a high-angle fracture from 352 ft bls to 356 (fig. 40). The center of the top packer was placed at 339 ft bls and the center of the bottom packer was placed at 364 ft bls. The static water levels prior to inflation were 1.08 ft als in the open borehole and 0.23 ft als in well MG-924 (NP-21). Sixty-two minutes after start of lower-packer inflation, the water level was 4.11 ft als in the isolated interval, 0.57 ft bls in the upper interval, 3.56 ft als in the lower interval, and 2.25 ft als in well MG-924 (NP-21) (fig. 41). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated and lower intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through the lower intervals.

The isolated interval was pumped at 3.4 gal/min for 30 minutes (fig. 42). Drawdown was 38.37 ft in the isolated interval, 0.30 ft in the upper interval, 0.60 ft in the lower interval, and 0.54 ft in well MG-924 (NP-21). Drawdowns in the upper and lower intervals indicated slight hydraulic connection between these intervals and the isolated interval. Drawdown in well MG-924 (NP-21) was similar in magnitude to drawdown in the lower interval and indicated a hydraulic connection between MG-924 (NP-21) and the lower interval. The specific capacity of the isolated interval was 0.09 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.08 ft after packer inflation (fig. 43). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.03 ft during pumping of well MG-1693 (NP-87). This drawdown indicated no connection between well MG-1661 (W-13) and the high-angle fracture at 352 to 356 ft bls in well MG-1693 (NP-87).

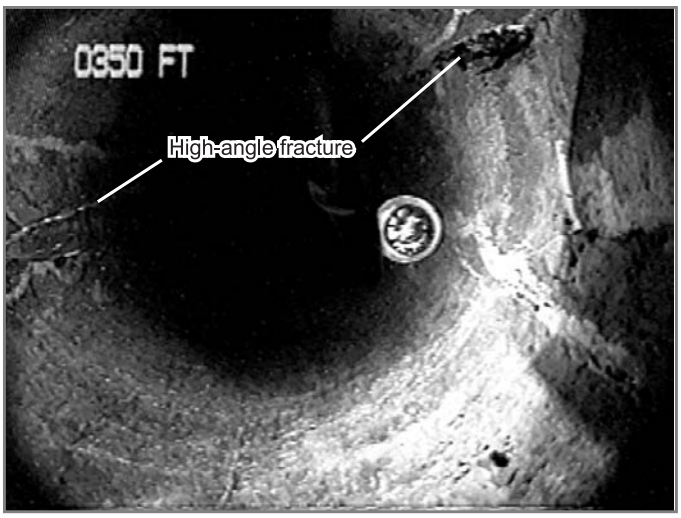

Figure 40. Borehole video still picture showing high-angle fracture at 350 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

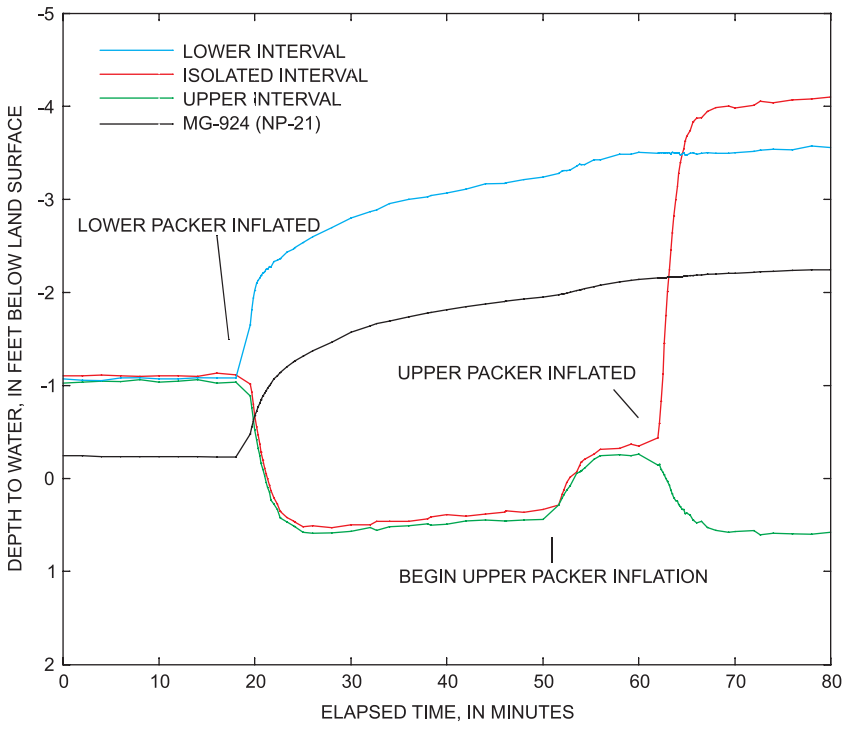

Figure 41. Hydrographs from packer inflation of interval 8 (339 to 364 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

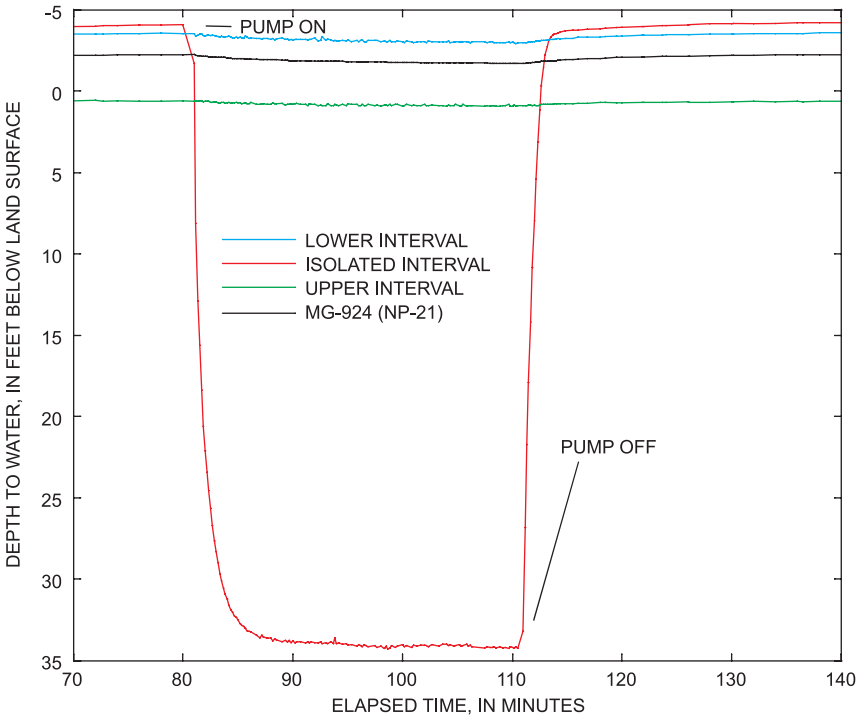

Figure 42. Hydrographs from aquifer-isolation test of interval 8 (339 to 364 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

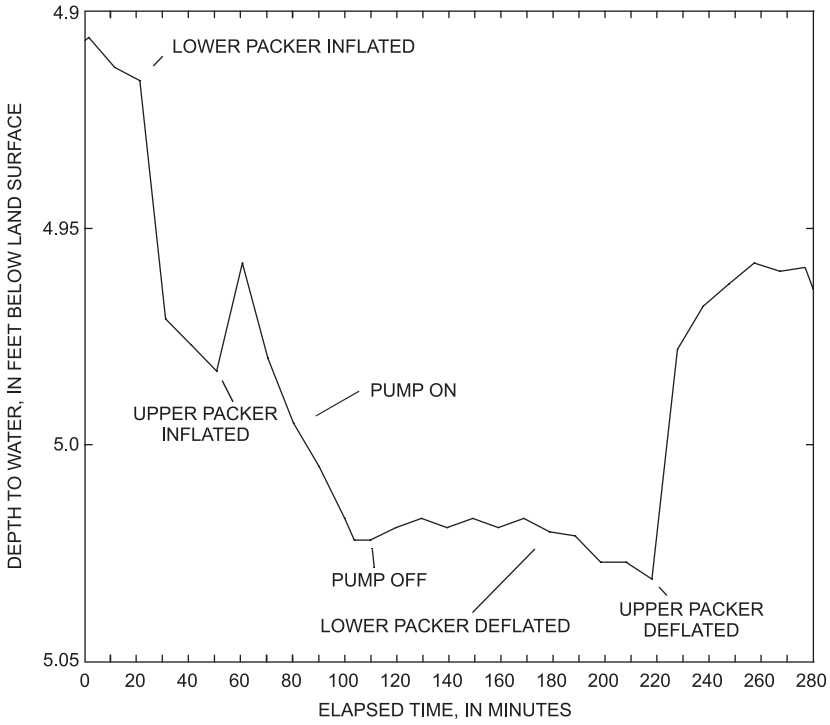

Figure 43. Hydrograph in well MG-1661 (W-13) during aquifer-isolation test of interval 8 (339 to 364 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 9 (362-TD Feet Below Land Surface)

Interval 9 isolated the entire borehole below 362 ft bls. The center of the top packer was placed at 362 ft bls and the bottom packer was not inflated. The static water levels prior to inflation were 1.07 ft als in the open borehole and 0.24 ft als in well MG-924 (NP-21). Fifty minutes after upper-packer inflation, the water level was 3.10 ft als in the isolated interval, 0.78 ft bls in the upper interval, and 1.68 ft als in well MG-924 (NP-21) (fig. 44). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated interval had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through the lower intervals at 362 ft bls.

The isolated interval was pumped at 20.8 gal/min for 105 minutes (fig. 45). Drawdown was 9.80 ft in the isolated interval, 2.15 ft in the upper interval, and 6.91 ft in well MG-924 (NP-21). Drawdown in the upper interval indicated some hydraulic connection between the isolated and upper intervals. Drawdown in well MG-924 (NP-21) indicated a strong hydraulic connection between that well and the borehole below 362 ft bls. The specific capacity of the interval (physically isolated by the packers) was 2.12 (gal/min)/ft, but because the interval was not hydraulically isolated, the test probably over-estimates the specific-capacity value of geologic units within interval 9

The water level in well MG-1661 (W-13) dropped 0.08 ft after packer inflation (fig. 46). The drop was probably the result of the isolation of the broken casing joint at 82 ft bls from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.28 ft during pumping of well MG-1693 (NP-87), which shows that the borehole below 362 ft bls (interval 9) was hydraulically connected to the shallow, weathered bedrock zone—probably through its hydraulic connection to MG-924.

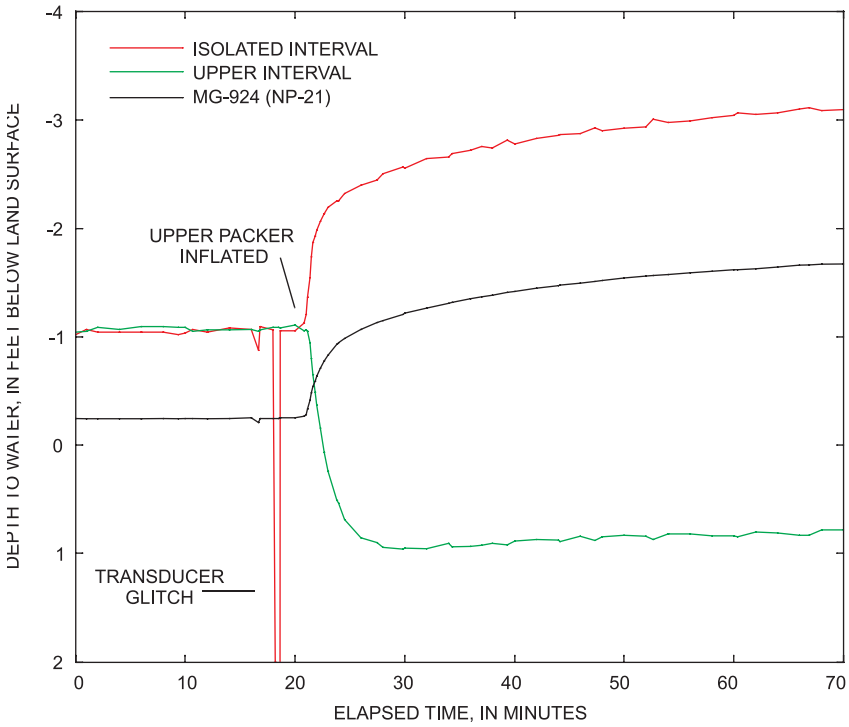

Figure 44. Hydrographs from packer inflation of interval 9 (362 feet below land surface to total depth) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

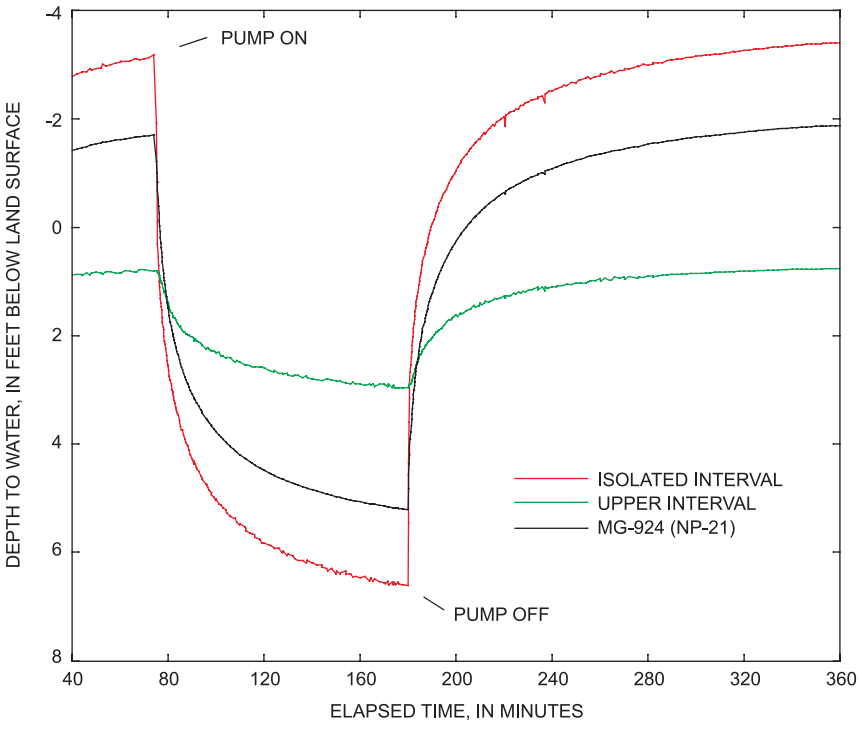

Figure 45. Hydrographs from aquifer-isolation test of interval 9 (362 feet to total depth below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

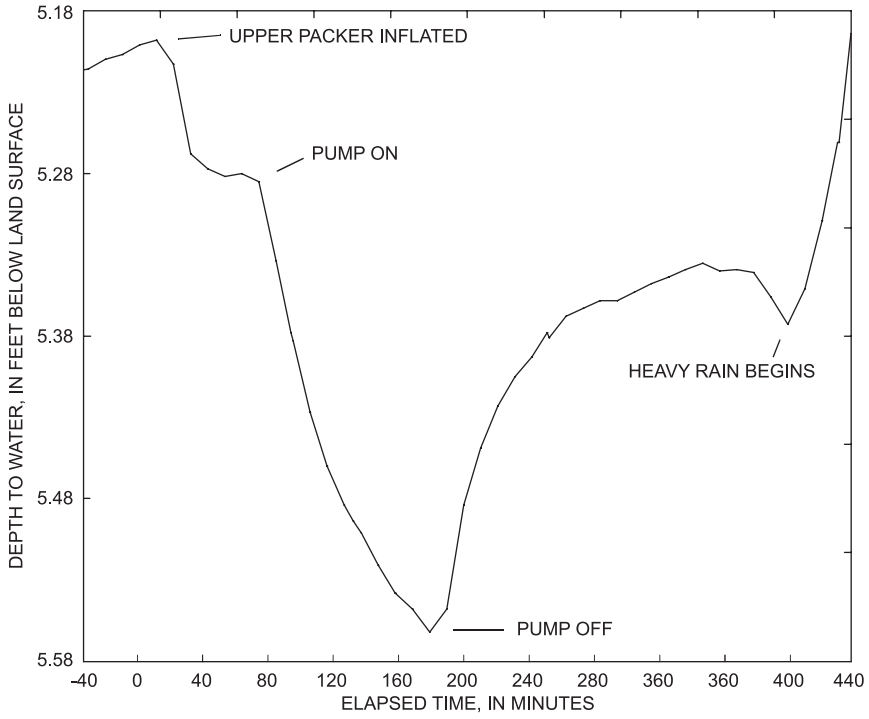

Figure 46. Hydrograph in well MG-1661 (W-13) during aquifer-isolation test of interval 9 (362 feet below land surface to total depth) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 10 (382-407 Feet Below Land Surface)

Interval 10 isolated a rough zone with possible high-angle fractures from 391 to 397 ft bls (fig. 47). The center of the top packer was placed at 382 ft bls and the center of the bottom packer was placed at 407 ft bls. The static water level in the open borehole prior to inflation was 1.06 ft als. Fifty minutes after start of lower-packer inflation, the water level was 2.51 ft als in the isolated interval, 0.73 ft bls in the upper interval, 2.88 ft als in the lower interval, and 1.95 ft als in well MG-924 (NP-21) (fig. 48). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated that isolated and lower intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through lower intervals.

The isolated interval was pumped at 3.2 gal/min for 30 minutes (fig. 49). Drawdown was 80.58 ft in the isolated interval, 0.31 ft in the upper interval, 0.52 ft in the lower interval, and 0.75 ft in well MG-924 (NP-21). Drawdown in the upper and lower intervals indicated a slight hydraulic connection among all intervals and between wells MG-1693 and MG-924 (NP-21). The specific capacity of the isolated interval was 0.04 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.10 ft after packer inflation (fig. 50). The drop was probably the result of the isolation of the broken casing joint from the lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.02 ft during pumping of well MG-1693 (NP-87). This drawdown indicated no connection between well MG-1661 (W-13) and the broken zone/high-angle fractures at 391 to 397 ft bls in well MG-1693 (NP-87).

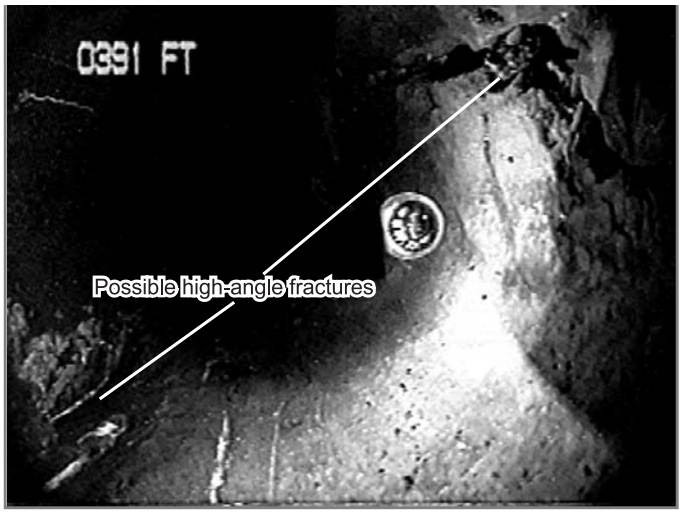

Figure 47. Borehole video still picture showing possible high-angle fractures at 391 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

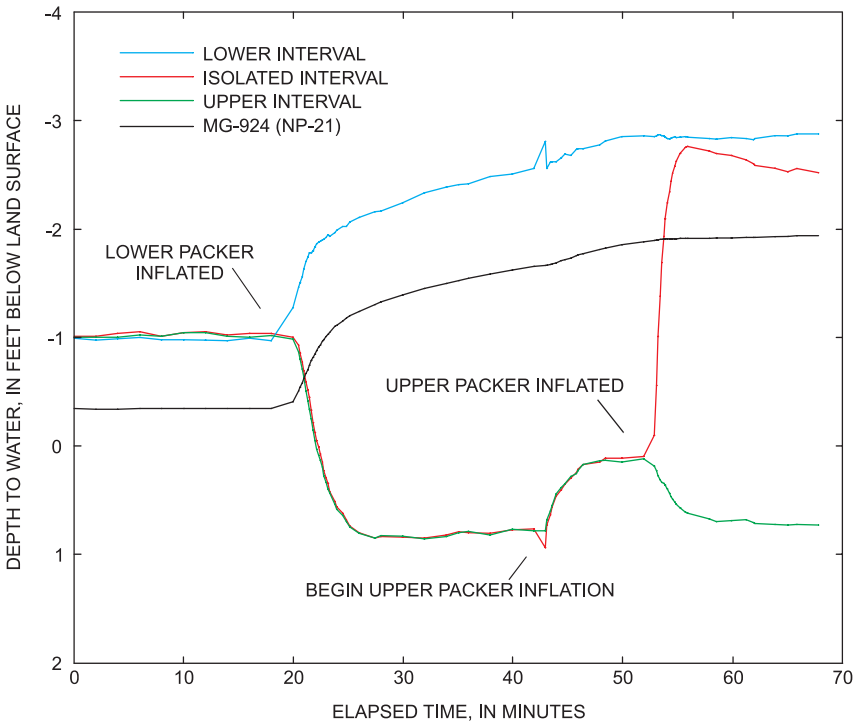

Figure 48. Hydrographs from packer inflation of interval 10 (382 to 407 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

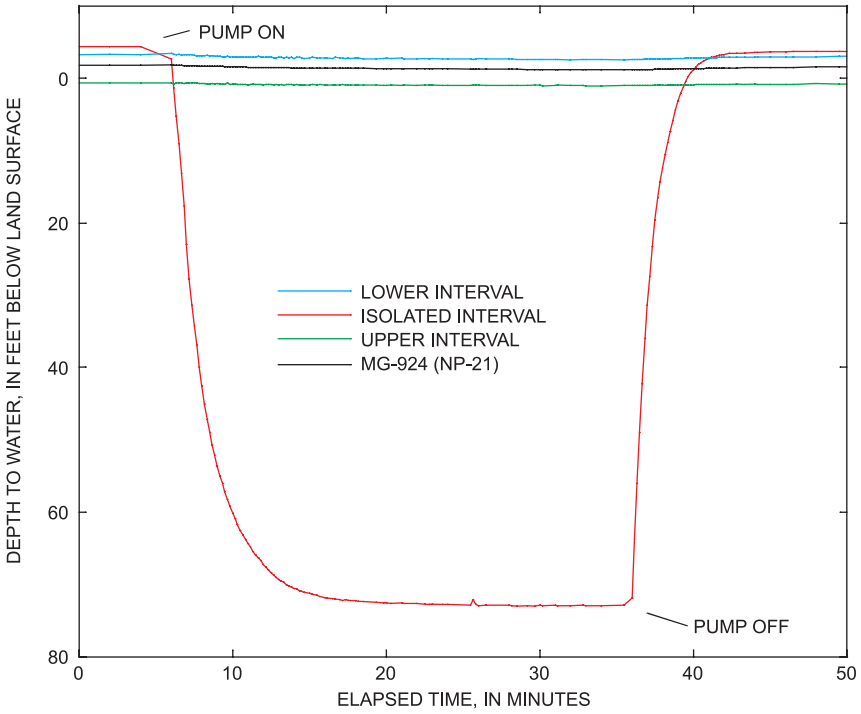

Figure 49. Hydrographs from aquifer-isolation test of interval 10 (382 to 407 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

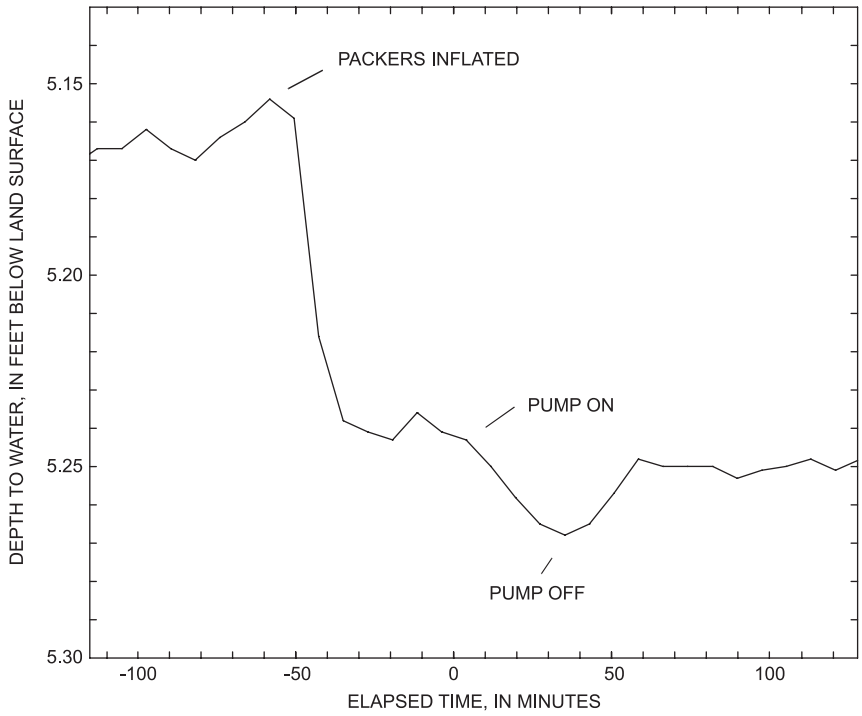

Figure 50. Hydrograph in well MG-1661 (W-13) during aquifer-isolation test of interval 10 (382 to 407 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 11 (412-437 Feet Below Land Surface)

Interval 11 isolated an extended high-angle fracture from 416 to 435 ft bls (fig. 51). The center of the top packer was placed at 412 ft bls and the center of the bottom packer was placed at 437 ft bls. The static water level in the open borehole prior to inflation was 1.08 ft als. Seventy minutes after start of lower-packer inflation, the water level was 3.19 ft als in the isolated interval, 0.52 ft bls in the upper interval, 2.82 ft als in the lower interval, and 1.50 ft als in well MG-924 (NP-21) (fig. 52). This is consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements, which indicated the isolated and lower intervals had a higher head than the upper interval. The inflation hydrograph showed a hydraulic connection with well MG-924 (NP-21) through the isolated interval.

The isolated interval was pumped at 20.6 gal/min for 105 minutes (fig. 53). Drawdown was 9.5 ft in the isolated interval, 2.34 ft in the upper interval, 8.08 ft in the lower interval, and 6.63 ft in well MG-924 (NP-21). Drawdown in the upper interval indicated some hydraulic connection with the isolated interval. Drawdowns in the lower interval and well MG-924 (NP-21) indicated a strong hydraulic connection with the isolated interval. The specific capacity of the isolated interval was 2.17 (gal/min)/ft.

The water level in well MG-1661 (W-13) dropped 0.09 ft after packer inflation (fig. 54). The drop was probably the result of the isolation of the broken casing joint from the isolated and lower intervals in well MG-1693 (NP-87). Drawdown in well MG-1661 was 0.30 ft during pumping of well MG-1693 (NP-87).

Figure 51. Borehole video still picture showing high-angle fracture at 423 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

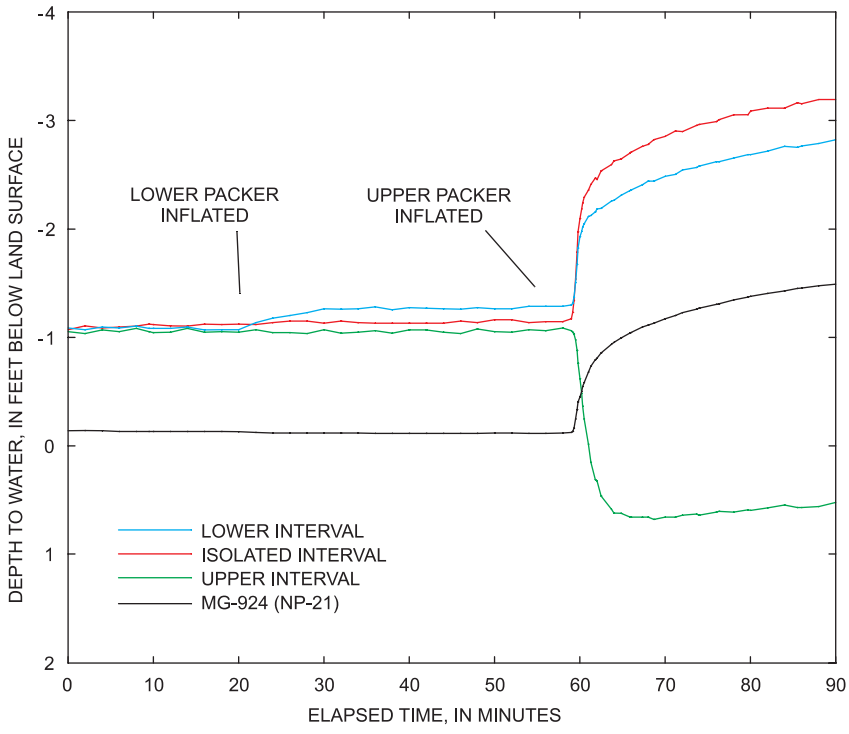

Figure 52. Hydrographs from packer inflation of interval 11 (412 to 437 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

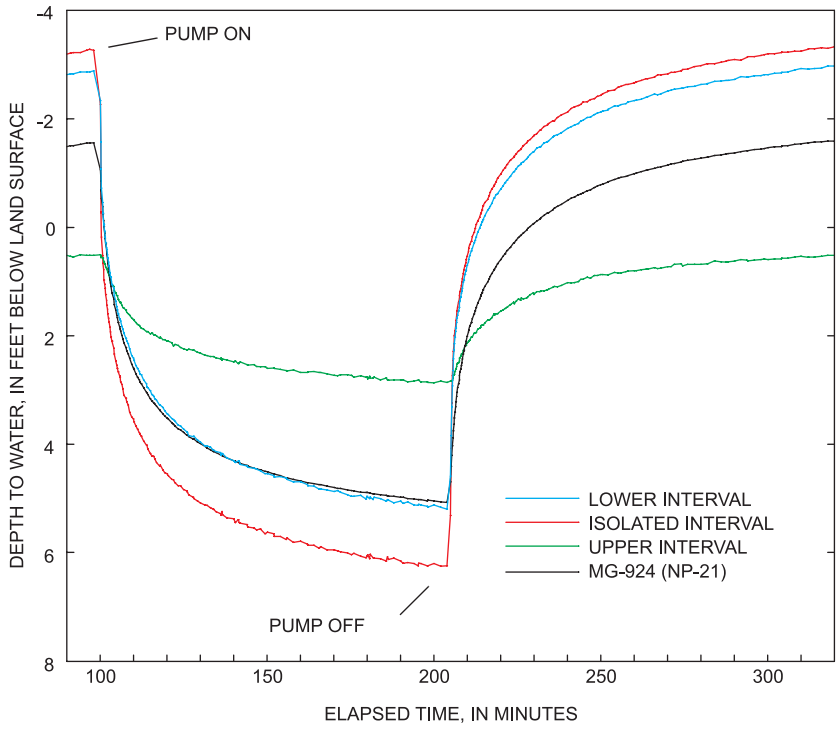

Figure 53. Hydrographs from aquifer-isolation test of interval 11 (412 to 437 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

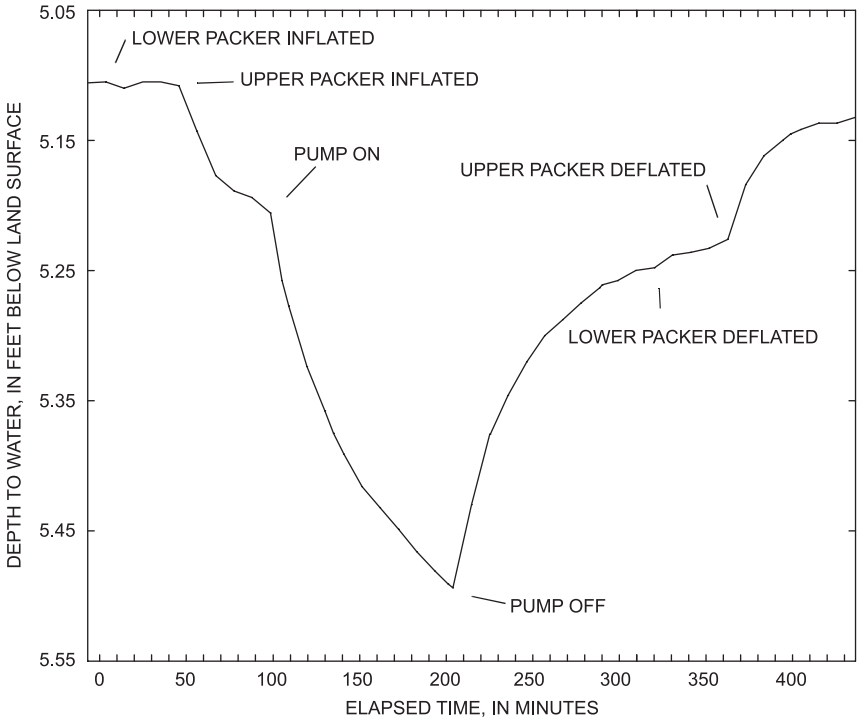

Figure 54. Hydrograph in well MG-1661 (W-13) during aquifer-isolation test of interval 11 (412 to 437 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 12 (436-TD Feet Below Land Surface)

Interval 12 isolated the entire borehole below 436 ft bls. The center of the top packer was placed at 436 ft bls and the bottom packer was not inflated. The static water levels prior to inflation were 1.06 ft als in the open borehole and 0.19 ft als in well MG-924 (NP-21). Forty-one minutes after upper-packer inflation, the water level was 1.10 ft als in the isolated interval, 1.10 ft als in the upper interval, and 0.19 ft als in well MG-924 (NP-21) (fig. 55). This is not consistent with the interpretation of the borehole geophysical logs and heatpulse-flowmeter measurements and indicated the isolated and upper intervals are hydraulically connected. Well MG-924 (NP-21) was not affected by packer inflation (fig. 55).

The isolated interval was pumped at 20.2 gal/min for 65 minutes (fig. 56). Drawdown was 6.54 ft in the isolated interval, 4.86 ft in the upper interval, and 3.84 ft in well MG-924 (NP-21). Drawdowns in the upper interval and well MG-924 (NP-21) indicated a strong hydraulic connection between the isolated and upper intervals and between the isolated interval and well MG-924 (NP-21). The specific capacity of the isolated interval was 3.09 (gal/min)/ft, but because the interval was not hydraulically isolated, the test probably overestimates the specific-capacity value of geologic units within interval 12.

The water level in well MG-1661 (W-13) dropped 0.03 ft after packer inflation (fig. 57). The drop is less than observed in the intervals above in which the high-angle fracture from 416 to 435 ft bls was isolated from the broken casing joint at 82 ft bls and indicates that the high-angle fracture from 416 to 435 ft bls is a primary source of the flow leaving the borehole through the broken casing joint at 82 ft bls. Drawdown in well MG-1661 was 0.40 ft during pumping of well MG-1693 (NP-87), which shows that the borehole below 436 ft bls (interval 12) was hydraulically connected to the shallow, weathered bedrock zone—probably through its hydraulic connection to MG-924.

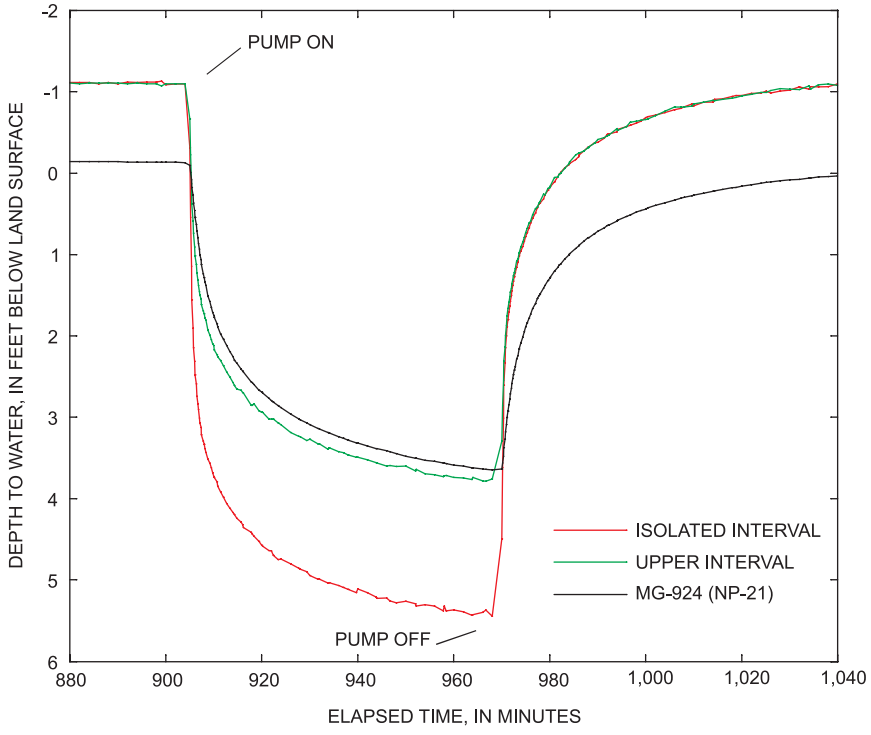

Figure 55. Hydrographs from packer inflation of interval 12 (436 feet to total depth below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

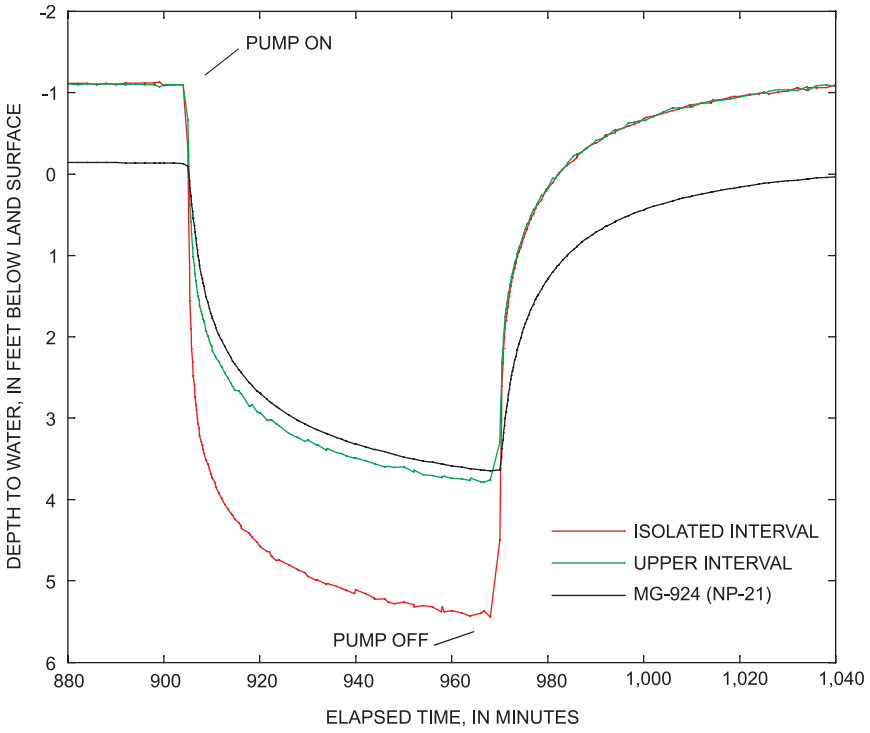

Figure 56. Hydrographs during aquifer-isolation test of interval 12 (436 feet to total depth below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania

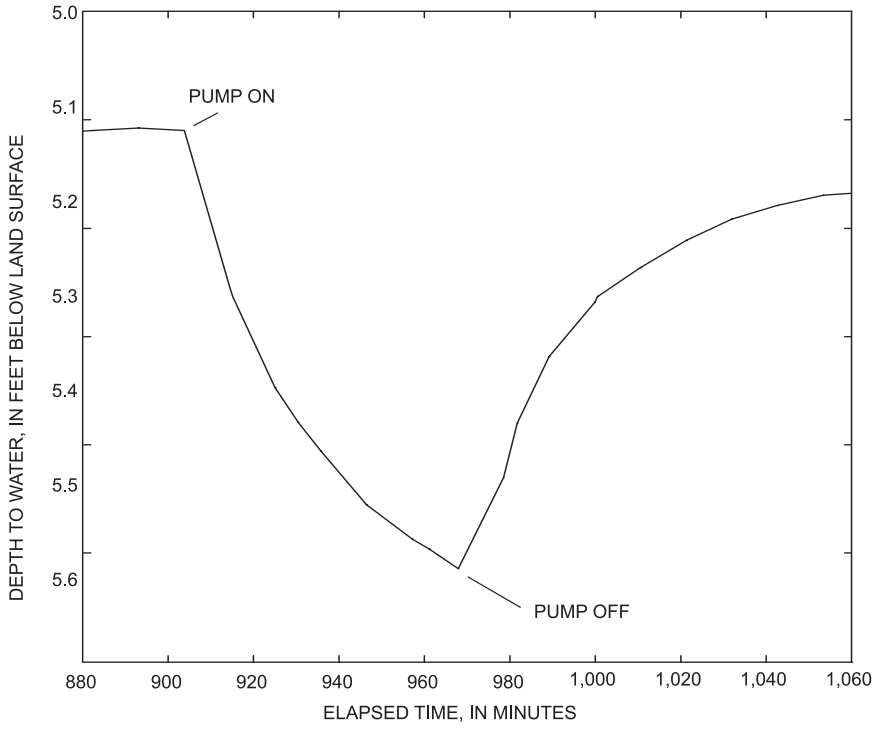

Figure 57. Hydrographs from packer inflation of interval 12 (436 feet to total depth below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Interval 13 (436-461 Feet Below Land Surface)

Interval 13 isolated a high-angle fracture from 457 ft bls to 459 (fig. 58). The center of the top packer was left inflated at 436 ft bls and the center of the bottom packer was inflated at 461 ft bls. The static water levels prior to start of lower-packer inflation were 1.09 ft als in the upper and isolated intervals and 0.01 ft als in well MG-924 (NP-21). Thirty-one minutes after start of lower-packer inflation, the water level was 1.12 ft als in the isolated interval, 1.10 ft als in the upper interval, 1.75 ft als in the lower interval, and 0.02 ft als in well MG-924 (NP-21) (fig. 59). This is not consistent with the heatpulse-flowmeter measurements, which indicated no flow at 464 ft bls and may indicate a water-bearing zone present in the borehole below 461 ft bls.

The isolated interval was pumped at 20.6 gal/min for 61 minutes (fig. 60). Drawdown was 6.70 ft in the isolated interval, 5.02 ft in the upper interval, 4.39 ft in the lower interval, and 3.81 ft in well MG-924 (NP-21). Drawdowns in the upper and lower intervals and well MG-924 (NP-21) indicated a strong hydraulic connection among the intervals in well MG-1693 and with well MG-924 (NP-21). The specific capacity of the isolated interval was 3.08 (gal/min)/ft, but because the interval was not hydraulically isolated, the test probably overestimates the specific-capacity value of geologic units within interval 13.

The water level in well MG-1661 (W-13) rose 0.02 ft after lower-packer inflation (fig. 61). Drawdown in well MG-1661 was 0.41 ft during pumping of well MG-1693 (NP-87), which shows that the borehole between 436-461 ft bls (interval 13) was hydraulically connected to the shallow, weathered bedrock zone—probably through its hydraulic connection to MG-924.

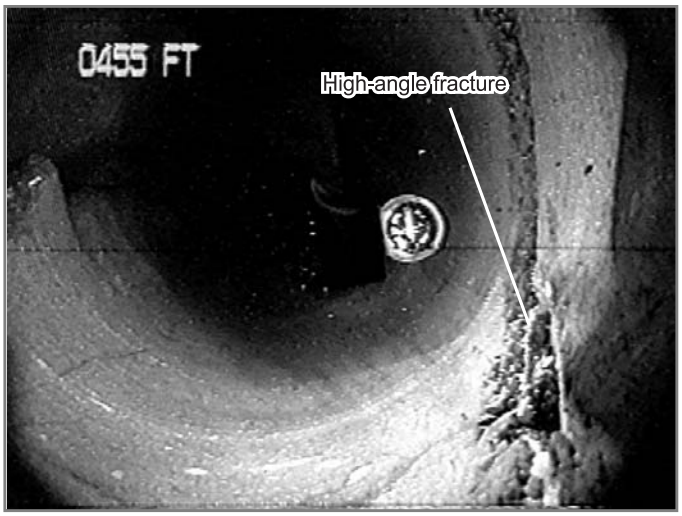

Figure 58. Borehole video still picture showing high-angle fracture at 455 feet below land surface in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

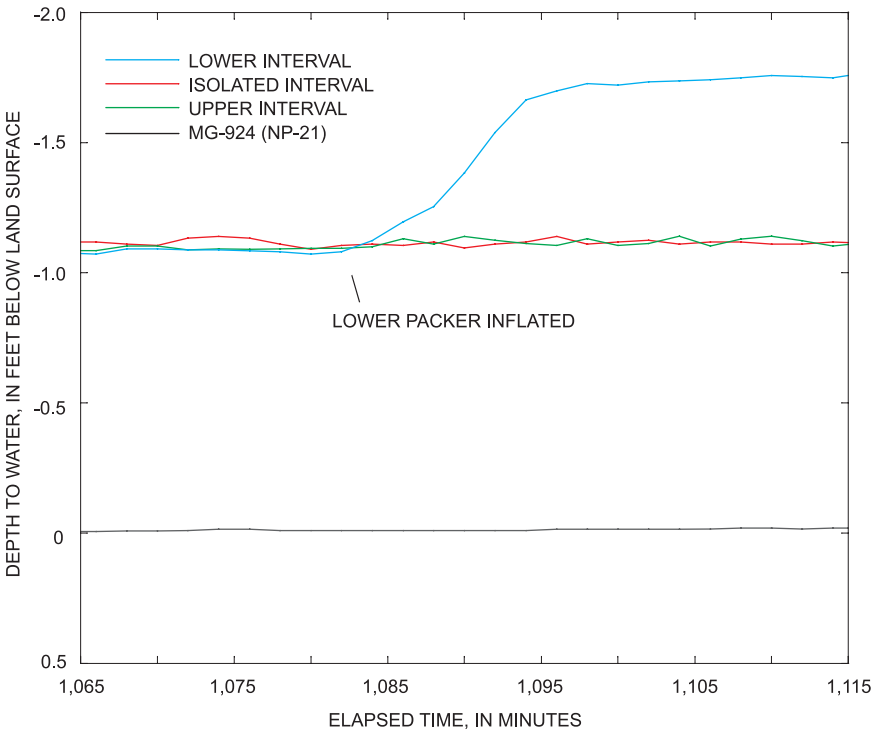

Figure 59. Hydrographs from packer inflation of interval 13 (436 to 461 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

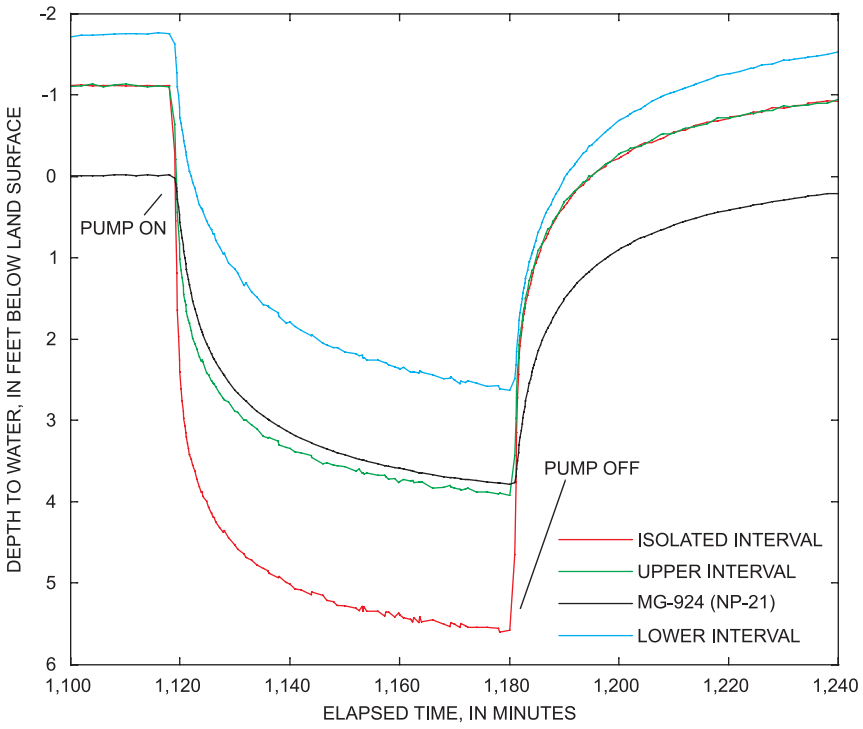

Figure 60. Hydrographs from aquifer-isolation test of interval 13 (436 to 461 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

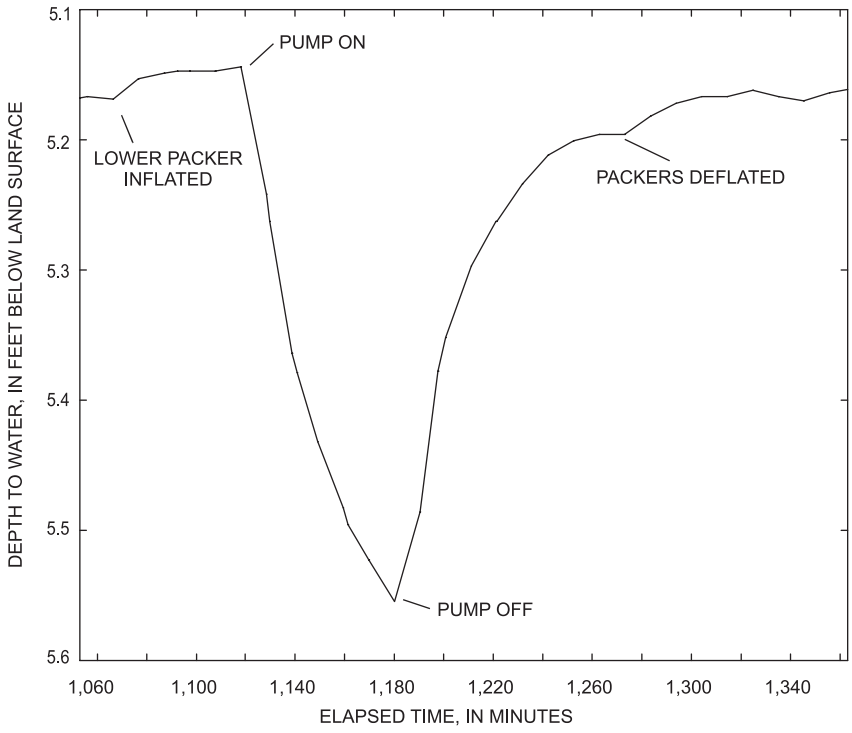

Figure 61. Hydrograph in well MG-1661 (W-13) during aquifer-isolation test of interval 13 (436 to 461 feet below land surface) in well MG-1693 (NP-87) at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania.

Distribution of Volatile Organic Compounds

Nine intervals in well MG-1693 were sampled by TetraTech, Inc., for VOCs during aquifer-isolation testing. Six compounds (1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethene, toluene, 1,1,1-trichloroethane, and trichloroethene (TCE)) were detected, and one compound, TCE, was found in all intervals. A summary of compounds detected is given in table 4.

Intervals 4 and 6 had the highest concentrations of VOCs (6.66 and 6.2 µg/L, respectively). Five compounds—1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethene, 1,1,1-trichloroethane, and TCE—were detected in intervals 1 and 4. These intervals had the highest number of compounds detected. The highest concentrations of TCE were 1.8 µg/L in a sample from interval 1 and 4.9 µg/L in a sample from interval 4. Four compounds, 1,1-dichloroethane, 1,1-dichloroethene, 1,1,1-trichloroethane, and TCE were detected in intervals 2, 7, 10, 11, and 12. The concentrations of these four compounds (1 µg/L or less) were similar in all five intervals. Three compounds—1,1-dichloroethane, toluene, and TCE—were found in interval 6. This is the only interval in which toluene (6.0 µg/L) was detected. Only TCE was detected in interval 5, at 0.08 µg/L; this was the lowest concentration of TCE found in any interval.

Table 4. Summary of concentrations of volatile organic compounds detected in ground water in well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pennsylvania. (Samples were collected by TetraTech, Inc., to determine distribution of contamination.)

[µg/L, micrograms per liter; --, not detected]

Interval	Isolated depth interval (ft below land surface)	1,1-Dichloroethane (µg/L)	1, 1-Dichloroethene (µg/L)	Cis-1,2-Dichloroethene (µg/L)	Toluene (µg/L)	1,1,1-Trichloroethane (µg/L)	Trichloroethene (TCE) (µg/L)
1	68-93	0.2	0.8	0.1	--	2.5	1.8
2	87-112	.3	.2	--	--	.2	1.0
4	124-149	.2	.8	.06	--	.7	4.9
5	252-277	--	--	--	--	--	.08
6	277-302	.1	--	--	6.0	--	.1
7	302-327	.2	.07	--	--	.06	.2
10	382-407	.2	.1	--	--	.09	.4
11	412-437	.2	.1	--	--	.1	.4
12	436-TD	.2	.1	--	--	.09	.4

Summary and Conclusions

Borehole geophysical logs and heatpulse-flowmeter measurements collected in well MG-1693 at North Penn Area 5 Superfund Site near Colmar, Montgomery County, Pa., were used to select intervals for aquifer-isolation testing. Heatpulse-flowmeter measurements and borehole-video logs showed water enters the borehole primarily through high-angle fractures at 416 to 435 feet below land surface (ft bls) and 129 to 136 ft bls, moves upward, and exits the borehole through a high-angle fracture at 104 to 107 ft bls, a broken casing joint at 82 ft bls, and occasionally through artesian flow at the surface.

Thirteen intervals were selected for aquifer-isolation testing based on analysis of the borehole geophysical logs and heatpulse-flowmeter measurements. A straddle-packer assembly was used to isolate these intervals. Intervals 1 through 8 and interval 10 were well-isolated from borehole intervals above and below the selected interval. The specific capacity of interval 1 was 2.09 (gal/min)/ft. The specific capacities of intervals 2, 3, and 4 were similar—0.27, 0.30, and 0.29 (gal/min)/ft, respectively. The specific capacities of intervals 5, 6, 7, 8, and 10 were similar—0.03, 0.04, 0.09, 0.09, and 0.04 (gal/min)/ft, respectively. Intervals 9, 11, and 12 showed a strong hydraulic connection outside the borehole with intervals above and below the isolated interval. The specific capacities of intervals 9, 11, 12, and 13 were similar—2.12, 2.17, 3.09, and 3.08 (gal/min)/ft, respectively.

The aquifer-isolation tests indicated wells MG-1693 (NP-87) and MG-924 (NP-21) are connected primarily through the high-angle fracture from 416 to 435 ft bls. Pumping in either of these wells directly affects the water level in the other well, allowing the pumped well to draw from water-bearing zones in the affected well that are not present in or directly connected to the pumped well. The two boreholes act as a single, U-shaped well. The aquifer-isolation tests also showed the lower zones in well MG-1693 (NP-87) are a major source of

water to well MG-1661 (W-13). This water is provided by upward flow and discharge through the broken casing joint at 82 ft bls. Water moving upward from the lower intervals in well MG-1693 (NP-87) exits the borehole through the broken casing joint, moves upward outside the borehole, possibly around and (or) through a poor or damaged casing seal, and through the weathered zone above bedrock to well MG-1661 (W-13).

Samples for volatile organic compounds (VOCs) were collected in nine isolated intervals by TetraTech, Inc. Six compounds were detected (1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethene, toluene, 1,1,1-trichloroethane, and trichloroethene (TCE)), and TCE was found in all nine intervals. Intervals 1 and 4 had the highest total concentration of VOCs and the highest number of compounds detected (five). Interval 5 had the lowest total concentration of VOCs and the least number of VOCs detected (one). Detected compounds were not distributed evenly throughout the intervals. VOCs were found in shallow, intermediate, and deep intervals and were associated with high-angle fractures and rough areas that showed no distinct fractures.

Acknowledgments

The author gratefully acknowledges the individuals and companies that allowed access to their wells for geophysical logging and packer testing. Thanks to Peter J. Cinotto, Leif E. Olson, Dennis W. Risser, and Robert Rosman of the U.S. Geological Survey for their help. Thanks also to Tad Yancheski and Dana Small of TetraTech for their assistance.

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