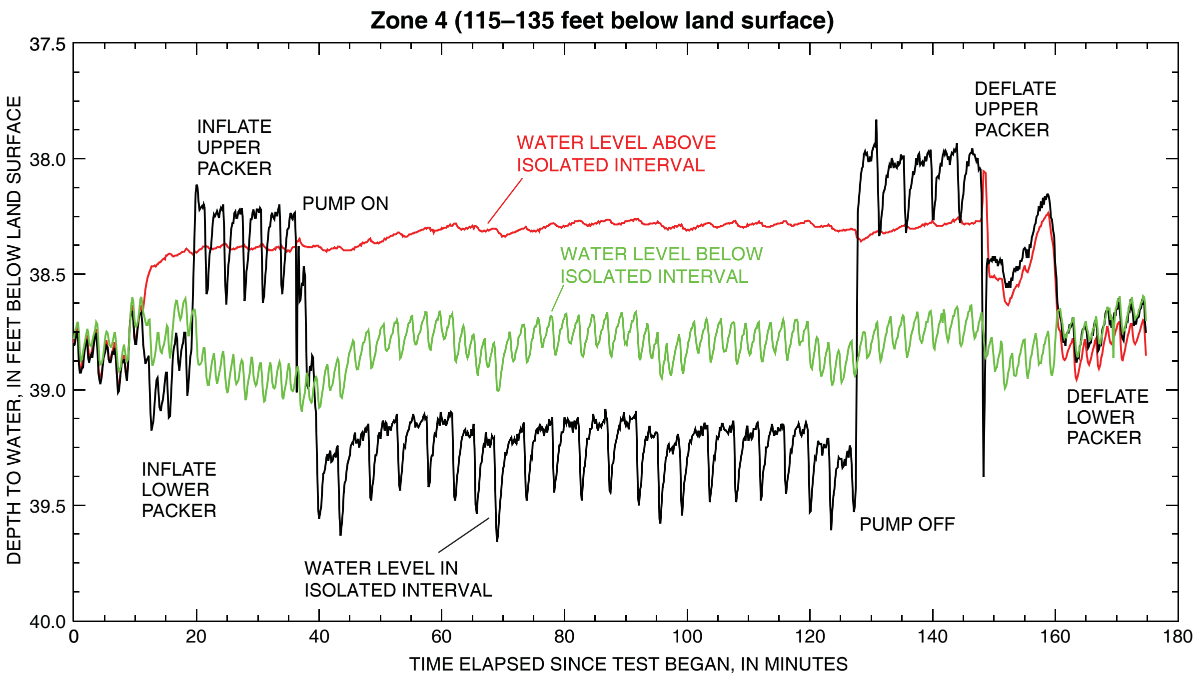
Prepared in cooperation with the U.S. Environmental Protection Agency

Geophysical Logs, Aquifer Tests, and Water Levels in Wells in and Near the North Penn Area 7 Superfund Site, Upper Gwynedd Township, Montgomery County, Pennsylvania, 2002-2006



Scientific Investigations Report 2008-5154

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

Geophysical Logs, Aquifer Tests, and Water Levels in Wells in and Near the North Penn Area 7 Superfund Site, Upper Gwynedd Township, Montgomery County, Pennsylvania, 2002-2006

By Lisa A. Senior, Randall W. Conger, and Philip H. Bird

In cooperation with the U.S. Environmental Protection Agency

Scientific Investigations Report 2008-5154

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

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

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Senior, L.A., Conger, R.W., and Bird, P.H., 2008, Geophysical logs, aquifer tests, and water levels in wells in and near the North Penn Area 7 Superfund fite, Upper Gwynedd Township, Montgomery County, Pennsylvania, 2002–2006: U.S. Geological Survey Scientific Investigations Report 2008-5154, 277 p.

Contents

Figures

Figures in Appendix 1

Figures in Appendix 3

Tables

Tables in Appendix 2

Conversion Factors and Datum Conversion

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
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]
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

°F=(1.8×°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 North American Vertical Datum of 1988 (NAVD 88).

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L), which are approximately equivalent to parts per million (ppm) or parts per billion (ppb), respectively.

Geophysical Logs, Aquifer Tests, and Water Levels in Wells in and Near the North Penn Area 7 Superfund Site, Upper Gwynedd Township, Montgomery County, Pennsylvania, 2002-2006

By Lisa A. Senior, Randall W. Conger, and Philip H. Bird

Abstract

Ground water in the vicinity of several industrial facilities in Upper Gwynedd Township and Lansdale Borough, Montgomery County, Pa., is contaminated with several volatile organic compounds (VOCs). The 2-square-mile area was placed on the National Priorities List as the North Penn Area 7 Superfund Site by the U.S. Environmental Protection Agency (USEPA) in 1989. The U.S. Geological Survey (USGS) conducted geophysical logging, aquifer testing, water-level monitoring, and streamflow measurements in the vicinity of North Penn Area 7 from October 2002 through December 2006. This followed work that began in 2000 to assist the USEPA in developing an understanding of the hydrogeologic framework in the area as part of the USEPA Remedial Investigation.

The study area is underlain by Triassic- and Jurassic-age sandstones, siltstones, and shales of the Lockatong Formation and the Brunswick Group. Regionally, these rocks strike northeast and dip to the northwest. The sequence of rocks form fractured-rock aquifers that act as a set of confined to semi-confined layered aquifers of differing permeabilities. The aquifers are recharged by precipitation and discharge to streams and wells. The Wissahickon Creek headwaters are less than 1 mile northeast of the study area. This stream flows southwest approximately parallel to strike and bisects North Penn Area 7. Ground water is pumped in the vicinity of North Penn Area 7 for industrial use and public supply.

The USGS collected geophysical logs for 42 wells that ranged in depth from 40 to 477 ft. Aquifer-interval-isolation testing was done in 17 of the 42 wells, for a total of 122 zones tested. A multiple-well aquifer test was conducted by monitoring the response of 14 wells to pumping and shutdown of a 600-ft deep production well in November-December 2004. In addition, water levels were monitored continuously in four wells in the area from October 2002 through September 2006, and streamflow was measured quarterly at two sites on Wissahickon Creek from December 2002 through September 2005.

Geophysical logging identified water-bearing zones associated with high-angle fractures and bedding-plane openings throughout the depth of the boreholes. Heatpulse-flowmeter measurements under non-pumping, ambient conditions in 16 wells greater than 200 ft in depth indicated that borehole flow, where detected, was only upward in 2 wells and only downward in 5 wells. In nine wells, both upward and downward flow were measured. Geologic structure and pumping in the area affect the spatial distribution of vertical gradients. Heatpulse-flowmeter measurements under pumping conditions were used to identify the most productive intervals in wells. Correlation of natural-gamma-ray logs indicated bedding in the area probably strikes about 45 to 65 degrees northeast and dips about 9 degrees northwest.

Aquifer intervals isolated by inflatable packers in 17 wells were pumped to test productivity of water-bearing zones and to collect samples to determine chemical quality of water produced from the interval. Interval-isolation testing confirmed the vertical hydraulic gradients indicated by heatpulse-flowmeter measurements. The specific capacities of the 122 isolated intervals ranged over about three orders of magnitude, from 0.01 to10.6 gallons per minute per foot, corresponding to calculated transmissivities of 1.2 to 2,290 feet squared per day. Intervals adjacent to isolated pumped intervals commonly showed little response to pumping of the isolated zone. The presence of vertical hydraulic gradients and lack of adjacent-interval response to pumping in isolated intervals indicate a limited degree of vertical hydraulic connection between the aquifer sections tested. Differences were apparent in inorganic water quality of water from isolated intervals, including pH, specific conductance, and dissolved oxygen. Concentrations of most VOC contaminants in most wells with predominantly upward vertical gradients were greatest in well-water samples from the relatively shallow isolated intervals. Trichloroethylene was the most frequently detected chlorinated VOC and was measured in samples from 14 of 17 wells tested; the maximum concentration was 640 micrograms per liter. Other halogenated VOCs detected in about half or less of the 17 wells tested included *cis*-1,2-dichloroethylene, tetrachloroethylene, freon-113, and freon-11 at maximum concentrations of 120, 37, 71, and 55 micrograms per liter, respectively.

Results of the aquifer test with multiple observation wells showed that water levels in 8 of 14 wells declined in response to pumping. Estimates of aquifer transmissivity determined using Theis-curve fitting ranged from 683 to 2,382 feet squared per day. The spatial distribution of the eight wells that responded to pumping are along strike and in the down-dip direction of producing zones of the pumped well. This spatial distribution suggests that hydraulic connections in the aquifer are structurally controlled by dipping beds to some extent.

Water-level monitoring in four wells from October 2002 through September 2006 shows the seasonal rise and decline of levels. Water levels in two wells near Wissahickon Creek were evaluated in relation to streamflow on dates of quarterly streamflow measurements. The Wissahickon Creek was a losing stream between the two measurement sites, and ground-water levels were lower than the stream-channel bottom for most dates. Water levels measured in the 2-square mile area around and including North Penn Area 7 in December 2004, June 2005, and September 2005 confirm previous findings that the potentiometric surface is relatively flat in the immediate vicinity of North Penn Area 7 and generally is similar to topography except in areas affected by large amounts of ground-water withdrawal. Comparison of water levels measured in boreholes completed at different depths in well clusters shows predominantly upward vertical gradients east of Wissahickon Creek, except where affected by nearby pumping, and predominantly downward vertical gradients west of Wissahickon Creek.

Results of geophysical logging, aquifer tests, and water-level measurements are consistent with the conceptual model of a layered leaky aquifer where the dip of the beds has a strong control on hydraulic connections in the ground-water system. Connections within and (or) parallel to bedding tend to be greater than across bedding.

Introduction

In 1979, ground water in the area in and around Lansdale Borough and Upper Gwynedd Township, Montgomery County, Pa., was found to be contaminated with organic chemicals, such as trichloroethylene (TCE) and tetrachloroethylene (PCE). The contamination was discovered by the North Penn Water Authority (NPWA), which at that time entirely relied on ground water to supply public drinking water. The U.S. Environmental Protection Agency (USEPA) investigated the sources of contamination in the vicinity of Lansdale and subdivided the areas of contamination into groups of properties. The group of contaminated properties in the vicinity of production well L-22 in Upper Gwynedd Township, southeast of Lansdale and northwest of North Wales, was designated North Penn Area 7 and encompasses about 2 mi^2 (fig. 1). The USEPA began its investigation at North Penn Area 7 in June 1986, and the site was placed on the National Priorities List on March 31, 1989 (CH2M Hill, 1992).

The North Penn Area 7 site includes eight industrial facilities reported to have used volatile organic compounds (VOCs). The most commonly used VOCs were the solvents TCE, PCE, 1,1,1-trichloroethane (1,1,1-TCA), methylene chloride (MC), trichloromonofluoromethane (Freon-11), and dichlorofluoromethane (Freon-21) (CH2M Hill, Inc., 1992, p. 2-1 to 2-6). Contaminants of concern detected in ground water in the vicinity of the site include TCE, PCE, 1,1,1-TCA, 1,1-dichloroethylene (1,1-DCE), 1,2-dichloroethylene (1,2-DCE), *cis*-1,2,-DCE, trans-1,2-DCE, vinyl chloride (VC), and carbon tetrachloride. Similar contamination also was detected in soils on at least six properties.

Ground water in the vicinity of North Penn Area 7 has been used and continues to be used for industrial and public supply. Although some wells were abandoned after contamination was discovered, other wells remain active. Abandoned wells include two contaminated North Wales Water Authority (NWWA) public supply wells just south of North Penn Area 7 and five industrial production wells at the former Ford Electronics and Refrigeration Corporation (FERCO) property on the northern part of the site. As of October 2002 through December 2006, ground-water pumping in the vicinity (within 0.5 mi) of North Penn Area 7 continues in the NPWA wells along Wissahickon Creek to the northeast of the site, at Precision Tube near the center of the site, and at the Merck & Co., Inc., West Point facility southwest of the site.

The USEPA requested technical assistance from the U.S. Geological Survey (USGS) to provide hydrogeologic data and interpretation to be used in the Remedial Investigation/Feasibility Study (RI/FS) of the site. In autumn 2000, the USGS began to collect data as part of the technical assistance. The data will be used to describe the ground-water system and to provide a basis for simulation of ground-water flow. The ground-water-flow simulation will be used to evaluate the effect of pumping on the directions of ground-water flow and contamination transport. The first phase of work, completed in September 2002, included geophysical logging of existing wells, aquifer tests of isolated intervals in existing wells, streamflow measurements, and water-level mapping and monitoring. The second phase of work, which is described in this report, extended from October 2002 through December 2006 and included geophysical logging of existing wells and new monitor wells drilled for the RI/FS, aquifer tests of isolated intervals in existing and new monitor wells, streamflow measurements, and water-level monitoring.

Purpose and Scope

This report presents and provides basic interpretation of geophysical-log, aquifer-test, and water-level data collected in the vicinity of the North Penn Area 7 site, Montgomery County, Pa., from October 2002 through December 2006 as part of technical assistance to USEPA for a RI/FS. This period (October 2002 through December 2006) is the second phase of data collection in a multi-phase project. Boreholes logged,

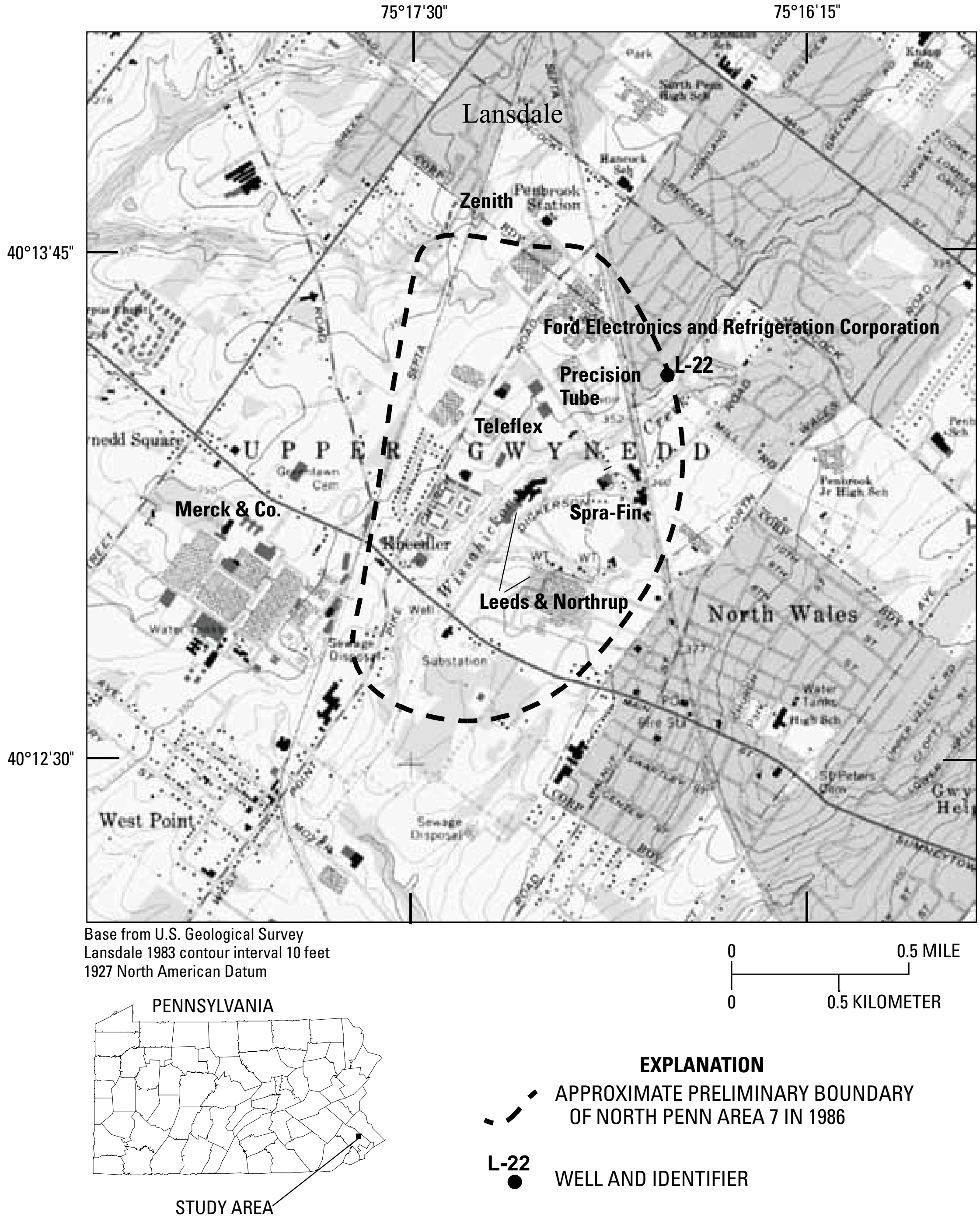


Figure 1. Location of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

tested, and monitored during this period were existing production and monitor wells and new monitor wells drilled for the RI/FS.

Geophysical logs for 18 boreholes are described and used to identify (1) water-bearing zones and relative productivity of water-bearing zones, (2) direction and magnitude of borehole flow under non-pumping and pumping conditions, and (3) lithologic intervals that can be used for stratigraphic correlation. Fifteen of the 18 wells were drilled as the deep well in a monitor-well cluster. Natural-gamma and single-point-resistance logs are correlated for wells, where possible, to estimate orientation of bedding. Geophysical logs for an additional 24 shallow- and intermediate-depth wells drilled adjacent to deep monitor wells are presented but not discussed. Results of single-well aquifer-interval-isolation tests (in which intervals are isolated by packers) are presented for 17 of the 18 wells and include, for each isolated interval, the measured potentiometric heads, calculated specific capacity, estimated transmissivity, and water quality of sampled water (pH, specific conductance, temperature, alkalinity, selected inorganic constituents, and selected VOCs). Results of one multiple-well aquifer test (one pumping well and multiple observation wells) are presented and include spatial distribution of drawdown and estimated aquifer transmissivity determined from an analytical solution. Streamflow measurements under base-flow conditions are discussed in relation to ground-water levels to gain insight into ground-water/surface-water relations. Water levels in wells are also discussed in relation to regional ground-water flow and a conceptual model of the ground-water system.

The information generated during the second phase of the investigation can be used to help describe the hydrogeology and provide a foundation for subsequent data collection, refinement, and the simulation and understanding of directions of ground-water flow and contamination migration in the area.

Physical and Hydrogeologic Setting

The study area in and near Lansdale and Upper Gwynedd Township is in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province (Berg and others, 1989) (fig. 2). The area is underlain by sedimentary rocks of the Lockatong Formation and lower beds of the Brunswick Group of the Newark Supergroup (Lyttle and Epstein, 1987) (fig. 3). Sediments of the Newark Supergroup were deposited in a rift basin during the Triassic and Jurassic Periods (about 251 to 145 million years ago). Following deposition, sediments in the Newark Basin (fig. 2) were buried, lithified, tilted, and faulted. The oldest sediments in the Newark Basin comprise the Stockton Formation, deposited along the southern margin on Paleozoic and older rocks (fig. 3). Overlying the Stockton Formation are the Lockatong Formation and Brunswick Group, which underlie the study area. The Lockatong Formation is relatively resistant to erosion and tends to form ridges that rise above flat or rolling topography underlain by rocks of the Brunswick Group.

The North Penn Area 7 site is on relatively flat terrain bisected by the Wissahickon Creek. The western boundary of the site is approximately along the railroad tracks just west of Church Road (fig. 1). Church Road lies near the surface-water divide between the Towamencin Creek Basin to the west and the Wissahickon Creek Basin to the east (figs. 1 and 3).

The Lockatong Formation consists of detrital sequences (cycles) of gray to black calcareous shale and siltstone, with some pyrite, and chemical sequences (cycles) of gray to black dolomitic siltstone and marlstone with lenses of pyritic limestone, overlain by massive gray to red siltstone with analcime (Lyttle and Epstein, 1987). Interbeds of reddish-brown, sandy siltstone have been mapped in the Lockatong Formation south of Lansdale (Lyttle and Epstein, 1987). Contacts between the Lockatong Formation and the overlying Brunswick Group are conformable and gradational, and the two formations may interfinger (Lyttle and Epstein, 1987). The lower beds of the Brunswick Group consist predominantly of homogeneous, soft, red to reddish-brown and gray to greenish-gray mudstones and clay- and mud-shales, with some fine-grained sandstones and siltstones. Bedding is irregular and wavy. Some beds are micaceous. Interbedded silt-shales and siltstones are moderately well sorted. Mudcracks, ripple marks, crossbeds, and worm burrows are common in all the beds. The Brunswick Group contains detrital cycles of medium- to dark-gray and olive- to greenish-gray, thin-bedded and evenly bedded shale and siltstone, similar to the underlying Lockatong Formation.

Unpublished lithologic mapping (Joseph Smoot, U.S. Geological Survey, unpub. mapping, 2005) indicates that deltaic and fluvial sequences are present in the geologic units mapped in the study area (fig. 4). This preliminary lithologic mapping retains geologic contacts presented in earlier mapping (Longwill and Wood, 1965) but adds a new contact delimiting the extent of deltaic sequences in the lower part of the Brunswick Group. The lithologic mapping identified interbedded fluvial to deltaic sandstone and conglomerate and lacustrine cyclic silstone and shale that are predominantly red (TrS/Sic) or predominantly gray (TrS/Sicg) (fig. 4). For the purposes of this report, these bedding units are assigned codes where B4, B6, B8, and B10 refer to units with the predominantly red lithology labeled TrS/Sic; L5, L7, and L9 refer to units with the predominantly gray lithology labeled TrS/Sicg; B refers to the predominantly red non-deltaic lower Brunswick Group rocks labeled TrSic [equivalent to Trb of Longwill and Wood (1965)]; and L refers to the predominantly gray non-deltaic Lockatong Formation rocks labeled TrSicg [equivalent to the Trl of Longwood and Wood (1965)]. Prior to the unpublished mapping by Smoot, Lyttle and Epstein (1987) had reclassified the predominantly gray beds mapped by Longwill and Wood (1965) as interfingered Lockatong Formation within the Brunswick Group (fig. 3) as part of the lower Brunwick Group (see units labeled JTrblg on figure 4) and the predominantly red beds mapped as interfingered Brunswick Group with the Lockatong Formation (fig. 3) as part of the Lockatong Formation (see unit labeled Trlr on figure 4)

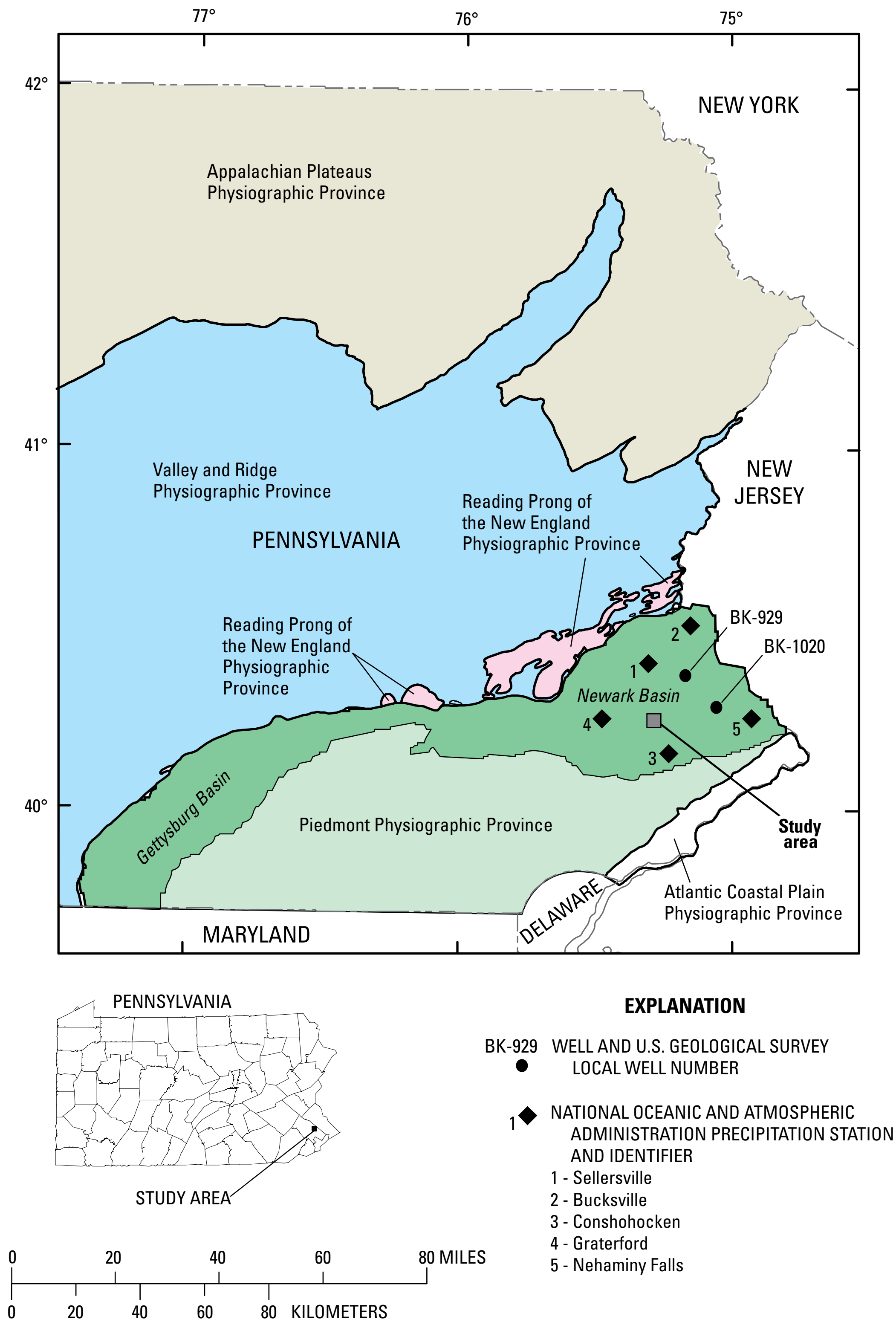


Figure 2 Physiographic provinces in Pennsylvania and location of selected wells and precipitation stations in southeastern Pennsylvania in the vicinity of North Penn Area 7.

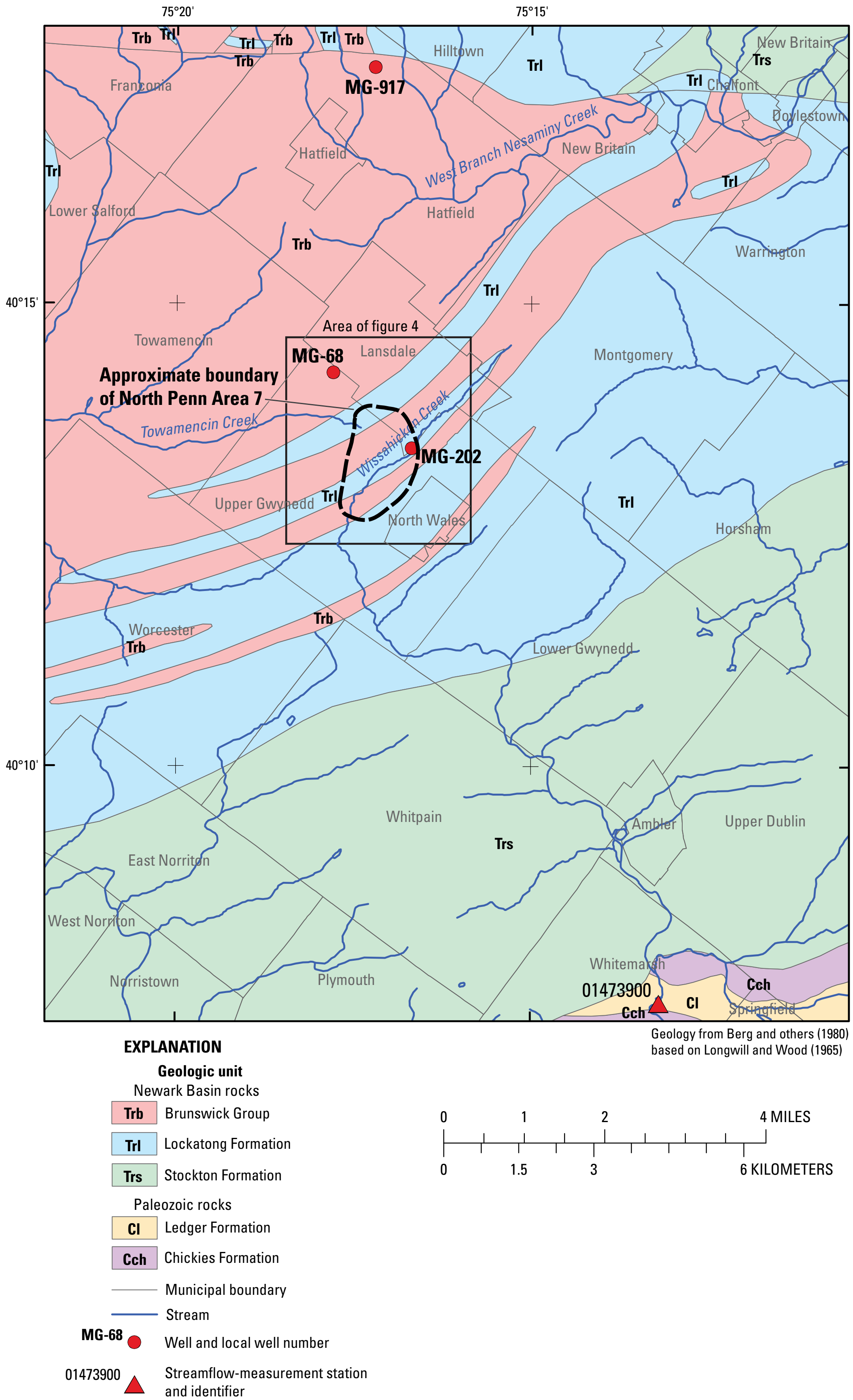
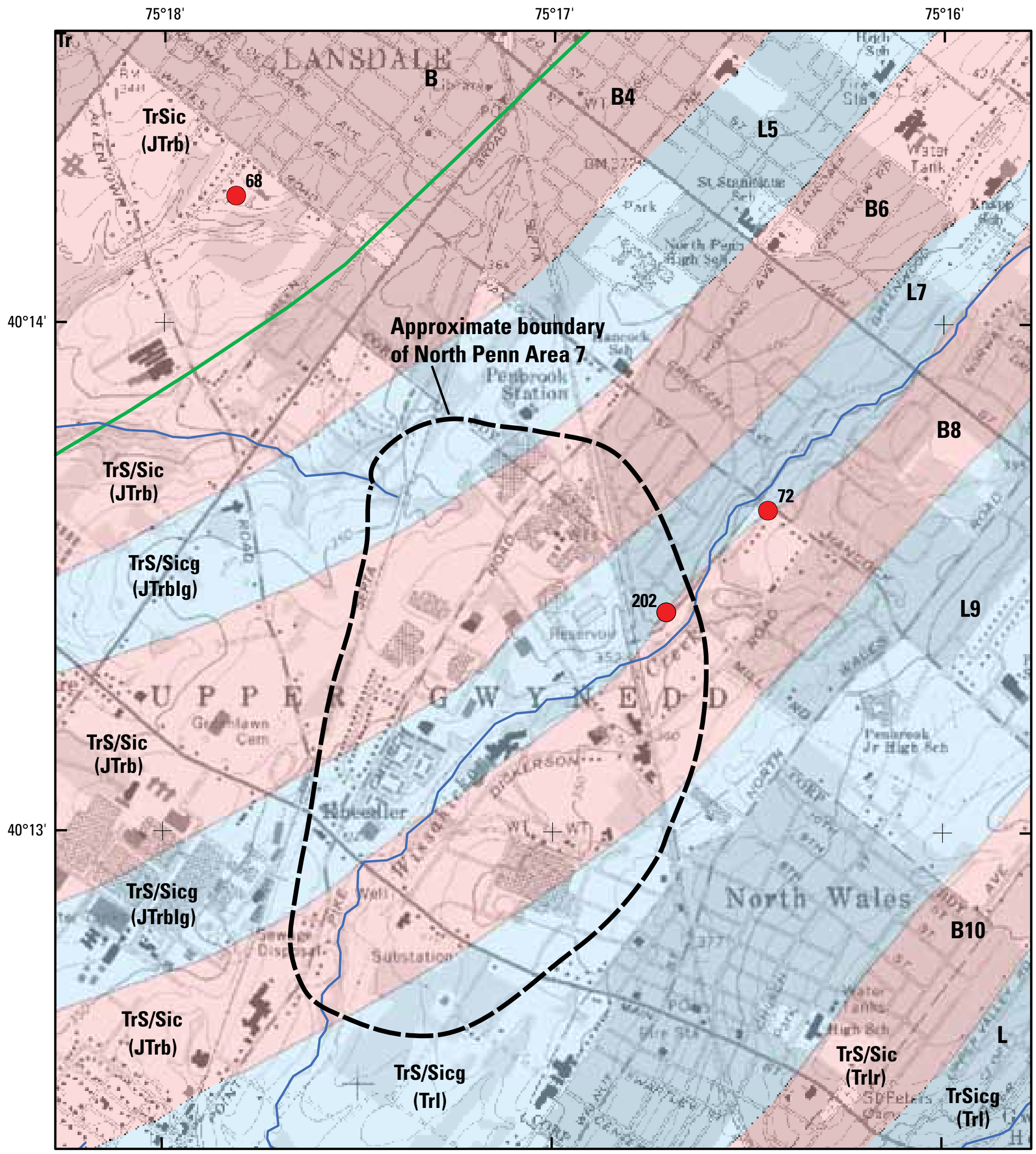


Figure 3. Bedrock geology in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.



Base from U.S. Geological Survey
Lansdale 1983 contour interval 10 feet
1927 North American Datum

Geology from Berg and others (1980) with nomenclature from Lyttle and Epstein (1987) and additional mapping and lithologic classification from Smoot (unpublished map, 2005)

EXPLANATION

Nomenclature			
Bed code this report	Lyttle and Epstein	Smoot	Lithology
B	**JTrb**	**TrSic**	Brunswick Group (non-deltaic)
B4, B6, B8, B10	**JTrb, Trlr**	**TrS/Sic**	Red beds predominant
L5, L7, L9	**JTrblg, Trl**	**TrS/Sicg**	Gray beds predominant
L	**Trl**	**TrSicg**	Lockatong Formation (non-deltaic)

Lower Brunswick contact with deltaic units

Stream

72 Well and local well number (prefix MG- omitted)

0 500 1,000 2,000 3,000 FEET

0 200 400 800 METERS

Figure 4. Lithologic mapping of bedrock geology in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa. (Joseph Smoot, U.S. Geological Survey, unpub. mapping, 2005).

Bedding in the Newark Basin regionally strikes northeast and dips to the northwest. The regional homoclinal dip has been cut by normal and strike-slip faults and warped by transverse folds (Schlische, 1992). Many faults with small displacements have not been mapped. The beds of the Brunswick Group and Lockatong Formation generally strike northeast and dip shallowly to the northwest in the vicinity of the North Penn Area 7 site, with a gradual shift in strike from northeast in central Lansdale to east-northeast in the area south of Lansdale near North Wales (fig. 3) (Longwill and Wood, 1965). Thin shale marker beds in the Brunswick Group identified by elevated natural-gamma activity on geophysical logs can be correlated over distances of 1,000 ft or more. High natural-gamma activity typically is associated with thin gray or black shale beds. Correlation of natural-gamma activity in logs collected by USGS in and near Lansdale shows these shale beds strike 48° to 60° N.E. and dip 6° to 30° N.W., with an average dip of about 11° (Conger, 1999).

Ground water in the bedrock underlying the North Penn Area 7 site originates from infiltration of local precipitation. After infiltrating through soil and saprolite (extensively weathered rock), ground water moves through near-vertical and bedding-plane fractures in the shale and siltstone bedrock. Depth to competent bedrock commonly is less than 20 ft below land surface (bls). The soil, saprolite, and individual beds of the sedimentary bedrock form a layered aquifer with varying degrees of hydraulic connection between the layers. Hydraulic properties of the soil, saprolite, and fracture networks in individual beds of the underlying sedimentary bedrock differ. Primary porosity, permeability, and storage in the Triassic- to Jurassic-age sedimentary bedrock is very low.

Ground water in the shallowest part of the sedimentary-rock aquifer may be under unconfined (water-table) or partially confined conditions; the unconfined part of the aquifer probably is thin and is difficult to delineate. In some areas, perched water is present at shallow depths (less than 50 ft). Ground water in the deeper part of the aquifer generally is confined or partially confined, resulting in artesian conditions.

Shallow (generally less than 50 ft below land surface) and deep (50 to 1,000 ft below land surface) ground-water-flow systems may be present at the site. Generally, shallow and deep ground water flows in a direction similar to the topographic gradient. Water from the shallow system likely discharges locally to streams and leaks downward to the deep ground-water-flow system. Deep ground water discharges to streams and to pumping wells, with the natural direction of shallow to deep ground-water flow altered by pumping. Pumping from deep zones may induce downward flow from shallow zones. Cones of depression caused by pumping have been observed to extend preferentially along strike of bedding planes or in the direction of fracture orientation in the Triassic- to Jurassic-age sedimentary rocks of the Brunswick Group and the Lockatong Formation (Longwill and Wood, 1965).

The conceptual model of the ground-water system in the study area consists of dipping, layered fractured rocks with ground-water flow occurring within partings developed primarily along bedding planes (Senior and Goode, 1999). Vertical fractures generally do not cut extensively across beds but may provide local routes of ground-water flow or leakage between beds.

Well-Identification System

This report uses the USGS local well number as the primary well identification. The USGS local well number consists of a two-letter county-abbreviation prefix followed by a sequentially assigned number. The prefix MG denotes a well in Montgomery County. The USGS also assigns each well a unique 15-digit site number based on latitude and longitude in degrees, minutes, and seconds and a 2-digit sequence number. Some wells have other names or numbers assigned by owners or used in the CH2M Hill Inc. report (1992). A complete listing of USGS local well and site numbers and owner-assigned well numbers is given in tables 79 and 80 at the back of the report.

Previous Investigations

Ground-water studies in the Lansdale Borough and Upper Gwynedd Township area have been prompted by concern about limited ground-water availability during periods of drought, by discovery of contaminated drinking water from public-supply wells, and by interest in commercial and industrial uses of the ground water. Rima (1955), Longwill and Wood (1965), and Newport (1971) provide well-characteristic and ground-water-quality data and description of ground-water resources in Montgomery County, Pa., including the Lansdale and Upper Gwynedd Township area. Longwill and Wood (1965) compiled a geologic map, which in the Lansdale area was based almost entirely on unpublished manuscripts by Dean B. McLaughlin of the Pennsylvania Geological Survey. Lyttle and Epstein (1987) compiled a geologic map of the Newark 1° × 2° Quadrangle that updates and revises 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.

Investigations of ground-water contamination after 1979 by USEPA and others are summarized in a report to the USEPA by CH2M Hill, Inc. (1992). An evaluation of ground-water pumpage at the Merck & Co., Inc., West Point plant was done by Geraghty & Miller, Inc. (1993). Investigations of ground-water quality at the FERCO facility in North Penn Area 7 were described by Converse Consultants East (1994). Sources of ground-water contamination in the nearby North Penn Area 6 site are identified in other reports to the USEPA by Black & Veatch Waste Science, Inc. (1994, 1999). A map of ground-water levels in the vicinity of Lansdale that includes ground-water levels within North Penn Area 7 was done by Senior and others (1998). Goode and Senior (1998) present a review of aquifer tests done in the Lansdale area from 1980 through 1995, including tests done in industrial supply wells at manufacturing facilities in and near North Penn Area 7. Senior and Goode (1999) describe the ground-water system and simulation of ground-water flow for the North Penn Area 6 site and vicinity, including an area in and near North Penn Area 7. Data collected during phase 1 of this study were published by Senior and others (2005) and include a map showing ground-water levels in and near North Penn Area 7 in December 2000 (Senior and Ruddy, 2003).

Geophysical Logs

Geophysical logs can provide information on the location and orientation of fractures, water-producing and water-receiving zones, intervals and quantification of vertical borehole flow, lithology, and well construction. Geophysical logs collected in wells at North Penn Area 7 include caliper, natural-gamma, single-point-resistance, fluid-temperature, fluid-resistivity, heatpulse flowmeter, borehole television (video), and acoustic-televiewer logs.

The caliper log records borehole diameter and may indicate the presence of fractures. The natural-gamma and single-point-resistance logs record physical properties of aquifer materials and are useful to determine lithology. Fluid-temperature and fluid-resistivity logs record properties of borehole fluid that when displaying inflection may indicate water-bearing zones; in addition, the overall profile of these fluid logs may provide information about fluid movement within the borehole. In this report, the fluid-resistivity logs are plotted as fluid conductivity (the inverse of fluid resistivity) to allow more direct comparison with water-quality data collected in the boreholes during aquifer-interval-isolation tests. The heatpulse flowmeter measures the direction and magnitude of vertical fluid movement in the borehole under specific conditions. The borehole television log records a video of the borehole and can be used to visually verify borehole construction, identify fractures and other openings, observe flow within the borehole, and determine lithologic changes. The acoustic-televiewer log is useful to determine orientation of borehole features, such as bedding planes and fractures. A deviation log that records the amount the hole deviates from vertical is produced with the televiewer log. More detailed information about the geophysical logs used for this study is provided in Senior and others (2005).

Interpretation of Individual Well Logs

The USGS collected geophysical logs in 42 wells during 2003–2006 (table 1; fig. 5), 39 of which were new monitor wells and 3 were existing wells. Borehole geophysical logs were used to identify and describe water-bearing fractures, lithology, and fluid movement and, additionally, in existing wells, to confirm or determine well construction. Of the 39 new monitor wells, 15 were the deepest hole (about 300 ft) and 24 were shallower holes in well clusters drilled in areas identified by USEPA and their consultant CDM Federal Programs Corporation for investigation. Geophysical logs in the 15 deep holes were run prior to other holes being drilled in each well cluster and served as a basis for selecting discrete water-bearing zones in the 15 wells for further testing (aquifer-interval-isolation tests using packers). Results of the aquifer-interval-isolation tests were used to determine drilling depths for up to two (and in one case three) shallower boreholes adjacent to the deep well in a cluster to intercept zones of interest identified in testing of the deep well. Geophysical logs were run in the shallower monitor wells in each cluster to identify the water-bearing fractures and confirm intervals for screening.

In the following section, geophysical logs are described in detail for 18 wells (table 1). Of the 18 wells, 3 were existing boreholes (MG-151, MG-1841, MG-1920) on industrial properties and 15 wells were drilled by CDM for the RI/FS during 2003–2005 as the deepest well in a proposed monitor-well cluster. Geophysical logs for the 24 shallower monitor wells, identified as shallow or intermediate in depth in the cluster, are shown in appendix 1 (figs. 1-1 through 1-24). All monitor wells were eventually reconstructed by CDM to be open to short intervals (10 to 20 ft) after geophysical logging. Well-construction information for the wells with geophysical logs is listed in table 80 at the back of the report.

Discussion of individual logs includes a description of the well construction and identification of (1) fractures, (2) direction and magnitude of borehole flow under non-pumping and pumping conditions, and (3) water-bearing zones and relative productivity of water-bearing zones, where possible. This characterization is based primarily on caliper, video, fluid-temperature, fluid-conductance (the inverse of fluid-resistivity), and heatpulse flowmeter logs. Differences in the magnitude and direction of vertical borehole flow can be used to infer water-producing or water-receiving intervals.

The geophysical tools used are calibrated only periodically, and accuracy of measurements may drift between calibrations. Therefore, the geophysical logs should be considered relative rather than absolute measures of borehole characteristics. Because the accuracy of the caliper tool in particular was known to vary during the investigation, the caliper logs are presented in terms of relative borehole diameter.

Many but not all fractures identified on the caliper and video logs were determined to be water bearing by evaluation of heatpulse-flowmeter measurements under non-pumping (ambient) and pumping conditions. Some water-bearing fractures may not be identified by heatpulse-flowmeter measurements if the fractures (1) are low yielding, (2) have little to no difference in hydraulic heads compared to other fractures in the borehole (resulting in lack of vertical flow), (3) have horizontal flow, or (4) are above the static water level in the hole, such as wells with cascading water that commonly can be seen on the video log or heard at the well head.

Interpretation of the acoustic-televiewer logs was done independently of other logs and yielded estimates of orientations of features, such as fractures and bedding. Interpretation

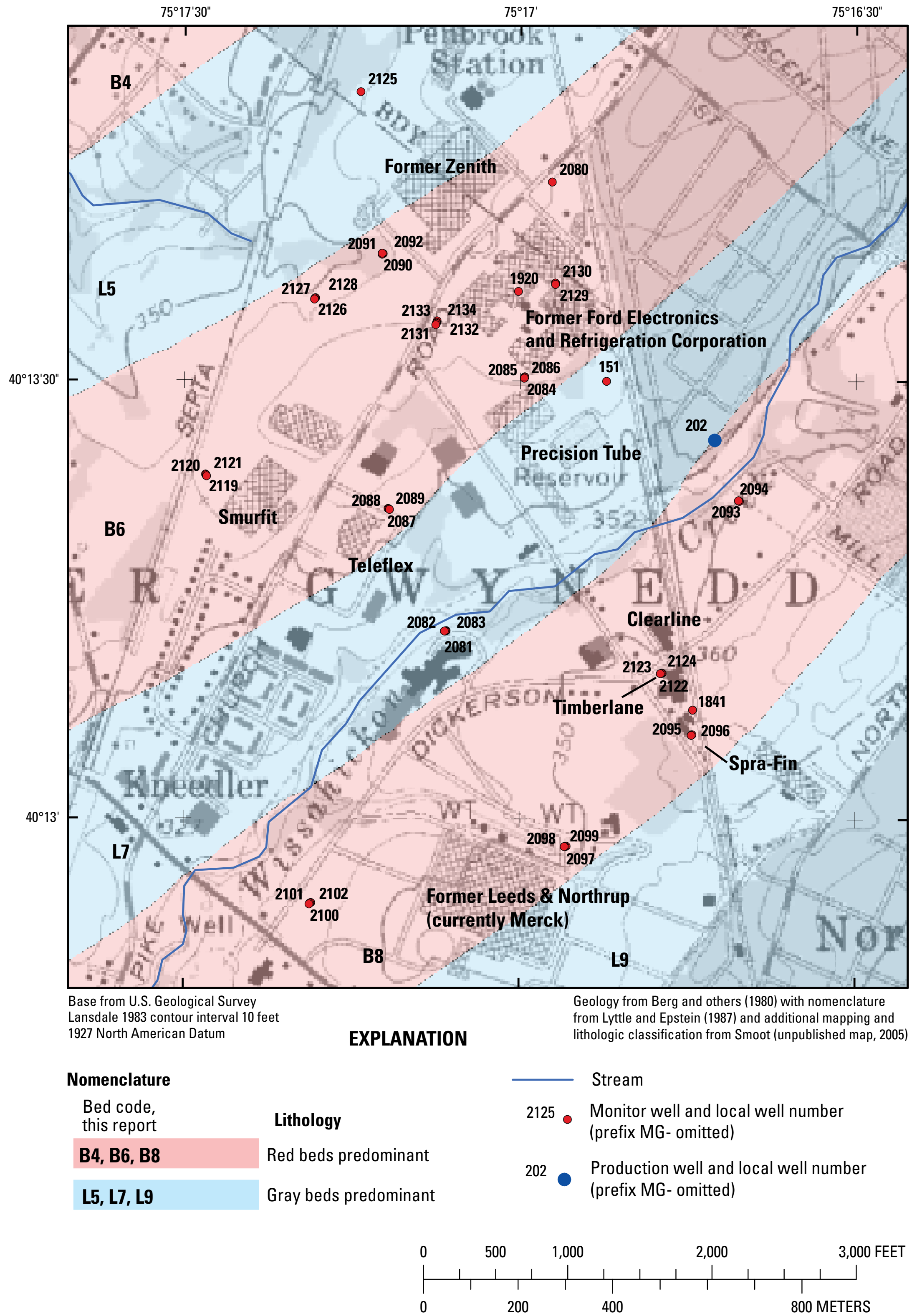


Figure 5. Location of wells with geophysical logs in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa. See figure 4 for location of North Penn Area 7 boundary.

Table 1. Boreholes with geophysical logs collected by U.S. Geological Survey at North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., 2004–2006.

[RI, remedial investigation; ~, estimated value; Abbreviations for type of logs: A, acoustic televiewer; B, borehole television (video); C, caliper; G, natural gamma; S, single-point resistance; T, fluid temperature; R, fluid conductivity (inverse of fluid resistivity); V, borehole flow; W, borehole deviation]

U.S. Geological Survey local well number MG-	Owner well name	Logged borehole depth, in feet	Casing length, in feet	Casing and hole diameter, in inches	Depth to water at the time of logging, in feet below land surface	Date of logging M/D/Y	Type of geophysical logs[1]
Existing and deep monitor wells (18 wells)							
151	Ford #5	477	86	8	25.22	3/26/04	ABCGSTRVW
1841	Spra-Fin 2	104	17	6	23.57	1/24/06	BCGSTRV
1920	Ford MW-1	125	47	6	39.42	4/1/04	ABCGSTRVW
2080	RI-1D	299	18	8	36.85	5/24/05	ABCGSTRVW
2081	RI-2D	300	18	8	~34	7/12/04	ABCGSTRVW
2084	RI-3D	300	15	8	38.16	2/13/04	ABCGSTRVW
2087	RI-4D	300	25	8	24.06	2/20/04	ABCGSTRVW
2090	RI-5D	300	19	8	21.16	2/27/04	ABCGSTRVW
2093	RI-6D	300	22	8	11.57	5/18/04	ABCGSTRVW
2095	RI-7D	246	19	8	23.58	2/4/04	ABCGSTRVW
2097	RI-8D	300	18	8	9.22	7/20/04	ABCGSTRVW
2100	RI-9D	286	19	8	54.14	7/16/04	ABCGSTRVW
2119	RI-10D	289	19	8	39.33	3/12/04	ABCGSTRVW
2122	RI-11D	299	25	8	21.62	7/6/04	ABCGSTRVW
2125	RI-12D	300	20	10	43.68	3/3/04	ABCGSTRVW
2126	RI-13D	279	20	8	24.61	5/25/04	ABCGSTRVW
2129	RI-14D	299	54	8	43.51	6/1/05	ABCGSTRVW
2131	RI-15DD	299	18	8	39.34	5/25/05	ABCGSTRVW
Shallow and intermediate monitor wells (24 wells)							
2082	RI-2I	188	18	6	13.04	8/16/04	BCGSTRV
2083	RI-2S	61	17.5	6	9.25	2/2/04	BCGSV
2085	RI-3I	137	18	6	42.23	7/27/04	BCGSTRV
2086	RI-3S	65	18.5	6	40.59	7/27/04	BCGSTRV
2088	RI-4I	137	18	6	28.07	7/23/04	BCGSTRV
2089	RI-4S	70	19	6	~ 69	8/3/04	BCGV
2091	RI-5I	98	18	6	23.68	7/23/04	BCGSTRV
2092	RI-5S	60	18	6	21.47	8/4/04	BCGSTRV
2094	RI-6S	62	18.5	6	8.13	7/28/04	BCGSTRV
2096	RI-7S	72	18	6	24.95	8/3/04	BCGSTRV
2098	RI-8I	81	18	6	12.25	9/1/04	BCGSV
2099	RI-8S	40	19	6	12.58	9/1/04	BCGSV
2101	RI-9I	188	19	6	[2]~61.4	9/1/04	BCGSV
2102	RI-9S	105	18	6	~67.7	9/8/04	BCGSV
2120	RI-10I	140	18.5	6	42.93	7/29/04	BCGSTRV
2121	RI-10S	90	19	6	41.68	8/11/04	BCGSTRV
2123	RI-11I	100	18.5	6	[3]~21	8/10/04	BCGSV
2124	RI-11S	60	19	6	23.94	9/3/04	BCGSV
2127	RI-13I	138	19	6	27.28	8/7/04	BCGSTRV
2128	RI-13S	75	18	6	27.15	8/12/04	BCGSTRV
2130	RI-14S	118	56	6	46.04	7/20/05	BCGSTRV
2132	RI-15D	220	17	8	41.94	7/14/05	BCGSTRV
2133	RI-15I	130	18	6	41.09	7/19/05	BCGSTRV
2134	RI-15S	100	18	6	40.53	7/20/05	BCGSTRV

[1]Fluid-resistivity logs are plotted as fluid conductivity (inverse of resistivity) to allow more direct comparison with water quality of discrete water-bearing zones determined during aquifer-interval-isolation tests, discussed in a later section of the report.

[2]Estimated from electric log, water cascading.

[3]Estimated from electric log.

usually was difficult because of zones with poor log resolution or features with low angles. Results of televiewer-log interpretations for individual wells are listed in appendix 2 and are summarized in a separate section of this report. Orientations are reported as the azimuth and magnitude of dip. The deviation log is run concurrently with the acoustic-televiewer log, providing information about the magnitude of hole deviation from vertical. As the borehole deviation from vertical increases, the actual vertical depth of the borehole is decreasingly less than the reported drilling depth. A summary of the relation of the deviation log to bedding orientation is discussed in a separate section of the report.

Natural-gamma logs and single-point-resistance logs are not discussed in detail. Generally these logs exhibit an inverse relation, indicating lithology of rocks in the vicinity of North Penn Area 7. Shalier beds are indicated where elevated natural-gamma activity corresponds to depressed resistance and sandier beds are indicated where depressed natural-gamma activity corresponds to elevated resistance. Extremely elevated natural-gamma activity (higher than 500 counts per second) typically corresponds to a dark shaly layer or marker bed that can be used for stratigraphic correlation. Only some wells intercepted marker beds. Discussion of lithologic intervals that can be used for stratigraphic correlation follows in a later section of the report.

MG-151 (Ford # 5)

The caliper log shows that the borehole is 477 ft in depth and constricts in diameter at 297 ft bls (fig. 6). The well is cased with 8.25-in.-diameter steel casing to 86 ft bls, is 8 in. in diameter below the casing down to 297 ft bls, and then is 6 in. in diameter to the bottom. The apparent increase in single-point resistance corresponds to the decrease in borehole diameter at about 300 ft bls (fig. 6). Major fractures are shown at 87–99, 111, 301–307, and 314 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-producing zones at 90, 109, 137, 161, 185, 189, 215, 229, 299, 312, 358, 370, 380, and 472 ft bls. The static water level at the time of logging was 25.22 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 87, 137, and 370 ft bls that correlate to fractures shown on the caliper log and indicate water-producing zones. Under non-pumping conditions, borehole flow was too great to measure at 147 ft bls using an 8-in.-diameter diverter in the 8-in. borehole; therefore, a smaller diameter diverter was used, which allowed some flow to bypass the flowmeter. Using a 6-in.-diameter diverter in the 8-in.-diameter borehole, the heatpulse flowmeter measured upward flow at 105 and 130 ft bls, downward flow from 138 to 368 ft bls, and no flow from 380 to 450 ft bls (table 2; fig. 6), indicating water entered the borehole through fractures at 137–140, 301, and 360–364 ft bls, moved upward and downward, and exited the borehole through fractures at 87–99, 301–307, and 371 ft bls. Under non-pumping conditions, the heatpulse-flowmeter measurements identified the fracture zone at 137–140 ft bls as the most productive. This borehole was not logged with the heatpulse flowmeter under pumping conditions.

Table 2. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 26, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions			
	Flow rate[1] (gal/min)	Flow[1] direction	Flow rate[2] (gal/min)	Flow[2] direction
105	0.48	up	0.12	up
130	--	--	.17	up
138	--	--	.1	down
147	>1.0	turbulence	.4	down
166	--	--	.4	down
181	--	--	.4	down
187.5	--	--	.3	down
204	--	--	.4	down
240	--	--	.3	down
260	--	--	.2	down
290	--	--	.2	down
310	--	--	.2	down
350	--	--	.1	down
368	--	--	.3	down
380	--	--	NF	--
398	--	--	NF	--
450	--	--	NF	--

[1]Measured using 8-in.-diameter diverter in the 8-in.-diameter borehole.

[2]Measured using 6-in.-diameter diverter in the 8-in.-diameter borehole.

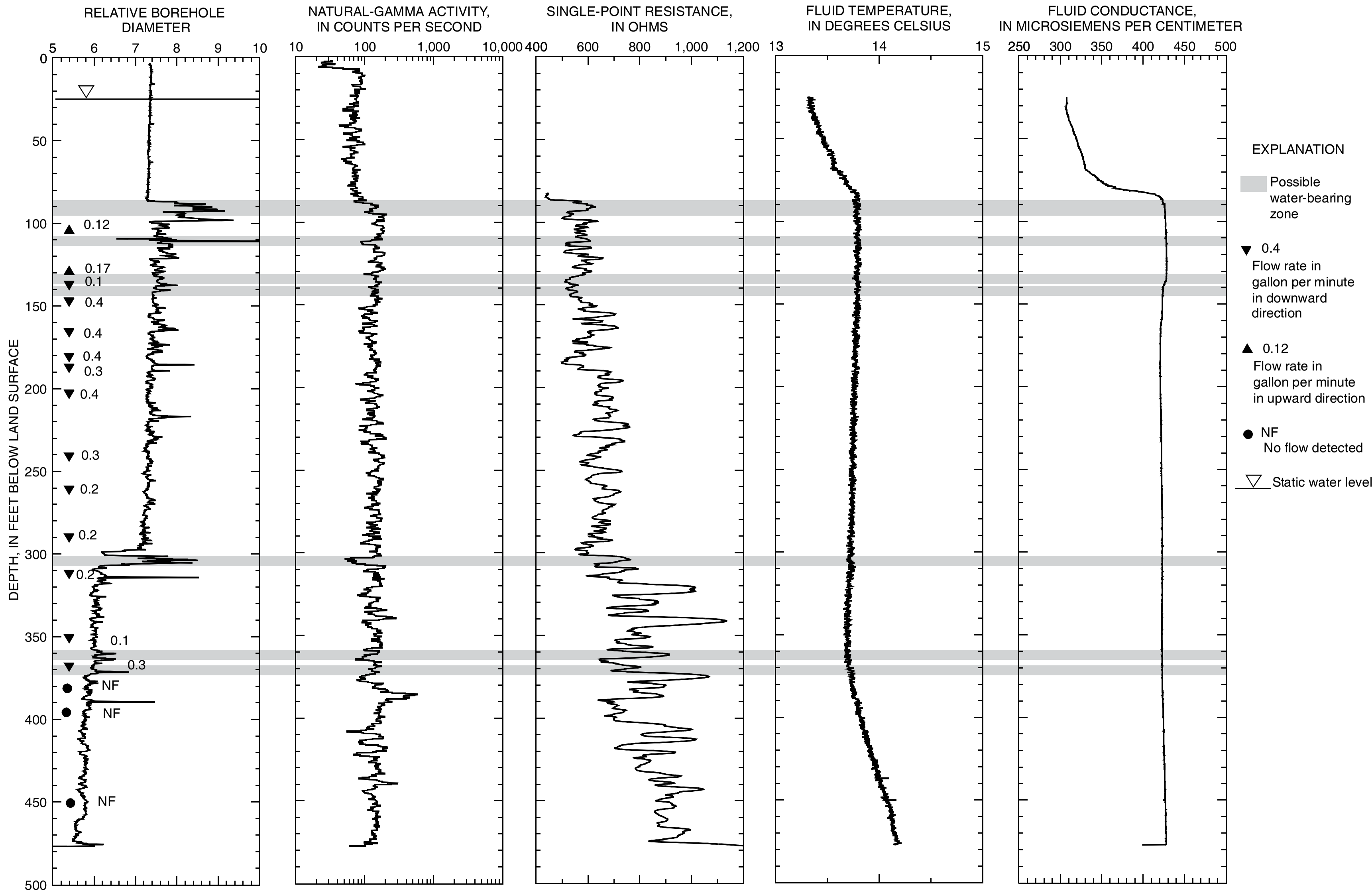


Figure 6. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-151 (Ford #5), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 26, 2004. Depicted flow measured with 6-in.-diameter diverter in the 8-in.-diameter borehole.

MG-1841 (Spra-Fin 2)

Well MG-1841 was previously an active production well and, after removal of a pump, was logged to determine construction characteristics and depth of water-bearing zones. The caliper log shows that the borehole is 104 ft in depth, is cased with 6-in.-diameter steel casing to 17 ft bls, and is 6 in. in diameter below the casing down to the bottom (fig. 7). Major fractures are shown at 29, 40–50, 67, 89, and 100 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-producing zones at 40–50, 89, and 100 ft bls. The static water level at the time of logging was 23.57 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 40, 50, and 90 ft bls that correlate to fractures shown on the caliper log, possibly indicating water-bearing zones. Also, the fluid logs show changes at 90 ft bls that correlate to a water-producing zone defined with the heatpulse flowmeter. Under non-pumping conditions, the heatpulse flowmeter measured upward borehole flow at numerous depths and no flow or turbulent flow at 38 ft bls (table 3; fig. 7). These measurements (table 3) indicate that, under non-pumping conditions, water entered the borehole through fractures at 100–102 ft bls, moved upward, and exited the borehole predominantly through fractures at 89 ft bls but also through fractures at 40–50 ft bls. Under non-pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones at 89 and 100–102 ft bls as the most productive. This borehole was not logged with the heatpulse flowmeter under pumping conditions because of no available water disposal at the time of logging.

Table 3. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-1841 (Spra-Fin 2), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., January 24, 2006.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions	
	Flow rate (gal/min)	Flow direction
38	NF/turbulent	--
52	0.03	up
64	.03	up
80	.04	up
88	.03	up
91	.18	up
94	.28	up

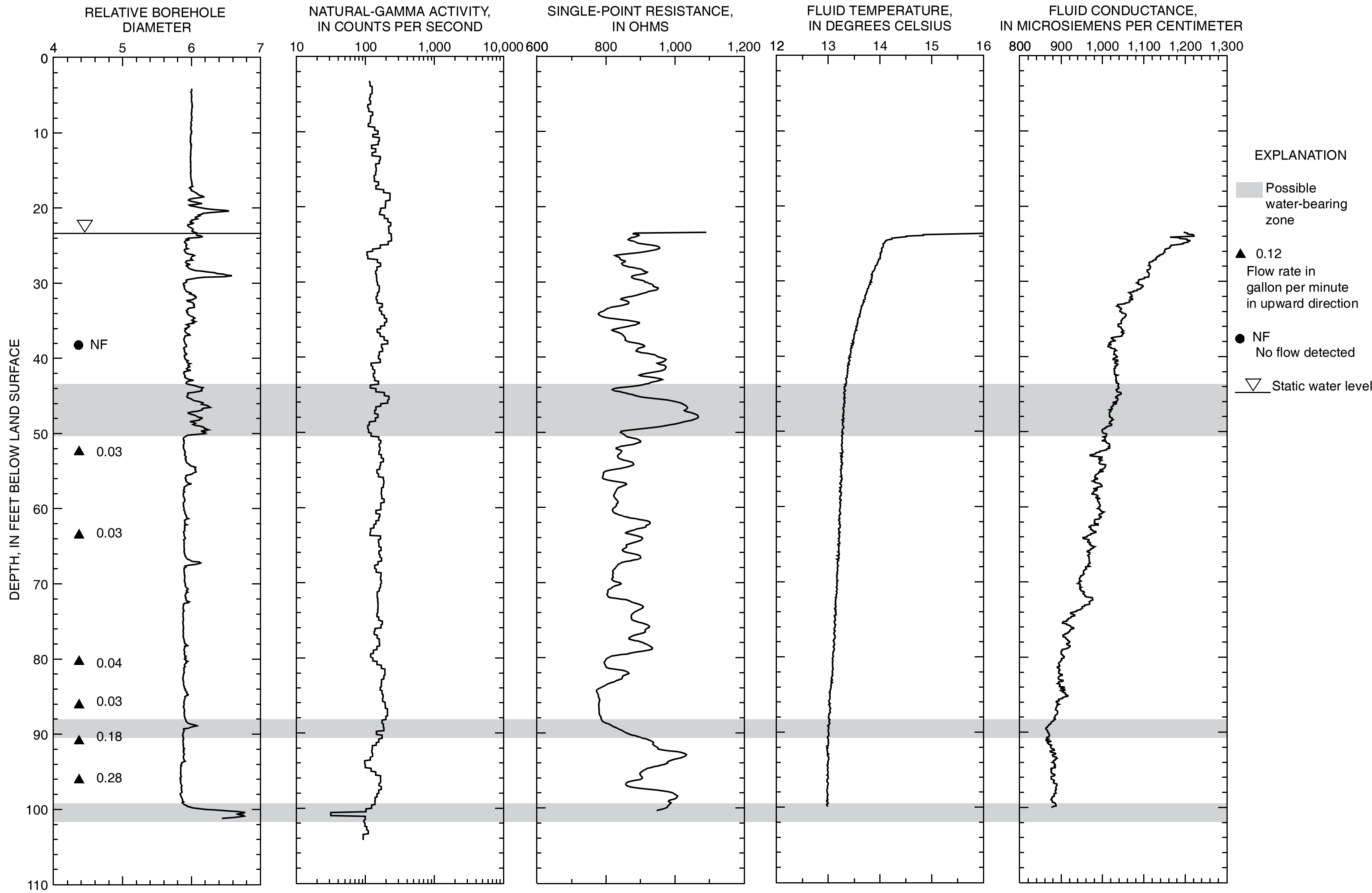


Figure 7. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-1841 (Spra-Fin 2), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., January 24, 2006.

MG-1920 (Ford MW-1)

The caliper log shows that the borehole is 125 ft in depth, is cased with 6.25-in.-diameter steel casing to 47 ft bls, and is 6 in. in diameter below the casing down to the bottom (fig. 8). Major fractures are shown at 50 and 72.2–77 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-producing zones at 59, 71, and 110–111 ft bls. The static water level at the time of logging was 39.42 ft bls. This well is a monitor well drilled on an unknown date near the old Ford #2 production well and was arbitrarily assigned a designation of Ford MW-1.

The fluid-conductance log shows inflections at approximately 55 and 59 ft bls that correlate to fractures shown on the caliper log and a sharp inflection at 123 ft bls that does not correlate to an observed fracture. These inflections indicate water-bearing zones at about 55–59 and 123 ft bls. Under non-pumping conditions, the heatpulse flowmeter measured upward and downward borehole flow (table 4; fig. 8). The flow measurements at each zone varied slightly in rate, suggesting the borehole is being stressed by local pumping. These measurements (table 4) indicate that, under non-pumping conditions, water entered the borehole through fractures at 55–59 and 123 ft bls, moved downward and upward, respectively, and exited the borehole through a series of vertical fractures seen on the borehole video log at 81–84 ft bls (appendix 1). Under non-pumping conditions, the suite of geophysical logs and the heatpulse flowmeter suggest the fracture zone at 81–84 ft bls is the most productive. This borehole was not logged with the heatpulse flowmeter under pumping conditions.

Table 4. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 1, 2004.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions	
	Flow rate (gal/min)	Flow direction
44	NF	--
66	0.2	down
80	.2	down
90	NF	--
100	NF to 0.1	up
110	NF	--
120	NF to 0.2	up

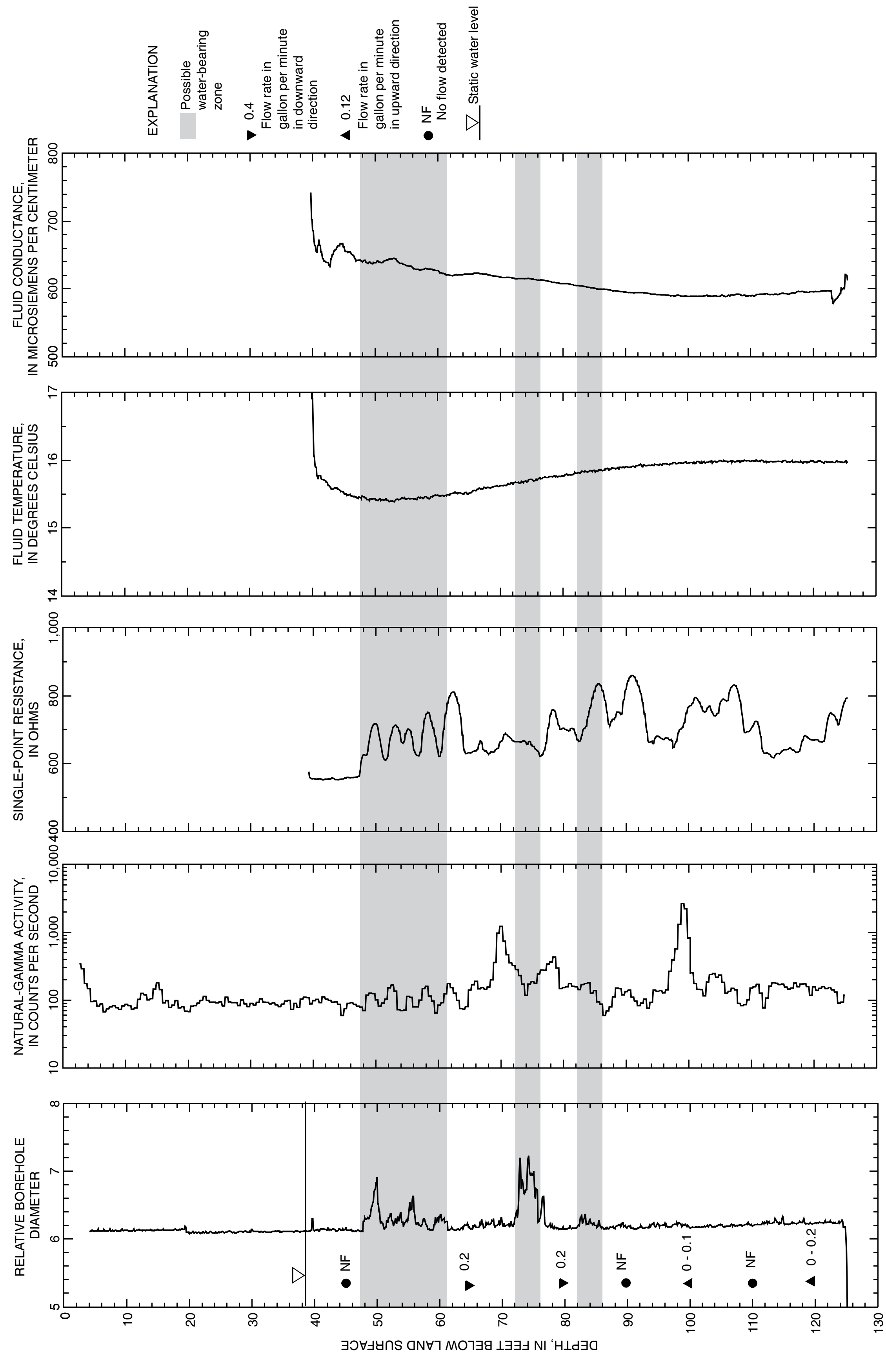


Figure 8. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 1, 2004.

MG-2080 (RI-1D)

The caliper log shows that the borehole is 298 ft in depth (fig. 9). The borehole is cased with 8.25-in.-diameter steel casing to 18 ft bls and is 8 in. in diameter below the casing. There are numerous minor fractures throughout the borehole. Major fracture zones are at 130–144 and 150 ft bls; the largest fracture is shown at 78–79.5 ft bls. The borehole video log indicated possible water-bearing zones associated with high-angle fractures observed at 62–65, 76–78, 132–140, 251–256, and 281–285 ft bls. The static water level at the time of logging was 36.85 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 60, 79, 134–141, and 255 ft bls that correlate to fractures shown on the caliper log and suggest water-bearing zones. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at various depths below 72 ft bls and no flow at 270 ft bls (table 5; fig. 9). The pattern of increases and decreases in flow indicates water entered the borehole at 62–65, 76–79, and 130–142 ft bls, moved downward, and exited the borehole through fractures at 150 and 246–256 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at a rate of 1.2 gal/min. After 42 minutes of pumping, the water level decreased by 0.13 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate fracture zones near 62–65 and 76–79 ft bls appear to be the most productive, because downward borehole flow was still measured at 90 ft bls and deeper (table 5).

Table 5. Depths, flow rates, flow directions, and pumping rates of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 24, 2005.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
60	--	--	0.35	up
70	0.09	down	.12	up
90	.23	down	.09	down
126	.23	down	.10	down
146	.30	down	--	--
164	.08	down	--	--
190	.06	down	--	--
240	.07	down	--	--
250	.02	down	--	--
270	NF	--	--	--

[1]Pumping rate of 1.2 gal/min.

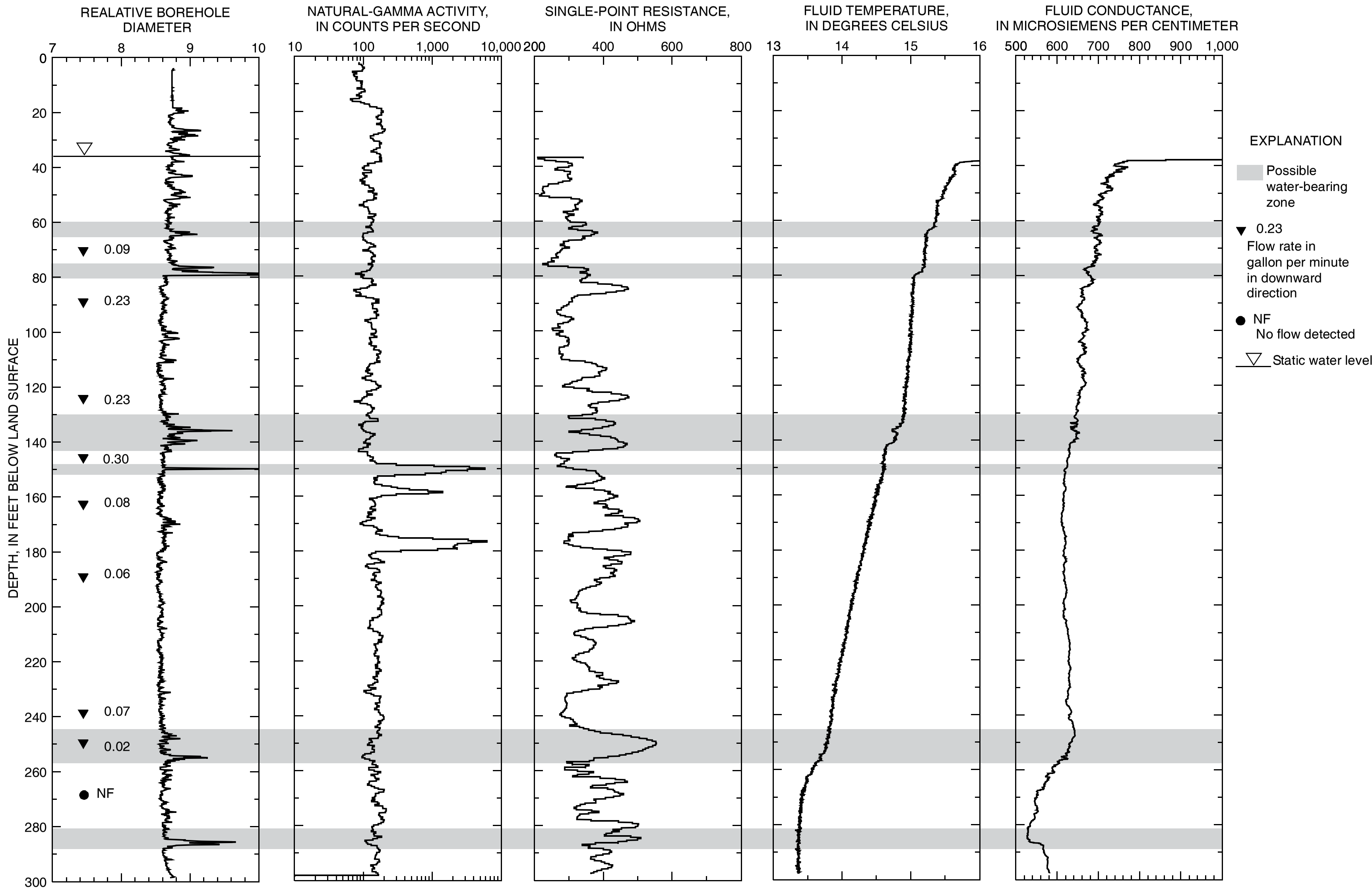


Figure 9. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2080 (RI-1D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 24, 2005.

MG-2081 (RI-2D)

The caliper log shows that the borehole is about 300 ft in depth (fig. 10). The borehole is cased with 6.25-in.-diameter steel casing to 18 ft bls and is 6 in. in diameter below the casing. There are numerous minor fractures throughout the borehole. Major fractures zones are at 19–29, 38–54, 78–83, 150, and 170–186 ft bls; the largest fracture is shown at 29 ft bls. The borehole video log indicated possible water-bearing zones associated with high-angle fractures observed at 19, 22, 26, 42, 69, 81, 122, 125, 149, 173, 176, 179, 181–187, 222, 283, and 294 ft bls. The static water level at the time of logging could only be approximated with the single-point-resistance log because of cascading water and was determined to be 34 ft bls.

The fluid-conductance log and, to a lesser extent, the fluid-temperature log show inflections at about 45, 54, 70, 80, and 122 ft bls that approximately correlate to fractures shown on the caliper and video logs and may indicate water-bearing zones. Under non-pumping conditions, borehole flow was too great to measure using an 8-in.-diameter diverter in the 8-in. borehole; therefore, smaller diameter diverters were used, which allow some flow to bypass the flowmeter. Using a 4-in.-diameter diverter in the 8-in.-diameter borehole, the heatpulse flowmeter measured downward flow at 41 ft bls and upward flow at various depths from 49 to 290 ft bls (table 6; fig. 10). The direction and magnitude of flow at 49, 60, 100, 140, and 160 ft bls could not be determined from heatpulse-flowmeter measurements at those depths, but flow was suspected to be greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole. Subsequently, the heatpulse flowmeter was run with no diverter, allowing more flow to bypass the flowmeter and possible detection of flow and flow direction. Using no diverter, the heatpulse flowmeter measured downward flow at 41 ft bls and upward flow at various depths from 49 to 290 ft bls (table 6). These measurements (table 6) indicate that, under non-pumping conditions, water entered the borehole at 19–28 ft bls, moved downward, and exited the borehole at 43–45 ft bls; additional water was produced at either about 70 or 80 ft bls and at 170, 186, and 294 ft bls, moved upward, and exited the borehole at 52–54 and 43–45 ft bls. When comparing measurements made with the 4-in. diverter to those made with no diverter, the apparent reversal in flow direction at many depths may be related to changes in nearby pumping or errors in the flowmeter measurements. Downward flow was observed at 131 ft bls on the video log run on July 9, 2004, 3 days earlier than the geophysical logs, suggesting that downward flow directions sometimes occur below 50 ft bls.

The most productive water-bearing zones are at about 19–29 and 170–186 ft bls. The zone between 170–186 ft bls appears to produce and receive water, depending on external conditions. The observed flow patterns during flow tracing suggest the borehole is interconnected through some fractures, such as those between 170–186 ft bls; the nearby pumping well(s) cause the borehole to periodically change flow patterns. This borehole was not logged with the heatpulse flowmeter under pumping conditions because maximum traceable upward flow was already present under ambient conditions.

Table 6. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 12, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; nd, not determined; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions			
	Flow rate[1] (gal/min)	Flow direction	Flow rate[2] (gal/min)	Flow direction
41	1.2	down	0.34	down
49	nd	--	.18	up
60	nd	--	.40	up
65	--	--	.40	up
90	--	--	.50	up
100	nd	--	.60	up
110	--	--	.60	up
120	--	--	.60	up
130	--	--	.60	up
140	nd	--	.60	up
160	nd	--	.80	up
170	--	--	.70	up
181	--	--	.45	up
190	.82	down	.12	up
216	.72	down	.13	up
234	.25	down	.07	up
250	.30	down	.07	up
276	.17	down	.06	up
290	.12	down	.05	up

[1]Measured using 4-in.diameter diverter in the 8-in.-diameter borehole.

[2]Measured using no diverter in the 8-in.-diameter borehole.

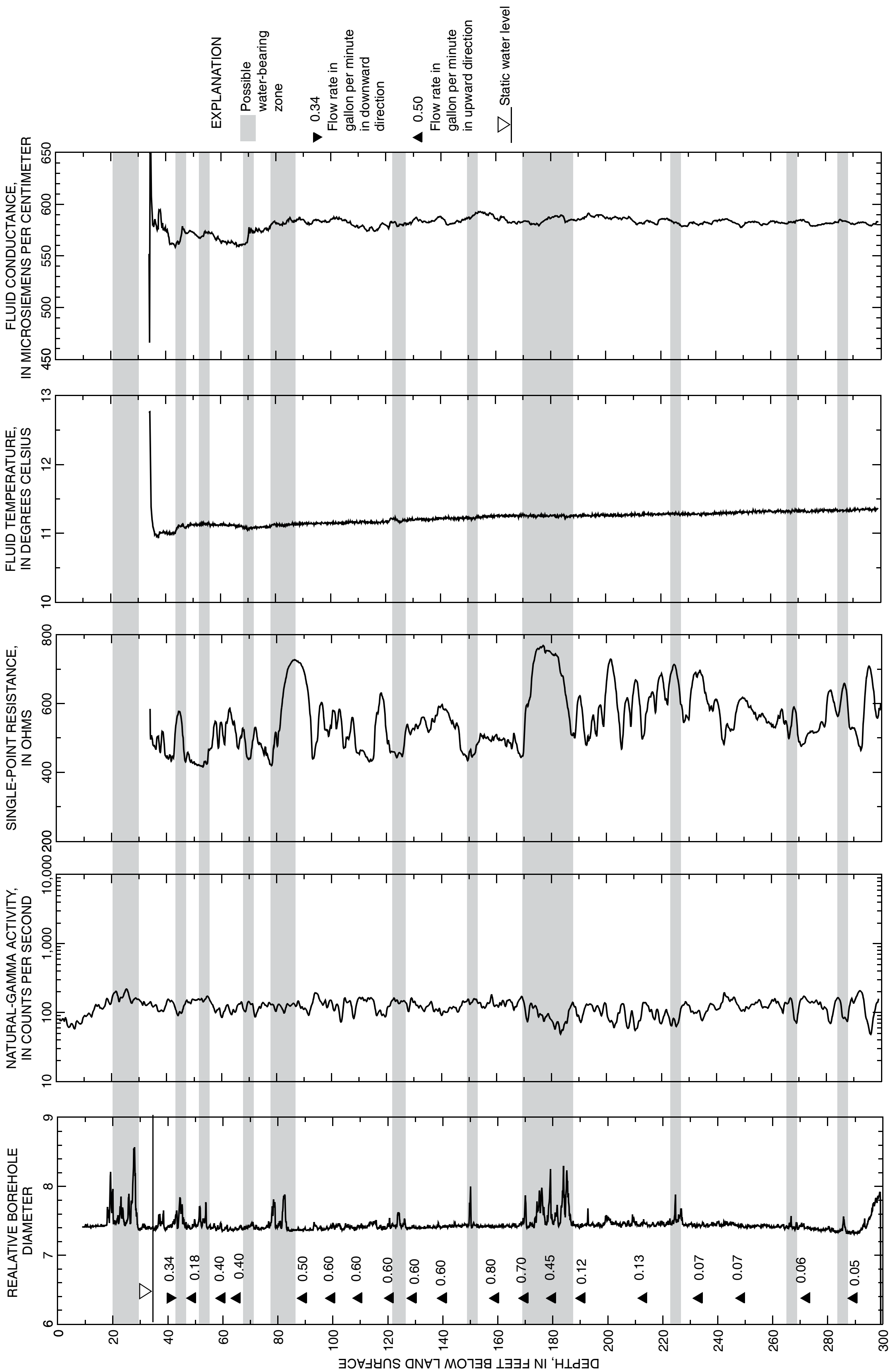


Figure 10. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2081 (RI-2D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 12, 2004.

MG-2084 (RI-3D)

The caliper log shows that the borehole is almost 300 ft in depth, is cased with 8.25-in.-diameter steel casing to 15 ft bls, and is 8 in. in diameter below the casing (fig. 11). There are numerous minor fractures throughout the borehole. Major fractures are shown at 21, 53, 75, 170–172, and 190–193 ft bls; the largest fracture is shown at 190–193 ft bls. The borehole video log indicated possible water-bearing zones associated with high-angle fractures observed at 52–54, 73, 108, 123, 170–172, 189–192, 229, and 265–272 ft bls. The static water level at the time of logging was 38.16 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at about 75, 109, 123, 193, 230, and 265 ft bls that correlate to fractures shown on the caliper and video logs and indicate water-bearing zones. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at various depths from 80 to 183 ft bls, upward flow at 220 and 250 ft bls, and no flow at 64, 270, and 290 ft bls (table 7; fig. 11), indicating that water probably entered the borehole and moved down from about 75, 109, and 123 ft bls, entered and moved up from about 230–240 and 265 ft bls (and possibly at 252–257 ft bls), and exited the borehole at 190–193 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at approximately 2 gal/min. After 56 minutes of pumping, the water level declined 0.05 ft to 38.68 ft bls. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate fracture zones at about 75, 109, and 123 ft bls are the most productive. The fractures at 190–193 ft bls remained a water-receiving zone during pumping, indicating a pumping rate greater than 2 gal/min would be required to reverse downward flow below the apparent flow boundary at 124 ft bls. During pumping, flowmeter measurements below 193 ft bls increased from non-pumping values; measurements at 220 and 250 ft bls showed an increase in upward flow, and measurements at 270 and 290 ft bls increased from no flow to upward flow. These zones appear separated from the stress of pumping near the top of the well during flow tracing because there was no change in downward flow measured at 183 ft bls. The observed flow patterns also suggest the borehole may be interconnected through the fractures at 190–193 ft bls with nearby well(s) that is (are) pumped at variable rates.

Table 7. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., February 13, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
64	NF	--	0.8 to 1.0	up
80	0.2 to 0.5	down	.6 to 1.2	up
96	.2 to 1.3	down	.6 to 1.2	up
117	.4 to 0.8	down	.9	up
145	1.0	down	.1 to 0.5	down
183	1.0 to 1.2	down	.55 to 1.1	down
220	.16	up	.54	up
250	.07	up	.34	up
270	NF	--	.06	up
290	NF	--	.06	up

[1]Pumping rate of 2 gal/min.

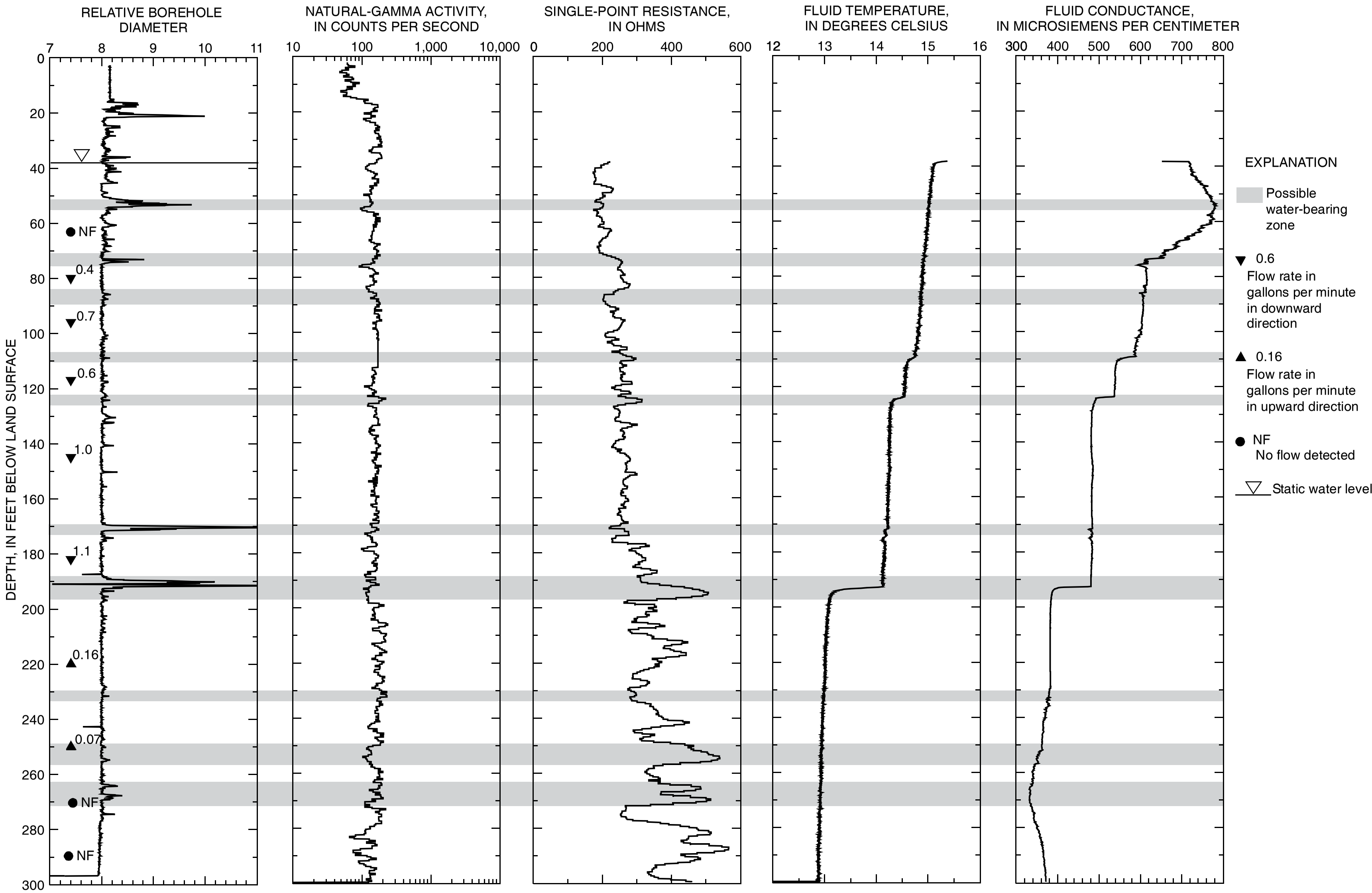


Figure 11. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2084 (RI-3D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., February 13, 2004.

MG-2087 (RI-4D)

The caliper log shows that the borehole is almost 300 ft in depth, is cased with 8.25-in.-diameter steel casing to 25 ft bls, and is 8 in. in diameter below the casing (fig. 12). Major fractures are shown at 61, 69, 86–89, 125.5, 146, 245, and 252 ft bls plus numerous minor fractures throughout the borehole. The largest fracture is shown at 86–89 ft bls. The borehole video log indicated possible water-bearing zones at 68, 86, 91, 123, 144, and 202 ft bls. The static water level at the time of logging was 24.06 ft bls.

The fluid-conductance log shows inflections at about 60 and approximately 205 ft bls that correlate to fractures shown on the caliper log and may indicate water-bearing zones. In addition, the fluid-temperature log shows an inflection at about 100 ft bls. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at depths from 65 to 92 ft bls, upward flow at depths from 105 to 285 ft bls, and no flow at depths from 33 to 57.5 ft bls (table 8; fig. 12). These measurements (table 8) indicate water entered the borehole at 60, 145, 203–209, and 291 ft bls, moved downward (from fractures near 60 ft bls) or upward (from other fractures), and exited the borehole through the fractures at about 86–90, 94–97, and 123 ft bls.

A submersible pump was placed at 40 ft bls, and the well was pumped at 1.0 to 1.65 gal/min. After 2 hours and 14 minutes of pumping, the water level declined 0.19 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate fracture zones at about 86–90, 94–97, and 146 ft bls are the most productive. The observed flow patterns also suggest the borehole may be interconnected through the fractures with nearby well(s) that are pumped at variable rates.

Table 8. Depths, flow rates, flow directions, and pumping rates of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., February 20, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
33	NF	--	--	--
52	NF	--	--	--
57.5	NF	--	0.9	up
65	1.0	down	.9	up
80	1.1	down	.4	up
92	.6	down	.1	up
105	.3	up	.8	up
117	.2	up	.8	up
122	.3	up	.7	up
130	.5	up	.8	up
141	.4	up	.9	up
151	.2	up	.5	up
160	.2	up	.4	up
190	.2	up	.4	up
212	.1	up	.1	up
235	.1	up	--	--
265	.1	up	--	--
285	.1	up	--	--

[1]Pumping rate of 1.0–1.65 gal/min.

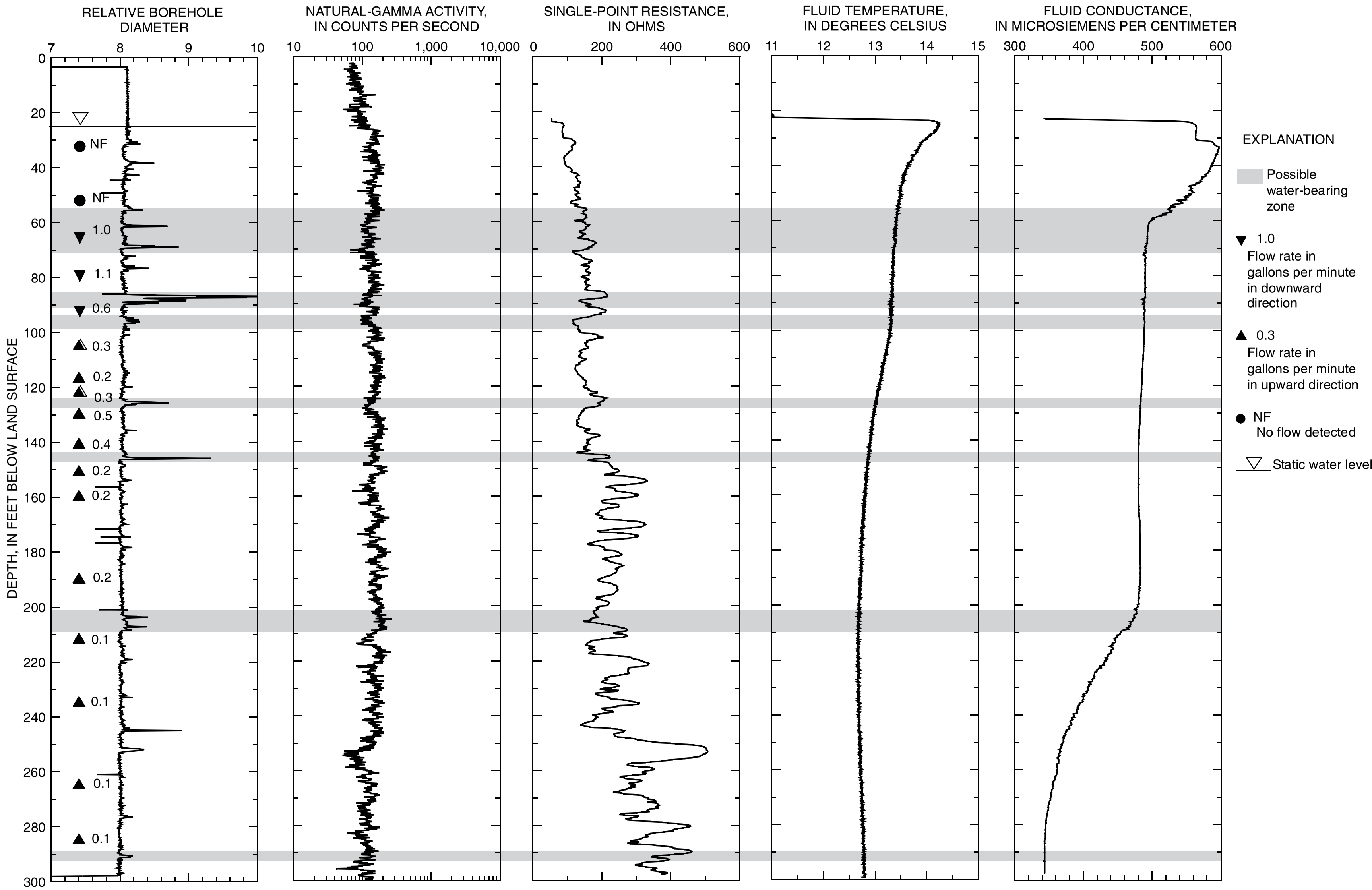


Figure 12. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2087 (RI-4D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., February 20, 2004.

MG-2090 (RI-5D)

The caliper log shows that the borehole is 300 ft in depth (fig. 13). The borehole is cased with 8.25-in.-diameter steel casing to 19 ft bls and is 8 in. in diameter below the casing. Major fractures are shown at 48, 82–84, and 296 ft bls plus numerous minor fractures throughout the borehole. The largest fractures are shown at 48 and 296 ft bls. The borehole video log indicated possible water-bearing zones associated with fractures at 65, 79, 105, 194, and 291 ft bls. The static water level at the time of logging was 21.16 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 48, 82, and 127 ft bls that correlate to fractures shown on the caliper log and suggest possible water-bearing zones. The fluid-temperature log also shows small inflections at about 218 and 236 ft bls that correspond to fractures on the caliper log. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at various depths from 62.5 to 280 ft bls and no flow at 30 ft bls (table 9; fig. 13), indicating water probably entered the borehole at about 48, 65, and 80–84 ft bls, moved downward, and exited the borehole through the fractures at about 173–178, 190–199, 272, and 296 ft bls. The flow measurement at 240 ft bls does not follow the general pattern other measurements show of decreasing downward flow in the borehole and suggests either an incomplete seal during flow metering at 210 and 220 ft bls or more water-bearing fractures than those described above.

A submersible pump was placed at 40 ft bls, and the well was pumped at a rate of less than 1.0 gal/min. After 56 minutes of pumping, the water level declined 0.06 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate fracture zones at 66–68 and 80–84 ft bls are the most productive.

Table 9. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., February 27, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; U, undetermined; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
30	NF	--	--	--
62.5	0.78	down	1.0	up
76	1.1	down	.15	up
90	U[2]	down?	U	--
120	1.1	down	.7	down
140	U[2]	down?	1.1	down
170	1.1	down	1.1	down
180	.98	down	--	--
190	.98	down	--	--
200	.75	down	--	--
210	.41	down	--	--
220	.45	down	--	--
240	.74	down	--	--
262.5	.46	down	--	--
280	.33	down	--	--

[1]Pumping rate of less than 1 gal/min.

[2]Flow possibly too fast to measure.

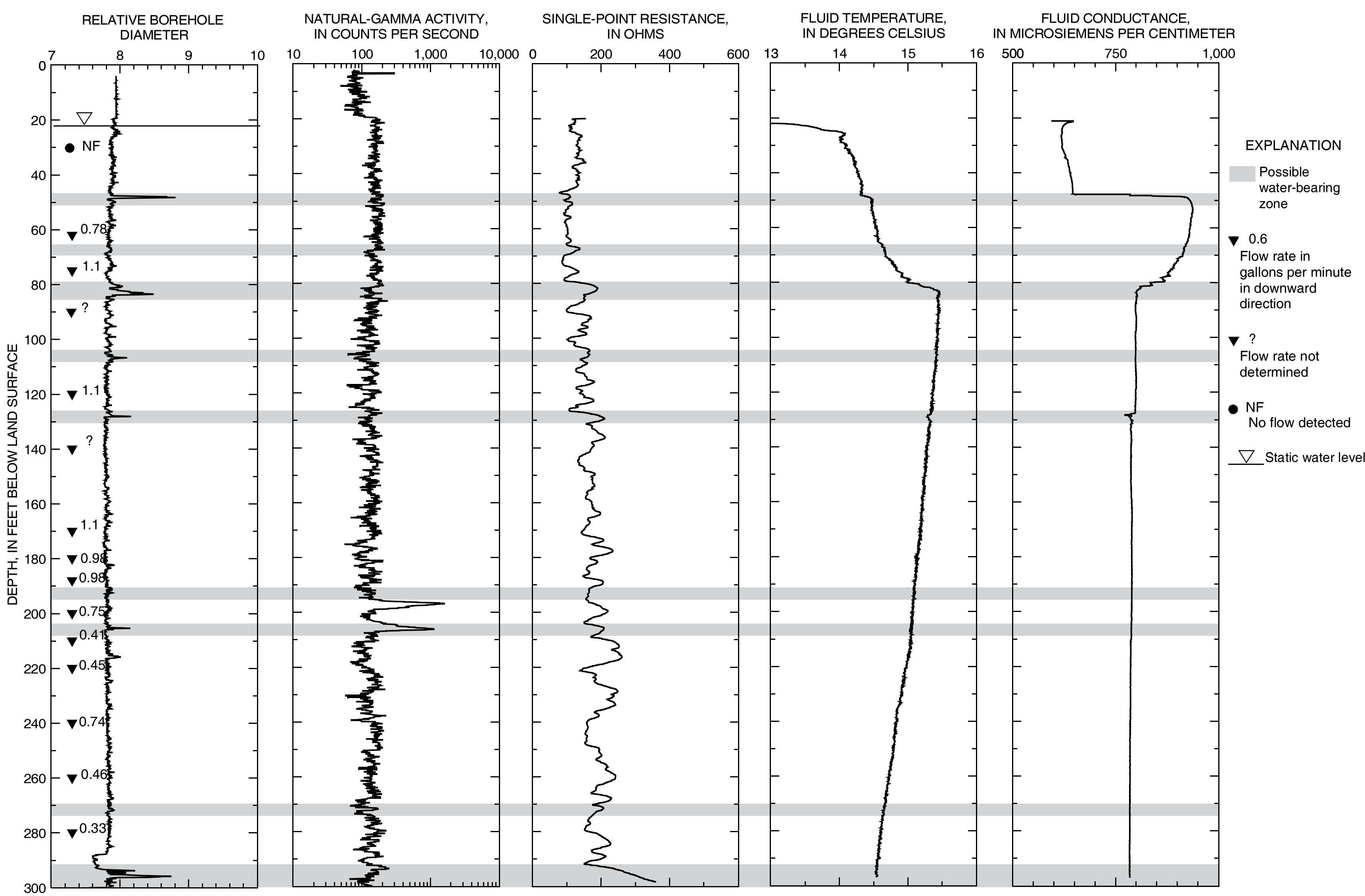


Figure 13. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2090 (RI-5D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., February 27, 2004.

MG-2093 (RI-6D)

The caliper log shows that the borehole is about 300 ft in depth (fig. 14). The borehole is cased with 8.25-in.-diameter steel casing to 22 ft bls and is 8 in. in diameter below the casing. Major fractures are shown at 22.5, 35, 72, and 85–95 ft bls plus numerous minor fractures throughout the borehole. The largest fracture is shown at 85–95 ft bls. The borehole video log indicated possible water-bearing zones at 55–56, 67, 85, 89, and 90 ft bls. The static water level at the time of logging was 11.57 ft bls.

The fluid-conductance log shows inflections at approximately 23, 33, 55, 90, 180, and 267 ft bls that correlate to fractures shown on the caliper log and suggest water-bearing zones. Under non-pumping conditions and using an 8-in.-diameter diverter, the heatpulse flowmeter indicated variable flow (turbulence) possibly associated with lateral flow or external pumping effects at 25 ft bls and downward flow at 40 and 62.5 ft bls. The flow at 62.5 ft bls was too large to quantify (greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole) (table 10). Subsequently, the heatpulse flowmeter was run using a 6-in.-diameter diverter, allowing some flow to bypass the flowmeter. Using the 6-in. diverter, the heatpulse flowmeter measured downward flow at depths from 25 to 80 ft bls and upward borehole flow at depths between 97.5–291 ft bls (table 10; fig. 14). These measurements (table 10) indicate that, under non-pumping conditions, water entered the borehole at about 23 and 54 ft bls, moved downward, and exited the borehole through the fractures at 85–95 ft bls. Water also entered the borehole at 102, 180, 265, and 287 ft bls, moved upward, and exited the borehole at 85–95 ft bls.

A submersible pump was placed at 20 ft bls, and the well was pumped at a rate of approximately 4.0 gal/min. After 46 minutes of pumping at 4.0 gal/min, the water level declined 0.42 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements identified the fracture at 56 ft bls as the most productive.

Table 10. Depths, flow rates, flow directions, and pumping rates of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 18, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions				Pumping conditions[1]	
	Flow rate[2] (gal/min)	Flow direction	Flow rate[3] (gal/min)	Flow direction	Flow rate[3] (gal/min)	Flow direction
25	--	turbulence	0.1	down	0.75	up
40	1.0	down	.07	down	.76	up
60	>1.0	down	1.0	down	NF	--
80	--	--	.9	down	NF	--
97.5	--	--	.23	up	.15	up
110	--	--	.1	up	.1	up
170	--	--	.1	up	--	--
200	--	--	.09	up	--	--
224	--	--	.08	up	--	--
270	--	--	.07	up	--	--
279	--	--	.07	up	--	--
291	--	--	.07	up	--	--

[1]Pumping rate of 4 gal/min.

[2]Measured using an 8-in.diameter diverter.

[3]Measured using a 6-in.-diameter diverter.

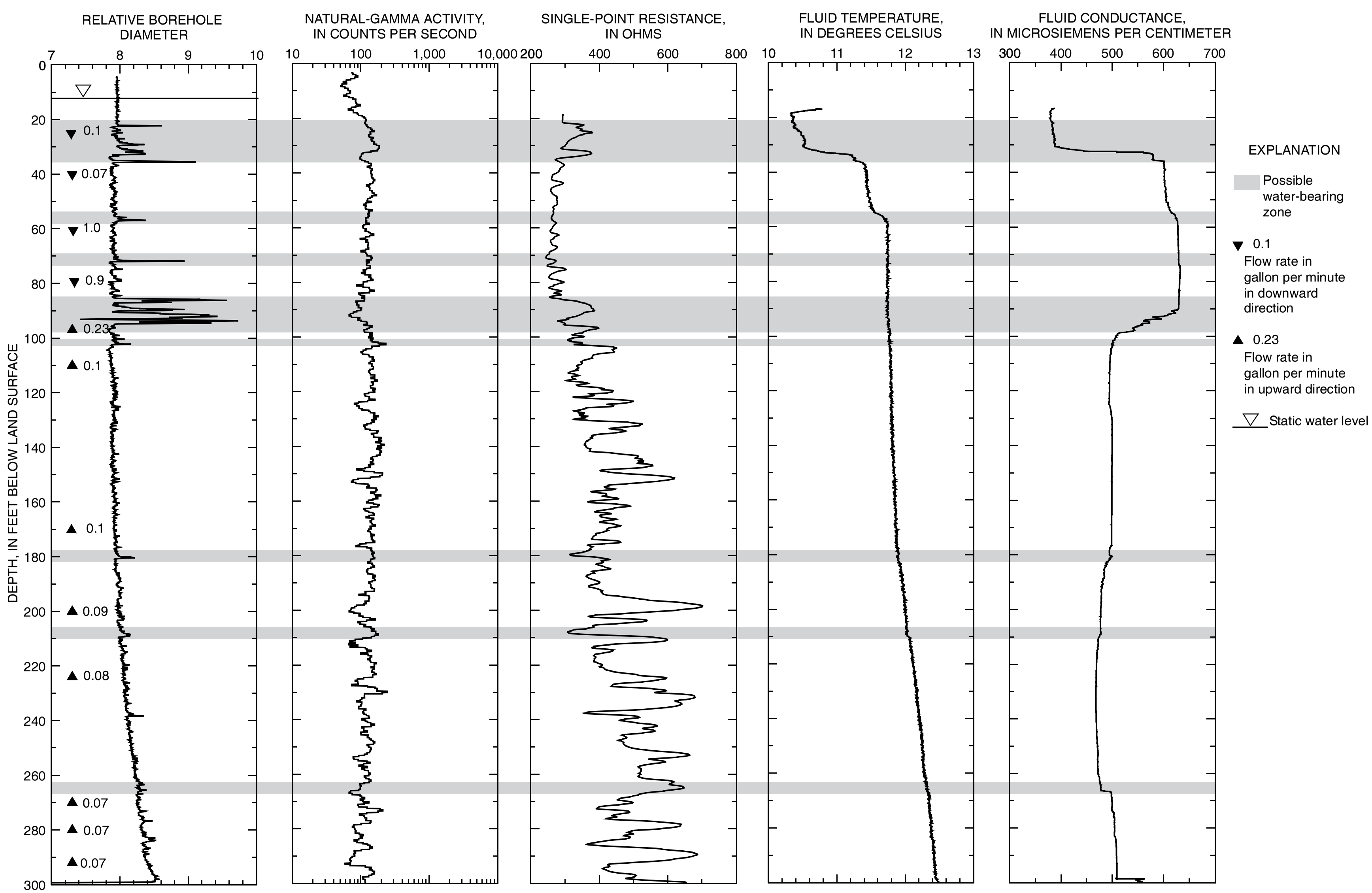


Figure 14. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2093 (RI-6D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 18, 2004. Depicted flow was measured with 6-in.-diameter diverter in the 8-in.-diameter borehole.

MG-2095 (RI-7D)

The caliper log shows that the borehole is 246 ft in depth, is cased with 8.25-in.-diameter steel casing to 19 ft bls, and is 8 in. in diameter below the casing (fig. 15). Major fractures are shown at 183–186.5 ft bls and a constriction at 188 ft bls plus numerous minor fractures throughout the borehole. The borehole video log indicated possible water-producing zones at 67, 79, 85, 99, 157, 181–188, 191, 197, 232, and 239–242 ft bls. The static water level at the time of logging was 23.58 ft bls.

The fluid-conductance log show inflections at approximately 37 ft bls that correlate to a minor fracture shown on the caliper log and suggest a water-bearing zone. Under non-pumping conditions, the heatpulse flowmeter measured upward flow at depths from 40 to 230 ft bls and no borehole flow at 33 ft bls (table 11; fig. 15). These measurements (table 11) indicate that, under non-pumping conditions, water entered the borehole at 160, 183–187, and 242 ft bls, moved upward, and exited the borehole through the fractures at 37, 68, 83, and 101 ft bls.

Borehole flow tracing under ambient conditions shows the greatest quantity of water is produced at 183–187 ft bls. A submersible pump was not placed in this borehole because maximum traceable upward flow was already present under ambient conditions.

Table 11. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., February 4, 2004.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions	
	Flow rate (gal/min)	Flow direction
33	NF	--
40	0.06	up
50	.06	up
65	.06	up
73	.15	up
80	.17	up
85	.37	up
90	.43	up
95	.54	up
106	1.0	up
120	1.0	up
154	1.0	up
164	.80	up
174	.70	up
196	.25	up
230	.21	up

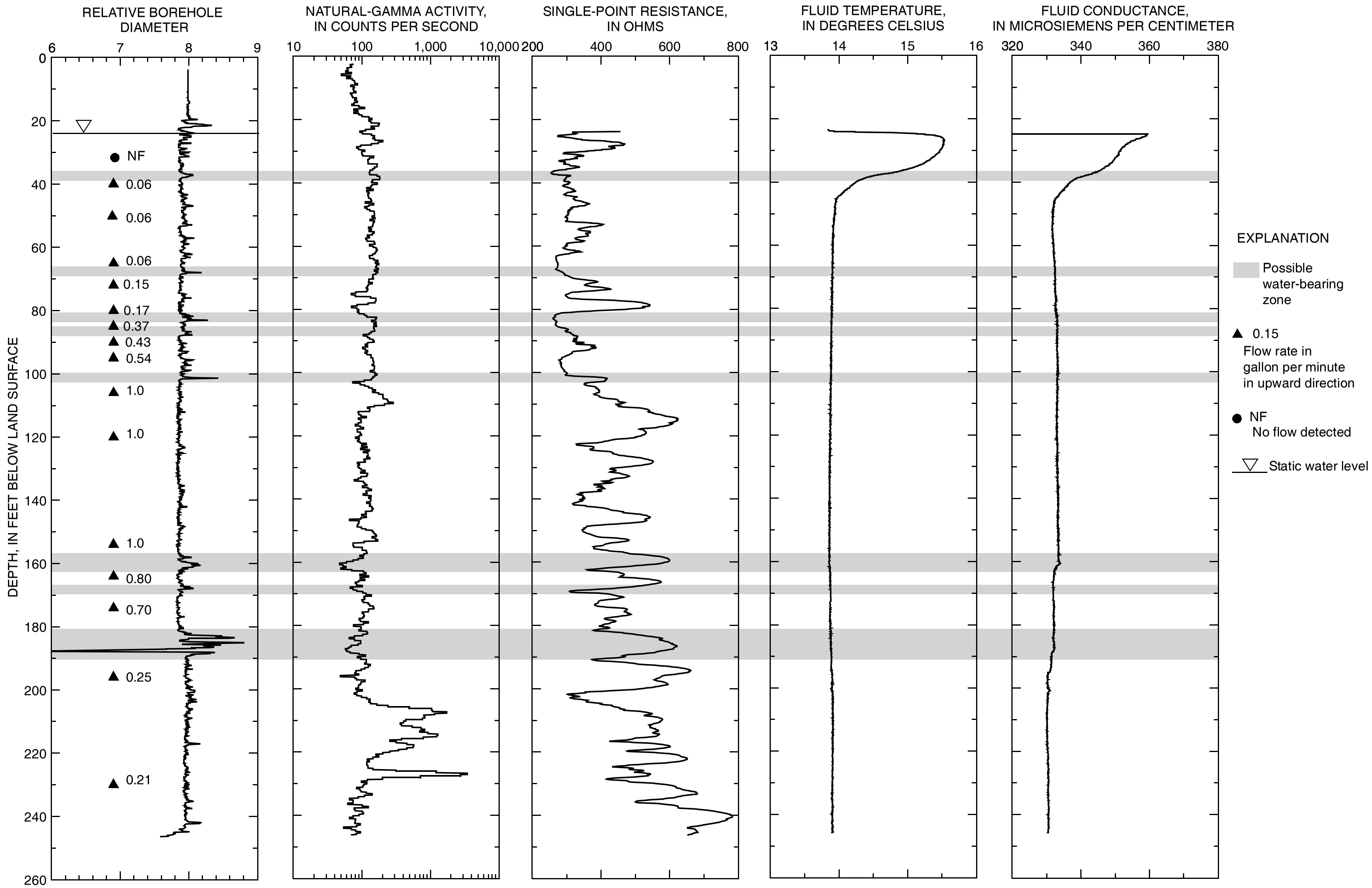


Figure 15. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2095 (RI-7D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., February 4, 2004.

MG-2097 (RI-8D)

The caliper log shows that the borehole is about 300 ft in depth, is cased with 8.25-in.-diameter steel casing to 18 ft bls, and is 8 in. in diameter below the casing (fig. 16). Major fractures are shown at 28–39 and 194 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The caliper log shows a constriction at 285 ft bls. The borehole video log indicated possible water-producing zones at 25–31, 52–55, 73, 109, 169–176, 181–195, 206, 210, 221, 240–253, and 283–292 ft bls. The static water level at the time of logging was 9.22 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 54 ft bls that correlate to a fracture shown on the caliper log and suggest a water-bearing zone. The fluid-conductance log also shows inflections at about 30, 160, and 195 ft bls. Under non-pumping conditions and using an 8-in.-diameter diverter, the heatpulse flowmeter indicated downward flow at 20, 26, 33, 42 ft bls, upward flow at 293 ft bls, and turbulent flow too great to quantify (greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole) at depths from 57 to 270 ft bls. Subsequently, the heatpulse flowmeter was deployed using a 6-in.-diameter diverter, allowing some flow to bypass the flowmeter. Using the 6-in. diverter, the heatpulse flowmeter measured upward flow at depths from 20 to 270 ft bls and no borehole flow at 293 ft bls (table 12; fig. 16). The measurements with the 6-in. diverter (table 12) indicate that, under non-pumping conditions, water entered the borehole at 289 and 257 ft bls, moved upward, and exited the borehole through the fractures at 18.5, 52, 59, 74, and possibly 25–31 ft bls. The first set of measurements using the 8-in. diverter (table 12) indicate water can enter the borehole through the fractures at 18.5 at least occasionally.

Borehole flow tracing under ambient conditions shows the greatest quantity of water is produced from fractures at 283–292 ft bls. A submersible pump was not placed in this borehole because maximum traceable upward flow was already present under ambient conditions.

Table 12. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 20, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data; >, greater than]

Depth of measurement (ft bls)	Non-pumping conditions			
	Flow rate[1] (gal/min)	Flow[1] direction	Flow rate[2] (gal/min)	Flow[2] direction
20	0.74	down	0.11	up
26	.26	down	.08	up
33	.60	down	.06	up
37	.60	down	--	--
42	.51	down	.08	up
57	>1.0	down	.37	up
70	>1.0	up?	.58	up
78	--	--	1.2	up
86	--	--	1.2	up
94	--	--	1.2	up
104	--	--	1.2	up
120	>1.0	up?	>1.2	up
160	--	--	1.1	up
182	--	--	1.1	up
220	>1.0	up?	1.2	up
236	--	--	1.2	up
255	--	--	1.1	up
270	>1.2	up	.8	up
293	.1	up	NF	--

[1]Measured using 8-in.-diameter diverter in 8-in.-diameter borehole.

[2]Measured using 6-in.-diameter diverter in 8-in.-diameter borehole.

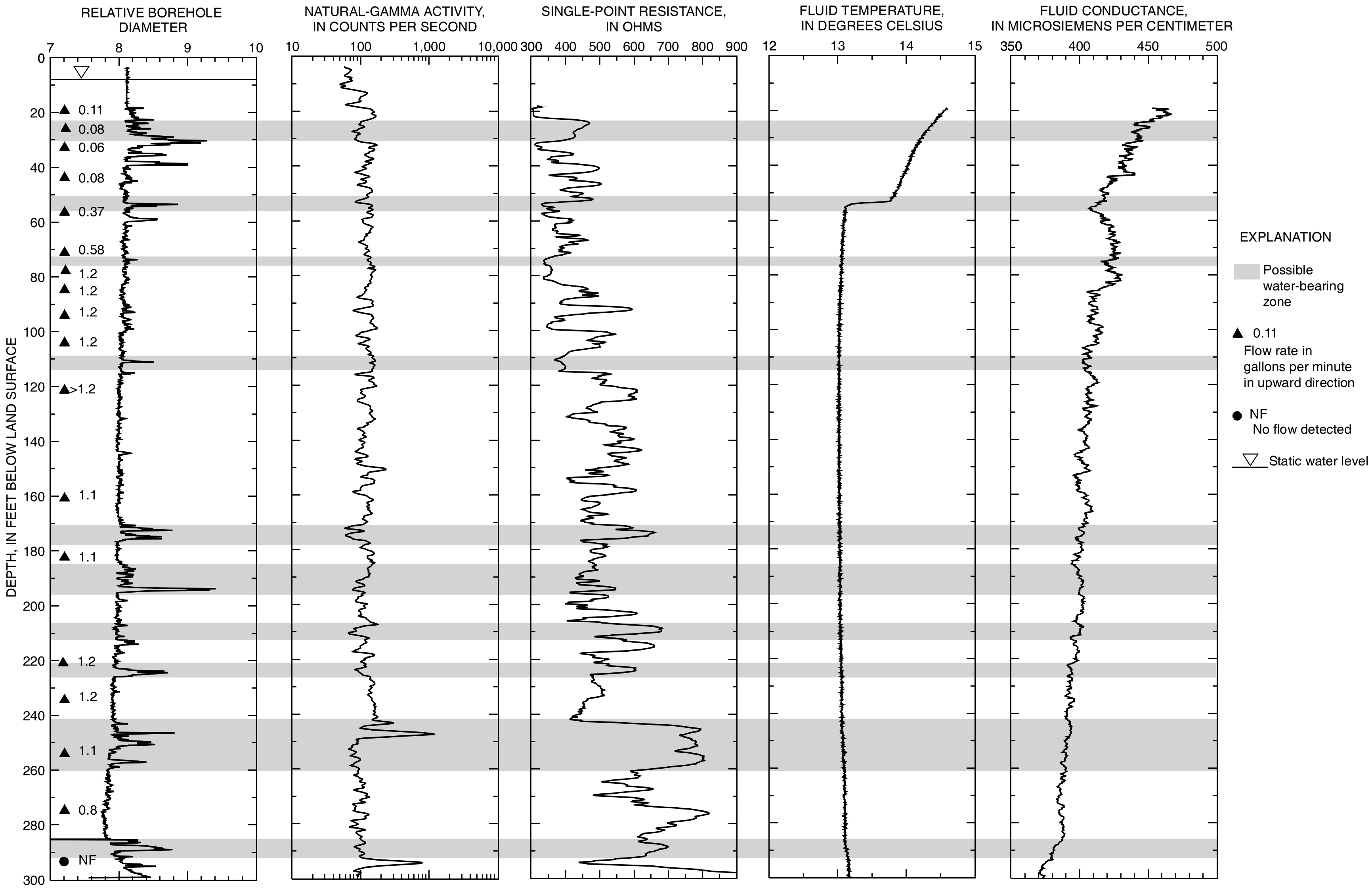


Figure 16. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2097 (RI-8D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 20, 2004. Depicted flow was measured with 6-in.-diameter diverter in the 8-in.-diameter borehole.

MG-2100 (RI-9D)

The caliper log shows that the borehole is 286 ft in depth (fig. 17). The borehole is cased with 8.25-in.-diameter steel casing to 19 ft bls and is 8 in. in diameter below the casing. Major fractures are shown at 176–182 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-producing zones at 33, 38, 88–96, 99–101, 116–122, 126–131, 139, 175–182, 254–258, 266–268, and 269–273 ft bls; water cascades into the borehole at 38 ft bls. The static water level at the time of logging was 54.14 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at about 90 and 180 ft bls that correlate to fractures shown on the caliper log and indicate water-bearing zones. Under non-pumping conditions and using an 8-in.-diameter diverter, the heatpulse flowmeter indicated no flow at 57 ft bls, downward flow at 70 and 85 ft bls, upward flow at 266 ft bls, and flow too great to quantify (greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole) at depths from 98 to 250 ft bls. Subsequently, the heatpulse flowmeter was run using a 6-in.-diameter diverter, allowing some flow to bypass the flowmeter. Using the 6-in. diverter, the heatpulse flowmeter measured downward flow at 70 and 85 ft bls, upward flow at depths from 98 to 266 ft bls, and no borehole flow at 57 and 280 ft bls (table 13; fig. 17). Because the upward flow from 126 to 173 ft bls measured using the 6-in. diverter was greater than 1 gal/min (upper limit of the flowmeter), the heatpulse-flowmeter measurements were rerun using a 4-in.diameter diverter, allowing more water to bypass the flowmeter. Using the 4-in. diverter, the measured upward flow decreased from 142 to 135 to 126 ft bls. These measurements (table 13) indicate that, under non-pumping conditions, water entered the borehole through fractures at 62 ft bls, moved downward, and exited the borehole through the fractures at 90–95 ft bls. Water also entered the borehole through fractures at 180, 262, and 273 ft bls, moved upward, and exited the borehole through the fractures at 90–95, 117–122, 128–132, and 139 ft bls.

Borehole flow tracing under non-pumping conditions suggests the major water-producing zones are at 176–182 and 269–273 ft bls. This borehole was not pumped because the maximum traceable upward flow was already present under non-pumping (ambient) conditions.

Table 13. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 16, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data; >, greater than]

Depth of measurement (ft bls)	Non-pumping conditions					
	Flow rate[1] (gal/min)	Flow[1] direction	Flow rate[2] (gal/min)	Flow[2] direction	Flow rate[3] (gal/min)	Flow[3] direction
57	NF	--	NF	--	--	--
70	1.1	down	0.13	down	--	--
85	1.0	down	.11	down	--	--
98	--	--	.38	up	0.14	up
112	--	--	.48	up	.10	up
126	--	--	>1.0	up	.27	up
135	--	--	--	--	.5	up
142	--	--	--	--	1.1	up
150	--	--	>1.0	up	1.1	up
173	--	--	>1.0	up	1.0	up
190	--	--	1.0	up	--	--
204	--	--	.92	up	--	--
224	--	--	.92	up	--	--
235	--	--	1.0	up	--	--
242	--	--	.86	up	--	--
250	--	--	.84	up	--	--
266	>1.0	up	.75	up	--	--
280	--	--	NF	--	--	--

[1]Measured using 8-in.-diameter diverter in 8-in.-diameter borehole.

[2]Measured using 6-in.-diameter diverter in 8-in.-diameter borehole.

[3]Measured using 4-in.-diameter diverter in 8-in.-diameter borehole.

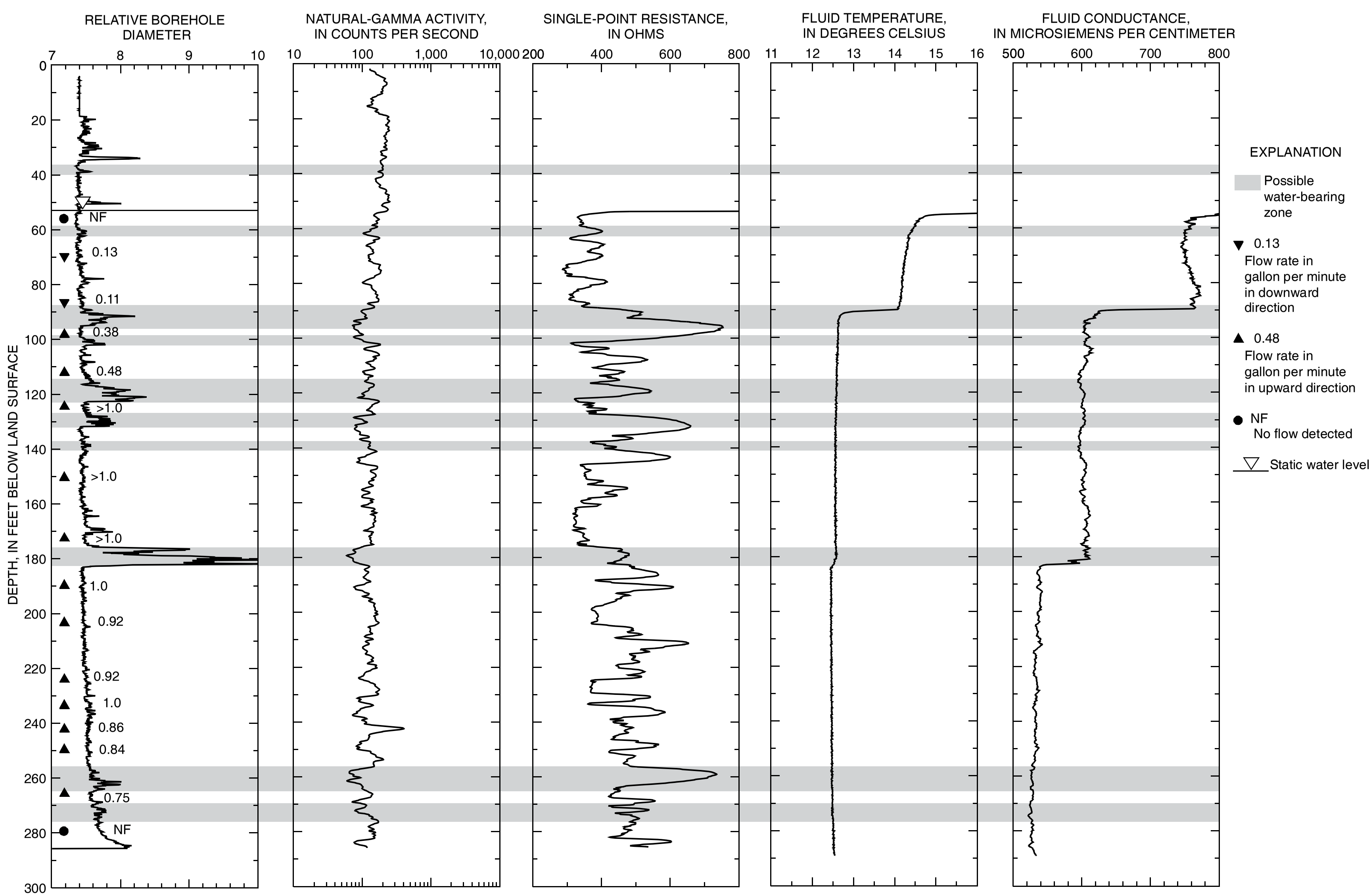


Figure 17. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2100 (RI-9D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 16, 2004. Depicted flow was measured with 6-in.-diameter diverter in the 8-in.-diameter borehole.

MG-2119 (RI-10D)

The caliper log shows that the borehole is 289 ft in depth, is cased with 8.25-in.-diameter steel casing to 19 ft bls, and is 8 in. in diameter below the casing (fig. 18). Major fractures are shown at 83 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-producing zones at 77, 115, 180, 219, and 256 ft bls. The static water level at the time of logging was 39.33 ft bls.

The fluid-conductance log shows inflections at about 70, 78, and 82 ft bls that correlate to fractures shown on the caliper log and indicate water-producing zones. The fluid-temperature log shows a change in temperature at 82 ft bls that correlates to a large fracture shown on the caliper log. Under non-pumping conditions and using an 8-in.-diameter diverter, the heatpulse flowmeter detected no flow at 50, 65, 90, and 105 ft bls, downward flow at 79 ft bls, and downward flow too great to quantify (greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole) at depths of 125 and 160 ft bls. Subsequently, the heatpulse-flowmeter measurements were run using a 6-in.-diameter diverter, allowing some flow to bypass the flowmeter. Using the 6-in. diverter under non-pumping conditions, the heatpulse flowmeter measured upward flow at 65 and 79 ft bls, downward flow at depths from 90 to 220 ft bls, and no flow at 50, 230, and 240 ft bls (table 14; fig. 18). These measurements (table 14) indicate that, under non-pumping conditions, water entered the borehole through the fracture at 82 ft bls, moved upward and downward, and exited the borehole through fractures at 60, 70–77, 185, 189, and 225 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at a rate of less than 0.5 gal/min. After 39 minutes of pumping at less than 0.5 gal/min, the water level declined 0.03 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements identified the fracture at 82 ft bls as the most productive.

Table 14. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 12, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data; >, greater than]

Depth of measurement (ft bls)	Non-pumping conditions				Pumping conditions[1]	
	Flow rate[2] (gal/min)	Flow[2] direction	Flow rate[3] (gal/min)	Flow[3] direction	Flow rate (gal/min)	Flow direction
50	NF[4]	--	NF	--	0.6	up
65	NF	--	0.08	up	.8	up
79	0.4	down	.12	up	0.4 to 0.7	up
90	NF	--	1.1	down	undetermined	--
105	NF	--	1.1	down	--	--
125	>1.1	down	1.1	down	--	--
160	>1.1	down	1.1	down	--	--
180	--	--	1.1	down	--	--
187	--	--	.43	down	--	--
195	--	--	.35	down	--	--
215	--	--	.29	down	--	--
220	--	--	.38	down	--	--
230	--	--	NF	--	--	--
240	--	--	NF	--	--	--

[1]Pumping rate of less than 0.5 gal/min.

[2]Measured using 8-in.-diameter diverter in 8-in.-diameter borehole.

[3]Measured using 6-in.-diameter diverter in 8-in.-diameter borehole.

[4]Turbulence detected.

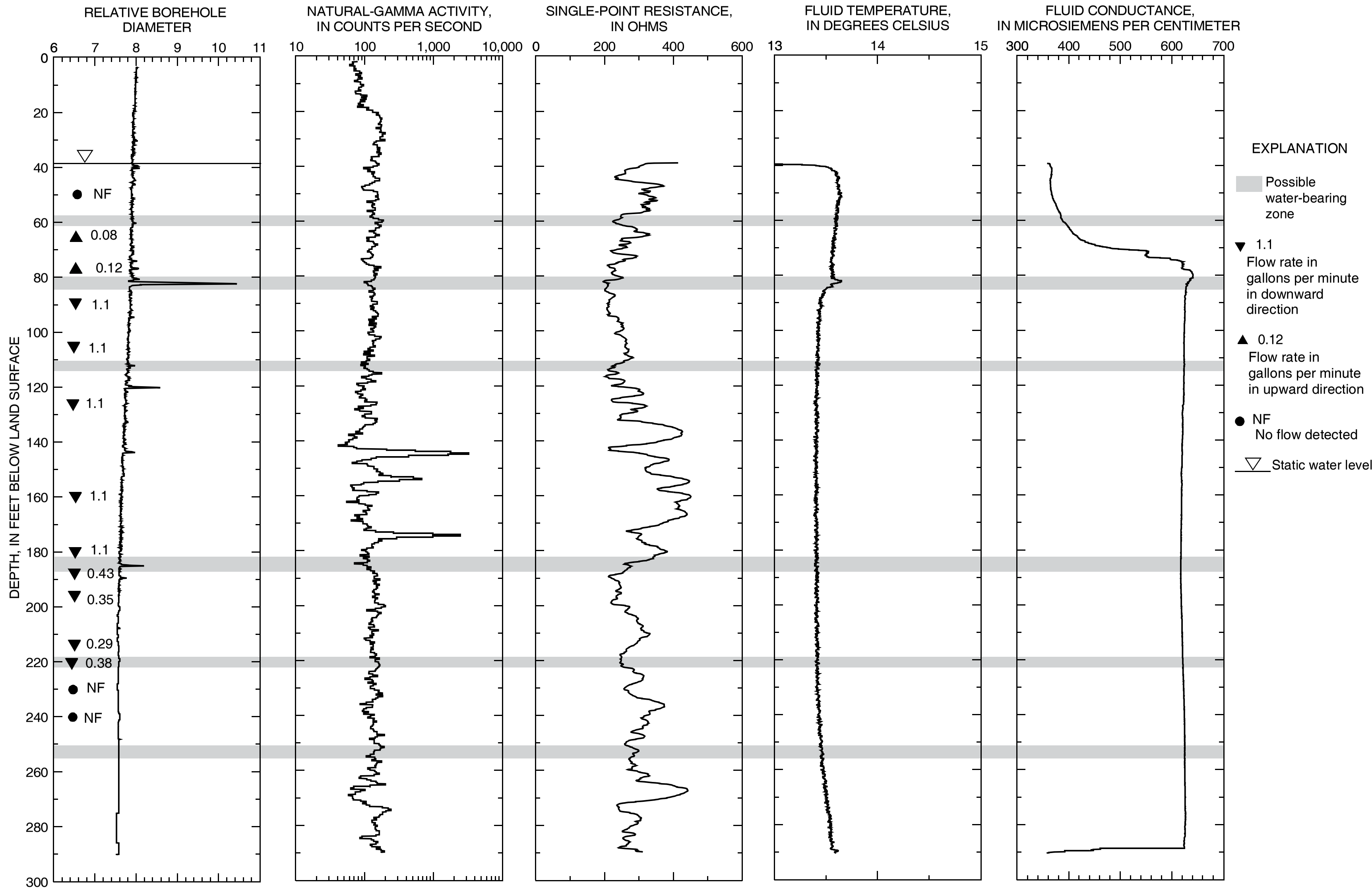


Figure 18. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2119 (RI-10D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 12, 2004. Depicted flow was measured with 6-in.-diameter diverter in the 8-in.-diameter borehole.

MG-2122 (RI-11D)

The caliper log shows that the borehole is 299 ft in depth (fig. 19). The borehole is cased with 8.25-in.-diameter steel casing to 25 ft bls and is 8 in. in diameter below the casing. Major fractures are shown at 25–26, 34–36, 49, 80, 87–91, and 96–101 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-bearing zones at 34–38, 48–50, 79–101, 215, 252–256, and 269 ft bls. The static water level at the time of logging was 21.62 ft bls.

The fluid-conductance log shows small inflections at about 45–55, 110, 130, 218, and 280 ft bls that may indicate water-bearing zones. Under non-pumping conditions, the heatpulse flowmeter measured upward flow at various depths from 42 to 259 ft bls and no flow at 266 ft bls (table 15; fig. 19). Because upward flow was too great to quantify (greater than 1 gal/min, the upper limit of measurable flow using an 8-in. diverter in an 8-in. hole) at depths from 60 to 240 ft bls, the heatpulse-flowmeter measurements subsequently were run using a 6-in.-diameter diverter, allowing some flow to bypass the flowmeter. Using the 6-in. diverter under non-pumping conditions, the heatpulse flowmeter measured upward flow ranging from 0.24 to 0.50 gal/min at those depths where flow had been too great to quantify. These measurements (table 15) indicate that, under non-pumping conditions, water entered the borehole through fractures at about 250–259 and 210–220 ft bls, moved upward, and exited the borehole through fractures at 80–100, 52–58, 45–48, 34–36, and above 28 ft bls.

Borehole-flow measurements under non-pumping (ambient) conditions suggest the most productive water-bearing zones are at about 25–26, 34–36, 49, 54–58, and 250–268 ft bls. This borehole was not pumped because the maximum traceable upward flow was already present under non-pumping conditions.

Table 15. Depths, flow rates, and flow directions of heatpulse-flowmeter measurements, under non-pumping conditions, for well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 6, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data; >, greater than]

Depth of measurement (ft bls)	Non-pumping conditions			
	Flow rate[1] (gal/min)	Flow[1] direction	Flow rate[2] (gal/min)	Flow[2] direction
33	0.27	up	--	--
42	.44	up	0.15	up
52	.94	up	.12	up
61	>1.0	up	.24	up
77	>1.0	up	.28	up
104	>1.0	up	.50	up
126	--	--	.44	up
155	>1.0	up	.49	up
184	>1.0	up	.48	up
200	--	--	.46	up
212	>1.0	up	.30	up
226	--	--	.27	up
240	>1.0	up	.24	up
251	.95	up	.21	up
259	.57	up	.08	up
266	.12	up	NF	--
274	NF	--	--	--

[1]Measured using 8-in.-diameter diverter in 8-in.-diameter borehole.

[2]Measured using 6-in.-diameter diverter in 8-in.-diameter borehole.

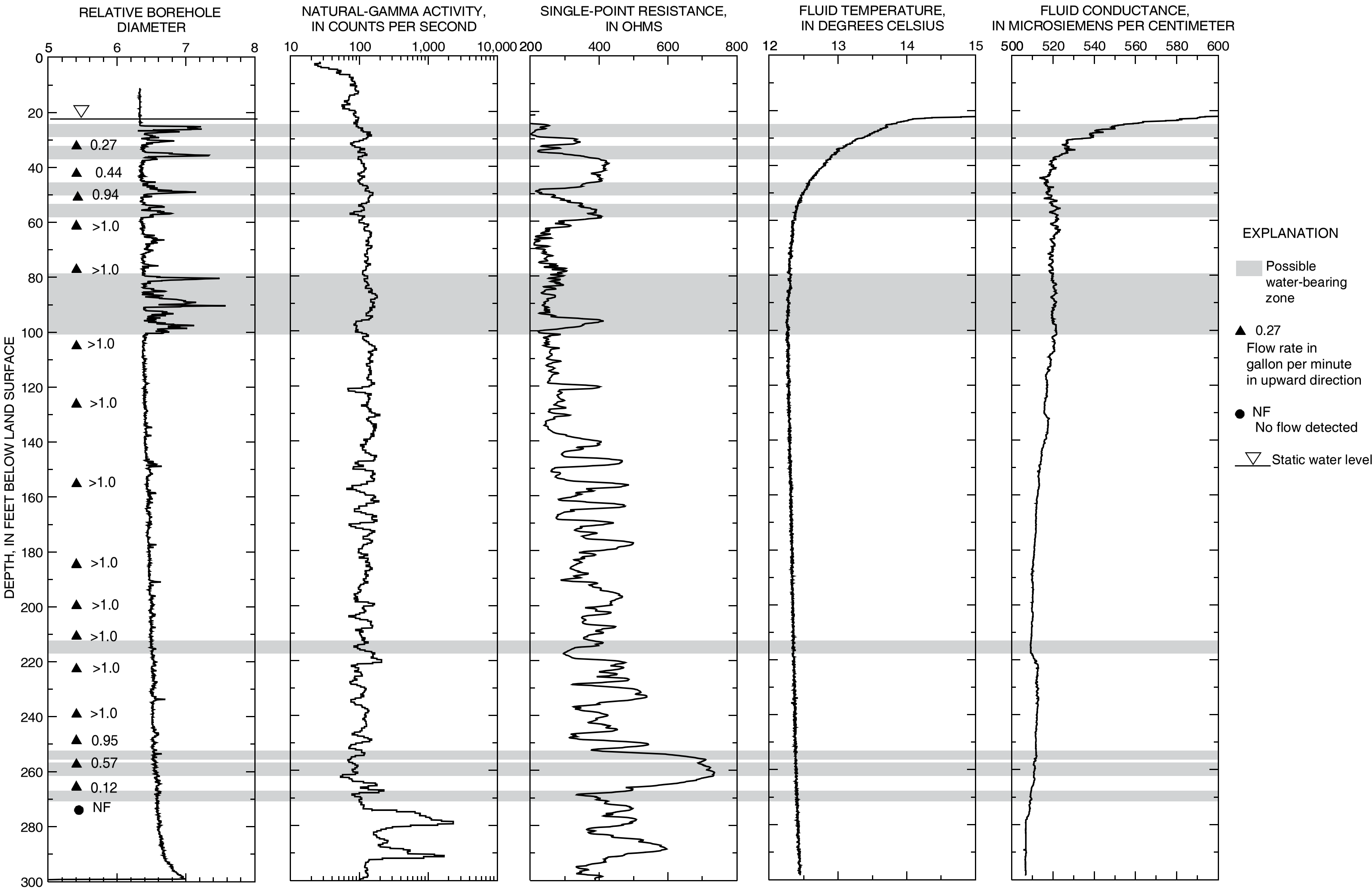


Figure 19. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2122 (RI-11D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 6, 2004. Depicted flow was measured with 8-in.-diameter diverter in the 8-in.-diameter borehole.

MG-2125 (RI-12D)

The caliper log shows that the borehole is 300 ft in depth (fig. 20). The borehole is cased with 10.25-in.-diameter steel casing to 20 ft bls and is 10-in. in diameter below the casing. Major fractures are shown at 21–24 and 72–75 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-bearing zones at 32–44, 46–51, 59–62, 70–75, 80–83, 96–98, 110, and 265 ft bls. The static water level at the time of logging was 43.68 ft bls.

The fluid-conductance log shows inflections at about 47, 60, 70, 80, 95, and 285 ft bls that correlate to fractures shown on the caliper log and may indicate water-bearing zones. The fluid-temperature log shows inflections at about 160 and 285 ft bls. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at various depths from 58 to 164 ft bls and no flow at 50, 180, 240, and 275 ft bls, with no or possible lateral flow at 291 ft bls (table 16; fig. 20). These measurements (table 16) indicate that, under non-pumping conditions, water entered the borehole through fractures at 42–47, 72–75, and 97 ft bls, moved downward, and exited the borehole through fractures at about 111, 119, 149, 158–161, and 176 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at a rate of approximately 1 gal/min. After 2 hours and 15 minutes of pumping, the water level declined 2.27 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements identified the fractures at 70–75 ft bls and possibly at 82 ft bls as the most productive.

Table 16. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 3, 2004.

[ft bls, feet below land surface; gal/min, gallons per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
50	NF	--	--	--
58	0 to 0.18	down	1.0	up
67	.32	down	1.2	up
77	--	--	.6	up
79	--	--	NF	--
86	.96	down	.6	down
94	.96	down	.4	down
102	1.0	down	.6	down
108	1.1	down	.6	down
112	.78	down	.4	down
134	.40	down	.2	down
153	.18	down	.1	down
164	.07	down	.1	down
180	NF	--	NF	--
240	NF	--	--	--
275	NF	--	--	--
291	NF	lateral flow?	--	--

[1]Pumping rate of 1 gal/min.

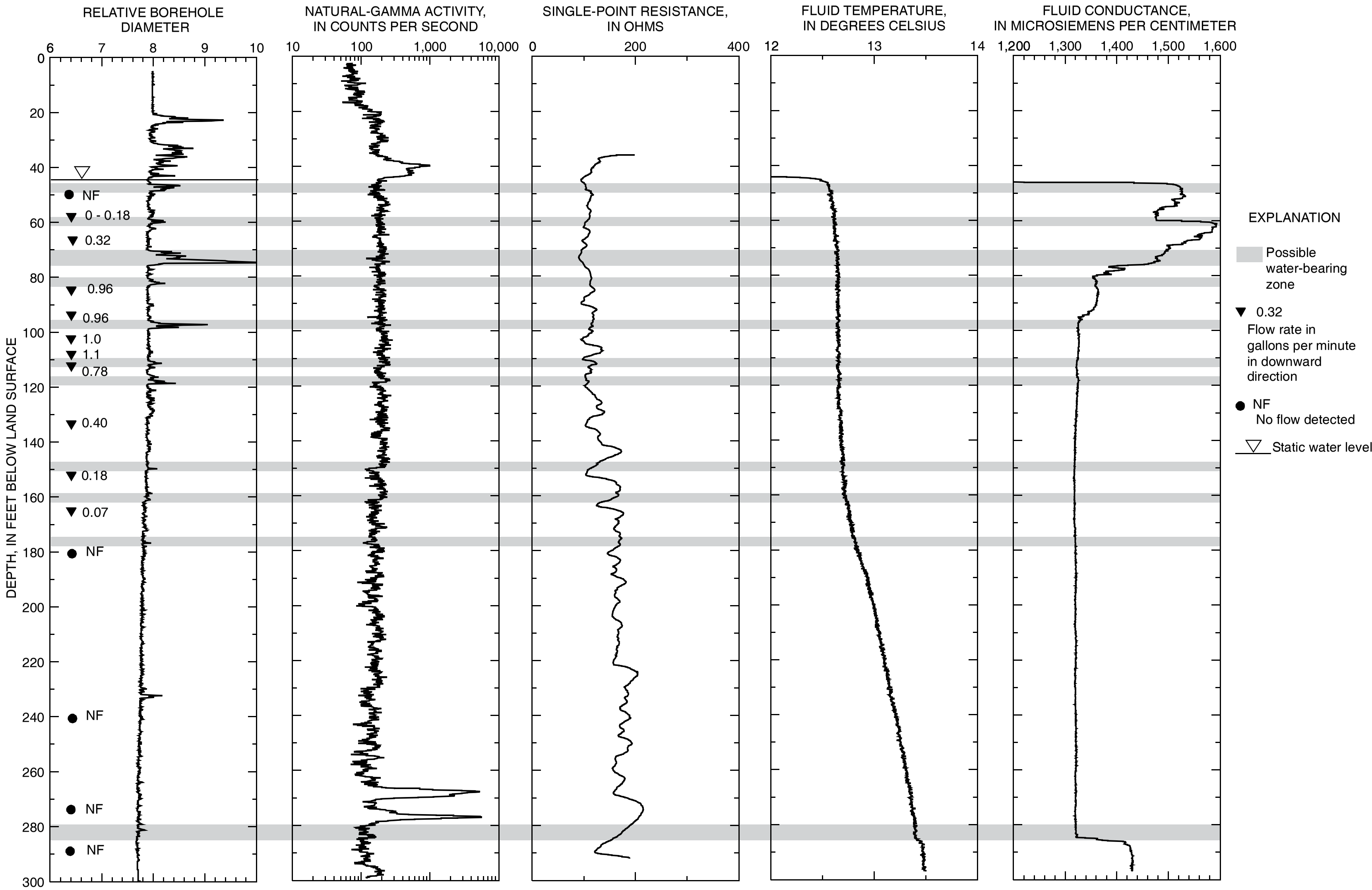


Figure 20. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2125 (RI-12D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 3, 2004.

MG-2126 (RI-13D)

The caliper log shows that the borehole is 279 ft in depth (fig. 21). The borehole is cased with 8.25-in.-diameter steel casing to 20 ft bls and is 8 in. in diameter below the casing. Major fractures are shown at 64, 65–68, 123–131.5, and 146.5 ft bls plus numerous smaller fractures throughout the open-hole section of the borehole. The borehole video log indicated possible water-bearing zones at 61, 63–68, 96, 119–132, 146, 203–207, and 220 ft bls. The static water level at the time of logging was 24.61 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at about 70, 98, and 148 ft bls that correlate to fractures shown on the caliper log and may indicate water-bearing zones. The fluid-temperature log also shows an inflection at about 222 ft bls that correlates with a fracture and possible water-bearing zone. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at 54, 138, 160, 180, and 216 ft bls, upward flow at 102, 111, and 117 ft bls, and no flow at 37, 80, 236, and 258 ft bls (table 17; fig. 21). These measurements (table 17) indicate that, under non-pumping conditions, water entered the borehole through fractures at about 43–47, 114, 123–132, and 147 ft bls, moved upward and downward from respective entry depths, and exited the borehole through fractures at about 96 and 222 ft bls.

A submersible pump was placed at 35 ft bls, and the well was pumped at a rate of less than 1 gal/min. After 14 minutes of pumping, the water level declined 0.02 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements identified the fractures at 64–68 ft bls as the most productive.

Table 17. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 25, 2004.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
37	NF	--	--	--
40	--	--	0.8	up
54	0.06	down	.6	up
80	NF	--	NF	--
102	.6	up	--	--
111	.9	up	--	--
117	.2	up	--	--
138	.7	down	--	--
160	.9	down	--	--
180	.8	down	--	--
216	.9	down	--	--
236	NF	--	--	--
258	NF	--	--	--

[1]Pumping rate of less than 1 gal/min.

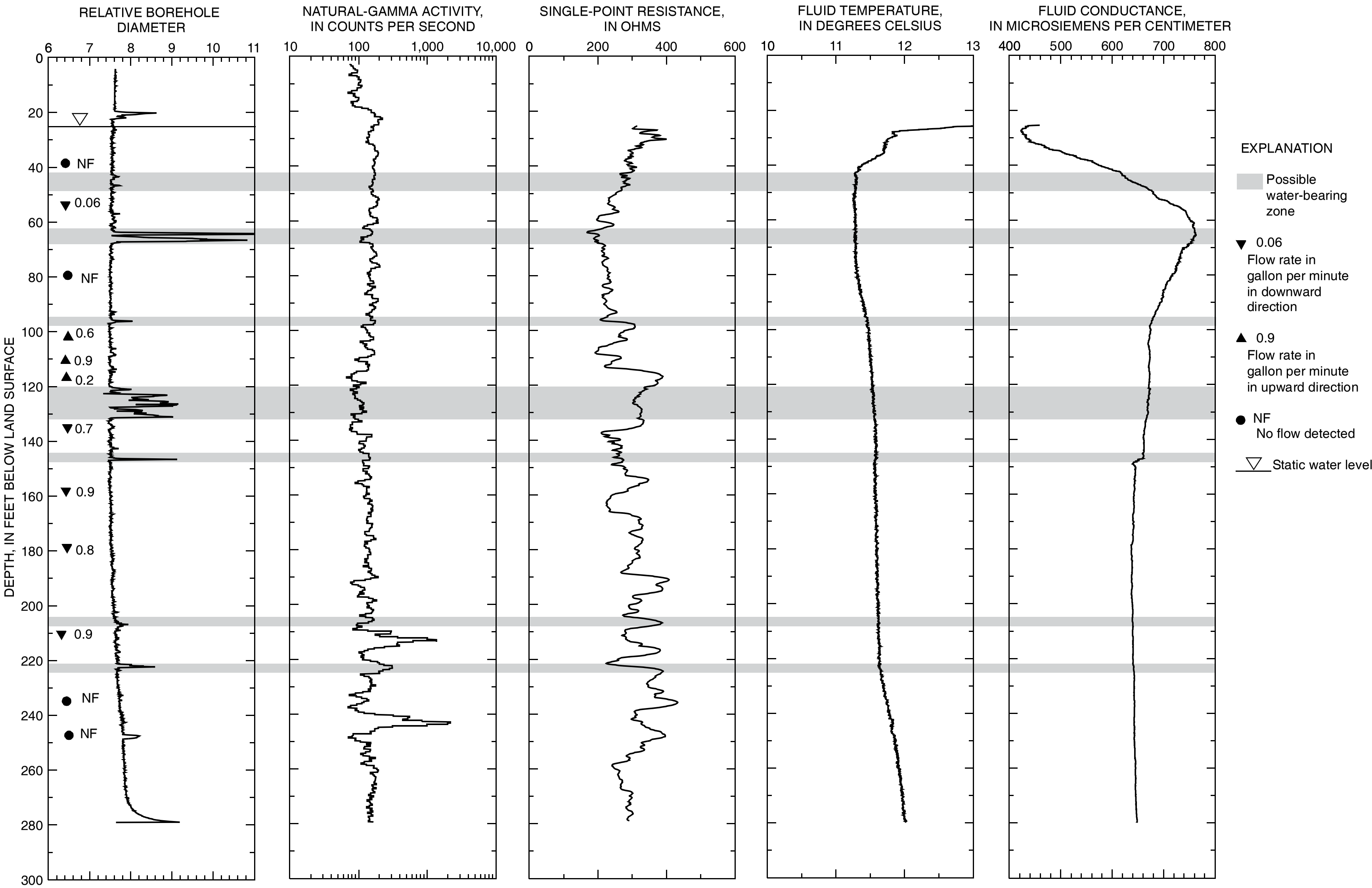


Figure 21. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2126 (RI-13D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 25, 2004.

MG-2129 (RI-14D)

The caliper log shows that the borehole is 299 ft in depth (fig. 22). The borehole is cased with 8.25-in.-diameter steel casing to 54 ft bls and is 8 in. in diameter below the casing. There are numerous minor fractures throughout the borehole. Major fractures zones are shown at 90–94 ft bls. The borehole video log indicated possible water-bearing zones associated with high-angle fractures observed at 90–99, 149, and 153 ft bls. The static water level at the time of logging was 43.51 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at about 72, 100, and 150 ft bls that correlate to fractures shown on the caliper log and suggest possible water-bearing zones. The fluid-temperature log also shows an inflection at about 240 ft bls, and the fluid-conductance log shows an inflection at about 270 ft bls. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at 80 ft bls, upward flow at 160 and 200 ft bls, and no flow at various depths from 95 to 153 and below 210 ft bls (table 18; fig. 22). These measurements (table 18) indicate that, under non-pumping conditions, water entered the borehole at about 70 and 210 ft bls, moved downward and upward, respectively, and exited the borehole through the fractures at about 90–94 and 155 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at an average rate of 0.85 gal/min. After 67 minutes of pumping, the water level decreased by 0.45 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate the fracture zone at about 90–94 ft bls is the most productive.

Table 18. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2129 (RI-14D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 1, 2005.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
60	--	--	0.2	up
80	0.07	down	.5	up
99	NF	--	.01	up
103	NF	--	--	--
114	NF	--	.01	up
140	NF	--	.01	up
153	NF	--	--	--
160	.01	up	.01	up
200	.01	up	--	--
210	NF	--	--	--
230	NF	--	--	--

[1]Pumping rate of 0.85 gal/min.

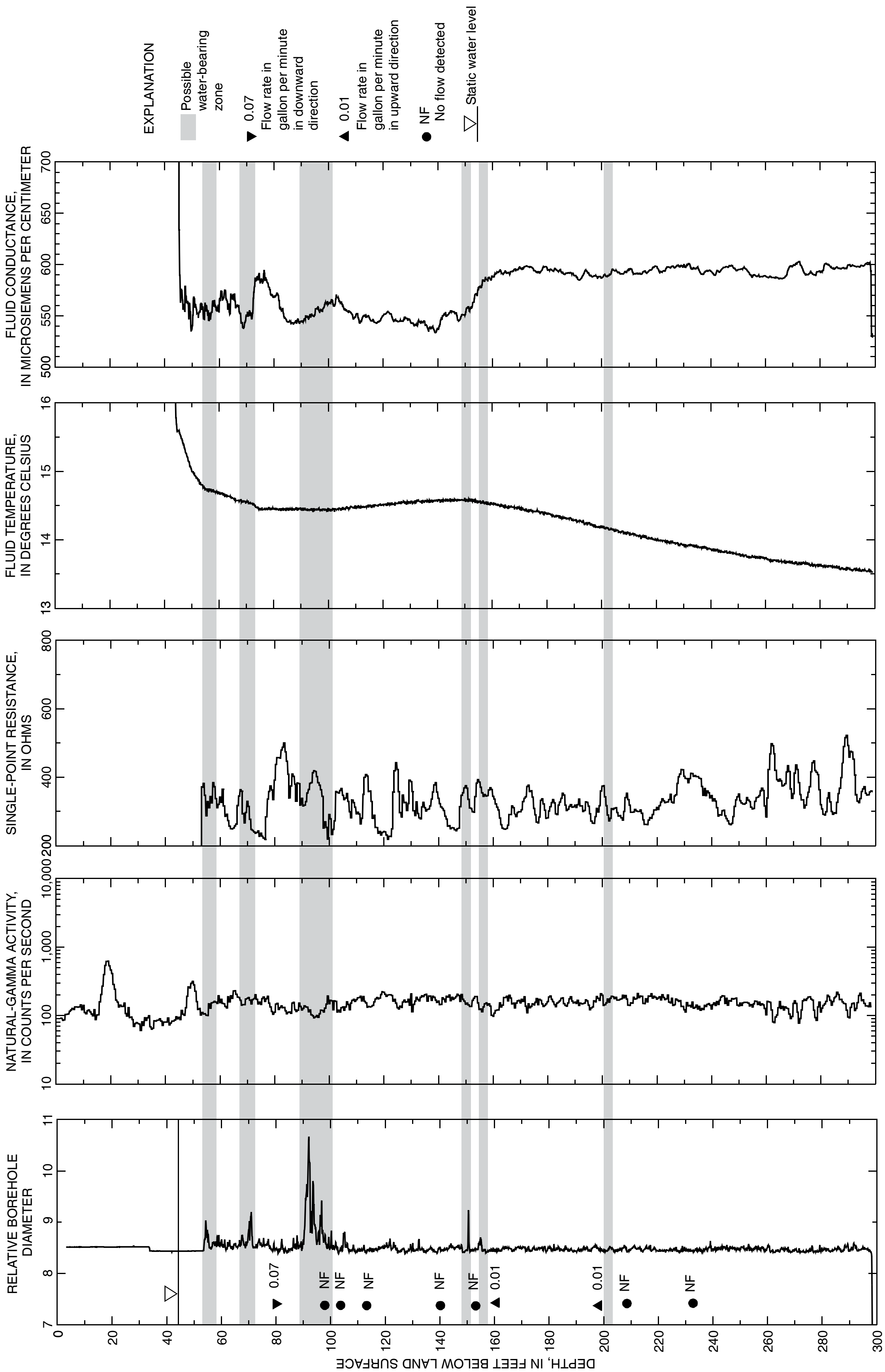


Figure 22. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2129 (RI-14D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 1, 2005.

MG-2131 (RI-15DD)

The caliper log shows that the borehole is 299 ft in depth (fig. 23). The borehole is cased with 8.25-in.-diameter steel casing to 18 ft bls and is 8 in. in diameter below the casing. There are numerous minor fractures throughout the borehole. Major fractures zones are shown at 27–33, 37–43, and 121 ft bls; the largest fracture is shown at 199–204 ft bls. The borehole video log indicated possible water-bearing zones associated with low-angle fractures at 81 and 119 ft bls and with high-angle fractures at 104–108, 196–203, and 246 ft bls. The static water level at the time of logging was 39.34 ft bls.

The fluid-temperature and fluid-conductance logs show inflections at approximately 79, 105, 205, and 250 ft bls that correlate to fractures shown on the caliper log and suggest possible water-bearing zones. Under non-pumping conditions, the heatpulse flowmeter measured downward flow at various depths from 84 to 188 ft bls and no flow at depths from 50 to 77 and below 220 ft bls (table 19; fig. 23). These measurements (table 19) indicate that, under non-pumping conditions, water entered the borehole near 81 and 130 ft bls, moved downward, and exited the borehole through the fractures near 150 ft bls and at 203 ft bls. A minor quantity continued down and existed at approximately 250 ft bls.

A submersible pump was placed at 50 ft bls, and the well was pumped at a rate of less than 0.6 gal/min. After 78 minutes of pumping, the water level increased by 0.06 ft. Under steady-state pumping conditions, the heatpulse-flowmeter measurements indicate the fracture zones near 81, 106, and 119 ft bls are the most productive.

Table 19. Depths, flow rates, flow directions, and pumping rate of heatpulse-flowmeter measurements, under non-pumping and pumping conditions, for well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 25, 2005.

[ft bls, feet below land surface; gal/min, gallon per minute; NF, no flow measured; --, no data]

Depth of measurement (ft bls)	Non-pumping conditions		Pumping conditions[1]	
	Flow rate (gal/min)	Flow direction	Flow rate (gal/min)	Flow direction
50	NF	--	--	--
62	NF	--	0.22	up
72	NF	--	--	--
77	NF	--	.20	up
84	0.22	down	.06	down
100	.19	down	0 to 0.03	down
116	.22	down	.27	down
126	.21	down	.15	down
140	.29	down	.09	down
150	--	--	.14	down
170	.08	down	.09	down
188	.07	down	--	--
220	NF[2]	--	--	--
260	NF	--	--	--

[1]Pumping rate of less than 0.6 gal/min.

[2]No measurable flow, possibly bad seal but likely downward.

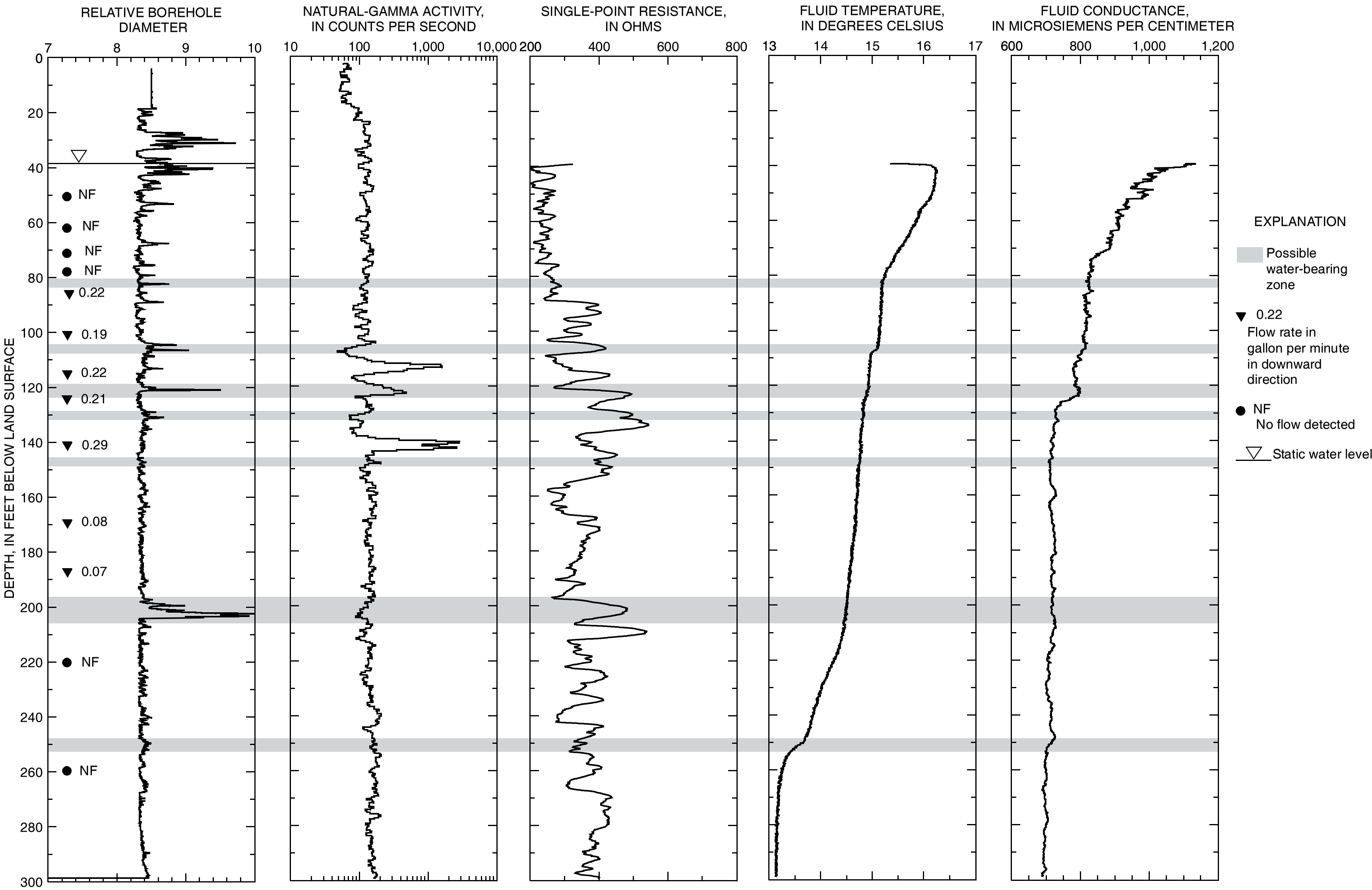


Figure 23. Borehole geophysical logs and direction of flow under non-pumping conditions within borehole MG-2131 (RI-15DD), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 25, 2005.

Comparison of Logs

Results of logging indicate that water-bearing zones are distributed throughout the boreholes, and the depths of water-bearing zones ranged from 18.5 to 292 ft bls in the 15 300-ft deep monitor wells. The deepest water-bearing zone identified was at 371 ft bls in the deepest well logged, the 477-ft deep existing well MG-151. The detection and presence of shallow water-bearing zones was partly controlled by depth to water. In the 15 deep monitor wells and 3 existing wells logged, static water levels ranged from 9.22 to 54.14 ft bls. Cascading water from a water-bearing zone above the static water level was noted in only one well [MG-2081 (RI-2D)]. Multiple water-bearing zones were identified in all boreholes.

Vertical gradients are indicated by vertical borehole flow in all boreholes under ambient conditions. Upward flow only was measured in four wells, MG-1841 (Spra-Fin 2), MG-2095 (RI-7D), MG-2097 (RI-8D), and MG-2122 (RI-11D), all east of Wissahickon Creek. Downward flow only was measured in four wells, MG-2080 (RI-1D), MG-2090 (RI-5D), MG-2125 (RI-12D), and MG-2131 (RI-15DD), all west of Wissahickon Creek in the northwestern part of the study area. Mixed upward and downward flow was measured in the other 10 wells, generally with wells on the east side of Wissahickon Creek having predominantly upward flow and wells on the west side of Wissahickon Creek having predominantly downward flow. The vertical gradients in well MG-2081 (RI-2D) changed during the period of logging, probably as a result of changes in nearby pumping. Nearby pumping may also affect observed vertical gradients in some other wells, including MG-2084 (RI-3D) and MG-2093 (RI-6D).

Acoustic Televiewer Logs

In the wells logged for the North Penn Area 7 study, water-bearing zones are associated with high-angle and low-angle fractures. Interpretation of the acoustic-televiewer logs resulted in a distribution of spatial orientations that shows differences between high-angle water-bearing fractures and low-angle or bedding-plane water-bearing zones. The acoustic-televiewer tool collects data relative to magnetic north, and these data are later corrected to true north for interpretation. The azimuth of features is presented relative to true north. The orientation of these features, assumed to be planar and plotted as azimuth and plunges of dips on figure 24, shows most high-angle water-bearing fractures strike northwest and dip steeply to the southeast (plotting near the center of the stereonet) and the low-angle water-bearing openings strike and dip in a broad range of directions (plotting around the rim of the stereonet from south clockwise to northeast). The orientation of the feature plane plots as a point on the lower-hemisphere stereonet in the dip direction (azimuth), where the magnitude of the dip (in degrees from horizontal) is indicated by the distance from the rim of the stereonet (0° at the rim and 90° at the center); the strike of the feature plane is oriented 90° to the dip. The largest cluster of low-angle orientations on the plot has a strike about N. 70° E. and dips shallowly to the northwest (fig. 24).

The lack of a focused spatial orientation for low- and moderate-angle features determined from acoustic-televiewer results for wells logged in the vicinity of the North Penn Area 7 may be related to geologic characteristics. The orientation of beds that dip at low angles (less than 10°), such as those in the North Penn Area 7 vicinity, are difficult to determine with certainty from the acoustic-televiewer logs. In addition, lithologic mapping indicates that the geologic units in the vicinity of North Penn Area 7 are transitional between the Lockatong Formation and Brunswick Group and may include interfingered facies and deltaic sediments (Joseph Smoot, U.S. Geological Survey, unpub. mapping, 2005). Interfingering or internal cross-bedding within sandstone units or varying depositional directions of deltaic deposits may result in apparent feature orientations on the acoustic-televiewer logs that differ from regional bedding planes.

Deviation Logs

Borehole deviation logs were collected in 17 wells during 2004 and 2005. The borehole deviation logs for 13 of the 17 wells show a generally linear trend (table 20). These 13 boreholes (MG-151, MG-1920, MG-2080, MG-2084, MG-2087, MG-2090, MG-2093, MG-2119, MG-2122, MG-2125, MG-2126, MG-2129, and MG-2131) deviate to the southeast (figs. 25-27, 29-32, 36-41); the azimuth of deviation direction ranged from 112 to 164° (table 20) and averaged about 141° or S. 39° E. If the direction of borehole deviation tends to migrate up-dip normal to bedding planes, as has been reported to occur in some cases where bedding dips less than 45° (Wilson, 1976; McLamore, 1971; Brown and others, 1981), then an average strike of about N. 51° E. for bedding was indicated by the borehole deviation in these 13 boreholes. Because the borehole deviation is to the southeast, the dip of the beds would be to the northwest. Assuming the deviation is normal to the bedding plane, the formation dip was estimated from the deviation data to be about 1.4 to 3.8° NW. A dip angle for bedding calculated from the total deviation (shallowest to deepest deviation measurements) does not account for probable non-linear inclination and underestimates actual bedding dip. As the hole is drilled, there is a tendency for increasing degrees of deviation with increasing depth because of greater flexibility in the drill string with additional rods. Thus, the dip angle calculated from the deviation logs is probably shallower than the actual formation dip.

In the four wells (MG-2081, MG-2095, MG-2097, MG-2100) that did not show a linear trend in deviation to the southeast, the deviation logs indicated the drill bit appeared to migrate to the southeast with depth (figs. 28, 33-35). Three (MG-2095, MG-2097, MG-2100) of the four boreholes are aligned approximately along strike (fig. 5), suggesting a possible geologic factor such as the potential for deltaic deposits in deviation patterns. All four wells are in the eastern part of the study area.

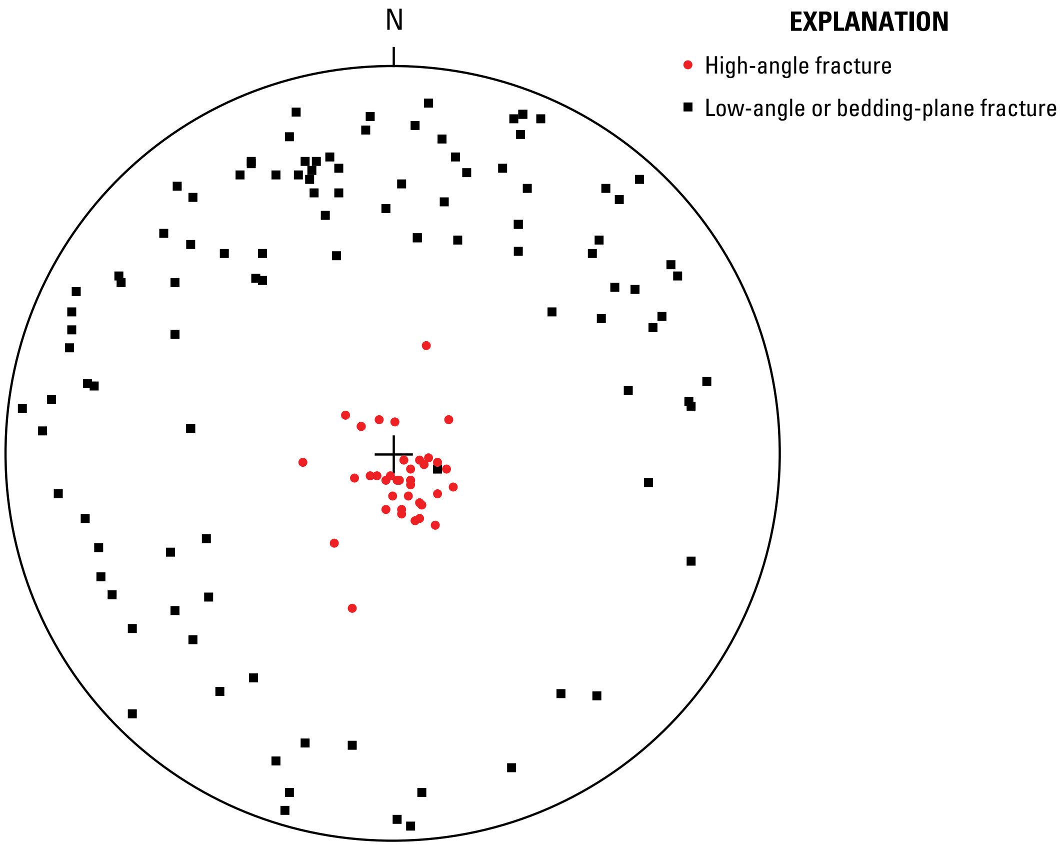


Figure 24. Stereonet showing orientation of dip projected onto lower hemisphere for water-bearing fractures, bedding, and other features interpreted from acoustic televiewer logs in 17 wells in and near North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa. Features are assumed to be planar.

Table 20. Summary of borehole deviation magnitude and orientation for 2 existing wells and 15 deep monitor wells drilled 2003–2004 at North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[--, no data or not calculated]

U.S. Geological Survey local well number	Other well name	Well log depth, in feet below land surface	Magnitude of deviation, in feet	Remark on deviation trend	Orientation of borehole deviation from vertical determined from deviation log — Azimuth, in degrees	Corresponding inferred strike of bed, in degrees East of North	Dip of bed, estimated from deviation, in degrees
Wells with linear or semi-linear deviation trend							
MG-151 upper	Ford #5	320	13.5	linear	143	53	--
MG-151 lower		477	23	linear	152	62	[1]22.7
MG-1920	Ford MW-1	131	3.2	linear	112	22	1.5
MG-2080	RI-1D	295	13	linear	150	60	3.1
MG-2084	RI-3D	297	15	drifting/linear	147	57	2.7
MG-2087	RI-4D	297	16	upper drift	151	61	3.1
MG-2090	RI-5D	295	11	semi-linear	134	44	2.1
MG-2093	RI-6D	295	4.5	semi-linear	134	44	2.7
MG-2119	RI-10D	295	13.5	linear	158	68	2.7
MG-2122	RI-11D	328	11	linear	130	40	2.1
MG-2125	RI-12D	295	7	linear	135	45	1.4
MG-2126	RI-13D	328	12	linear	117	27	2.3
MG-2129	RI-14D	298	20	linear	164	74	3.8
MG-2131	RI-15DD	295	19	linear	158	68	3.7
Wells with non-linear deviation trend							
MG-2081	RI-2D	295	14	not linear	110	20	--
MG-2095 upper	RI-7D	131.6	1.6	drifting	60	-30	--
MG-2095 lower	180 to 246	246	4	redirected	130	40	--
MG-2097	RI-8D	328	9.5	not linear	118	28	--
MG-2100	RI-9D	328	7.5	not linear	107	17	--

[1]For total length of borehole.

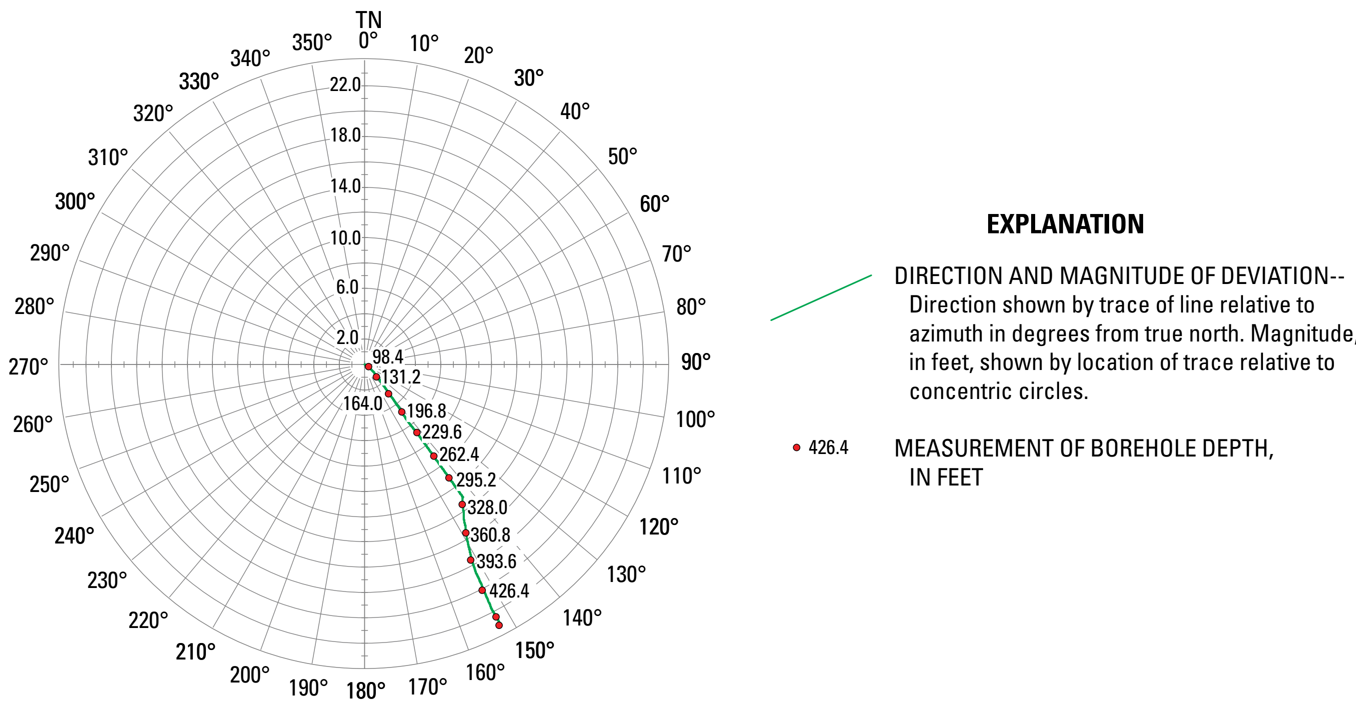


Figure 25. Magnitude and direction of deviation from vertical of borehole MG-151 (Ford #5). Points show depth of deviation measurement. The borehole deviates from vertical about 23 feet toward the southeast over the length of the borehole, and the amount of deviation with depth decreases suddenly at 320 feet below land surface, indicating a change in lithology with a change in bedding angle.

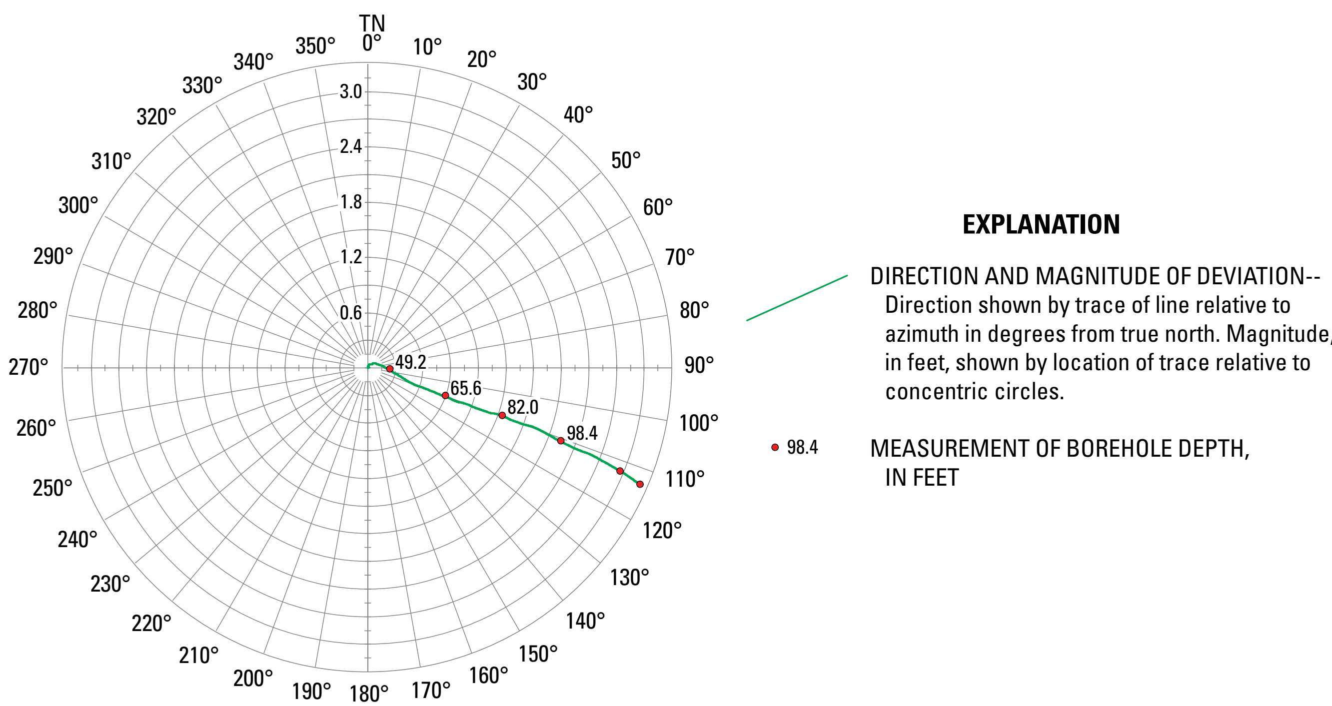


Figure 26. Magnitude and direction of deviation from vertical of borehole MG-1920 (Ford MW-1). Points show depth of deviation measurement. The borehole deviates from vertical about 3.8 feet toward the southeast over the length of the open borehole, and the amount of deviation with depth is consistent over the length of the borehole, indicating only minor changes in lithology.

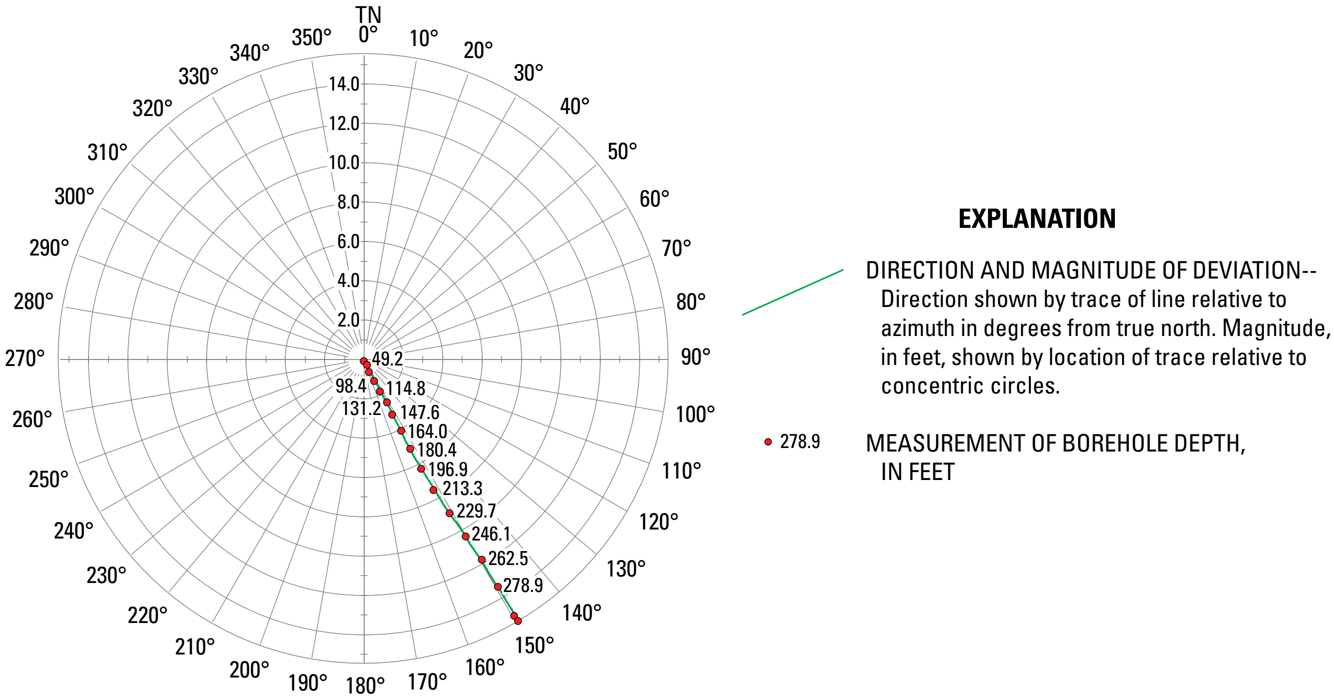


Figure 27. Magnitude and direction of deviation from vertical of borehole MG-2080 (RI-1D). Points show depth of deviation measurement. The borehole deviates from vertical about 14.5 feet to the south-southeast over the length of the open borehole.

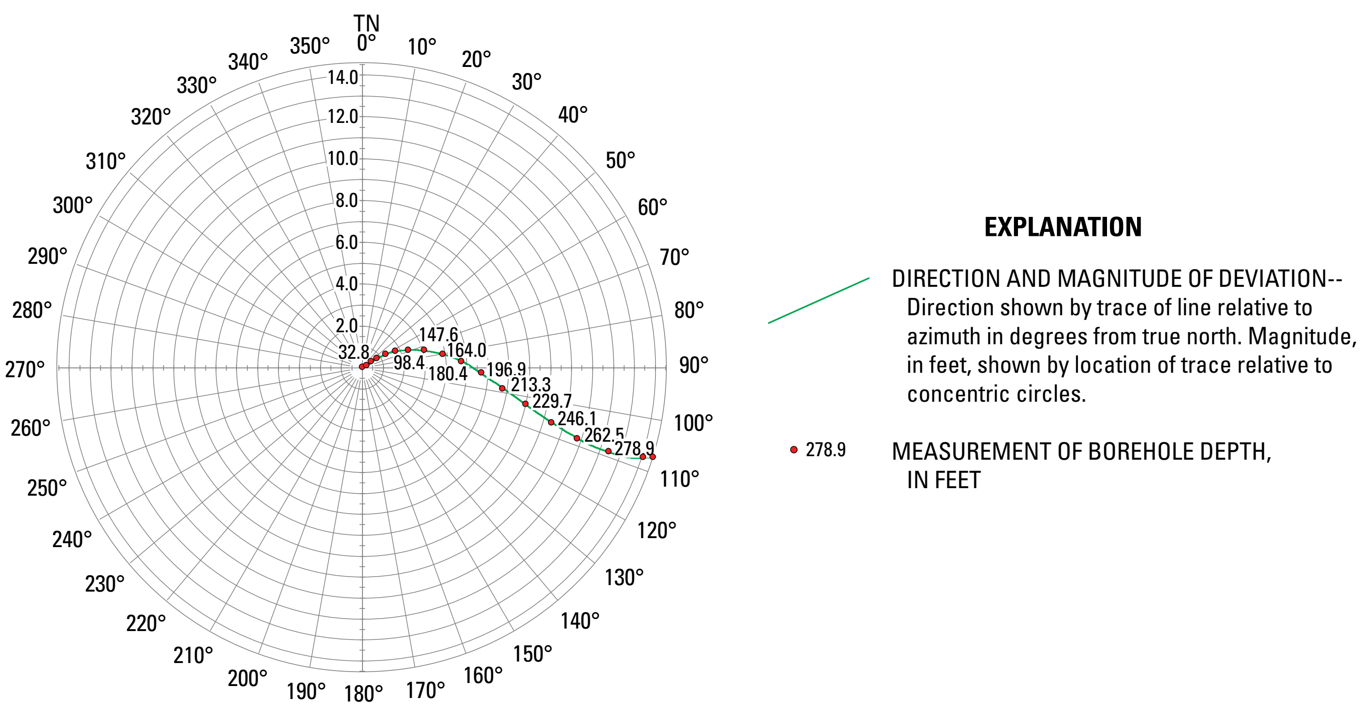


Figure 28. Magnitude and direction of deviation from vertical of borehole MG-2081 (RI-2D). Points show depth of deviation measurement. The borehole deviates from vertical about 3.8 feet toward the southeast over the length of the open borehole, and the amount of deviation with depth is consistent over the length of the borehole, indicating only minor changes in lithology.

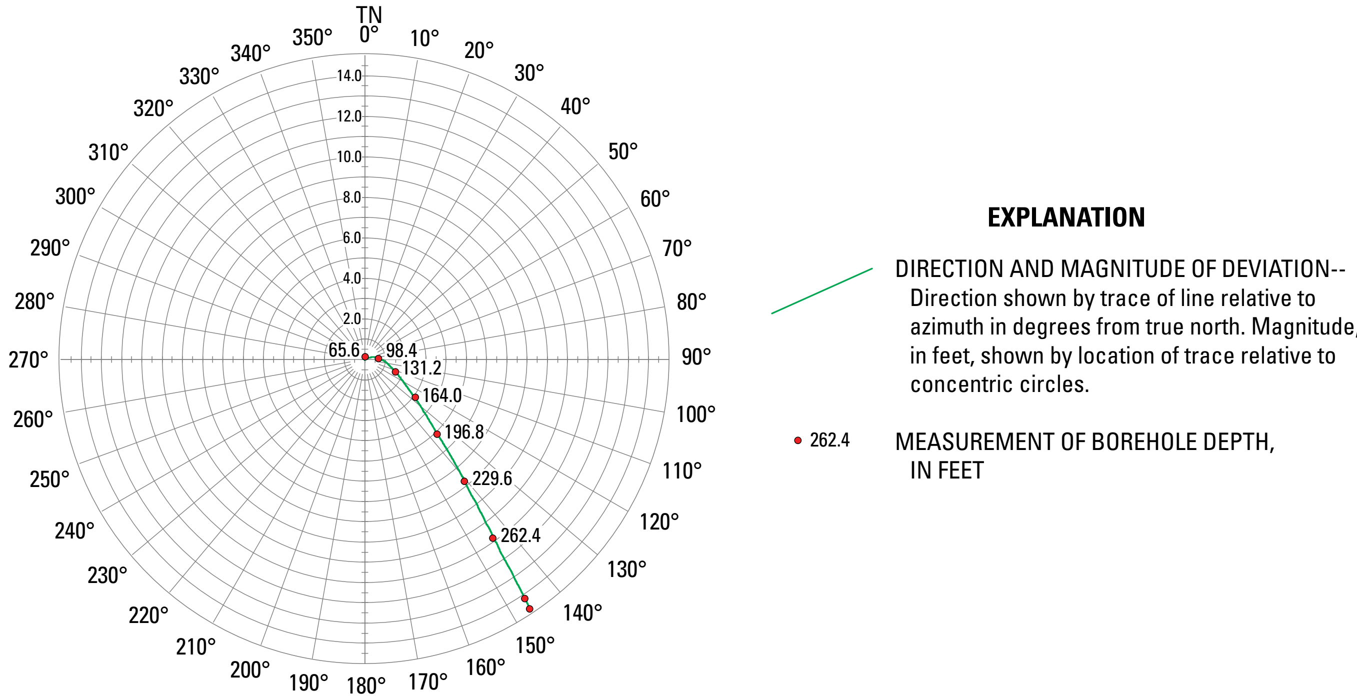


Figure 29 Magnitude and direction of deviation from vertical of borehole MG-2084 (RI-3D). Points show depth of deviation measurement. The borehole deviates from vertical about 15 feet toward the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below about 130 feet below land surface.

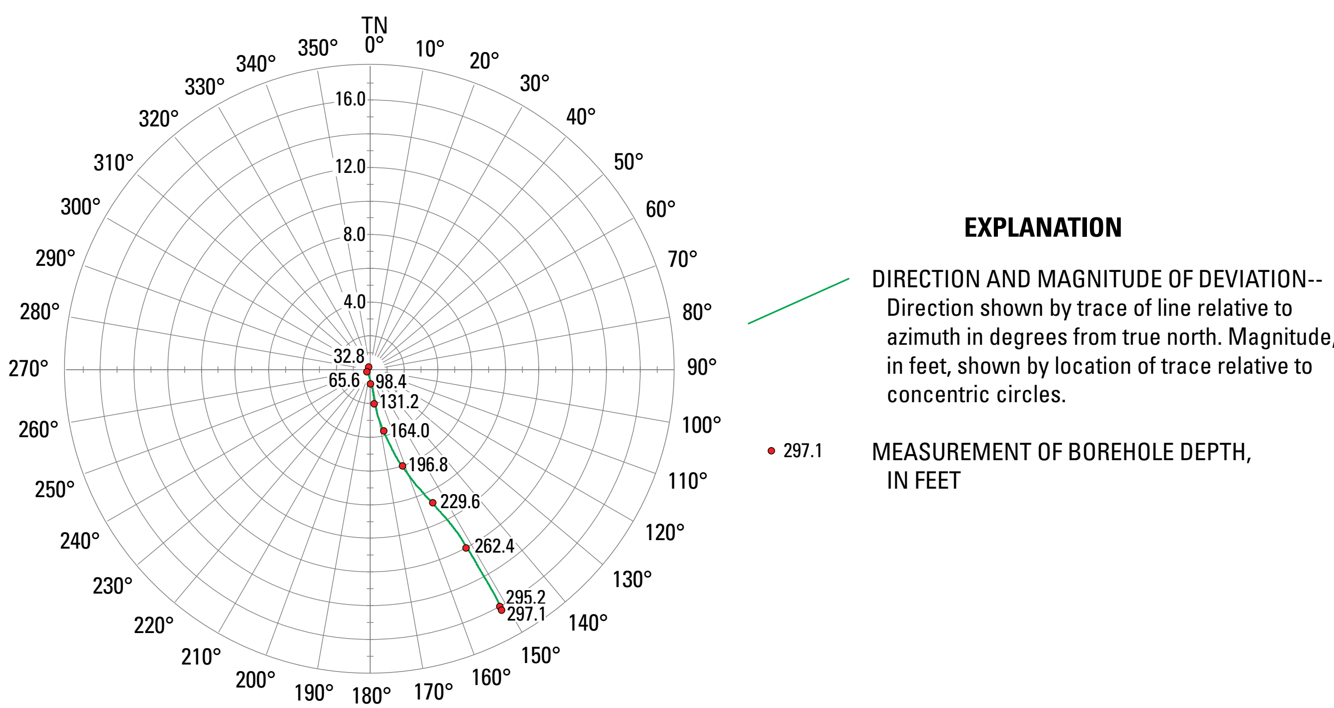


Figure 30. Magnitude and direction of deviation from vertical of borehole MG-2087 (RI-4D). Points show depth of deviation measurement. The borehole deviates from vertical about 16 feet to the southeast over the length of the borehole, and the amount of deviation with depth increases consideraably below about 130 feet below land surface.

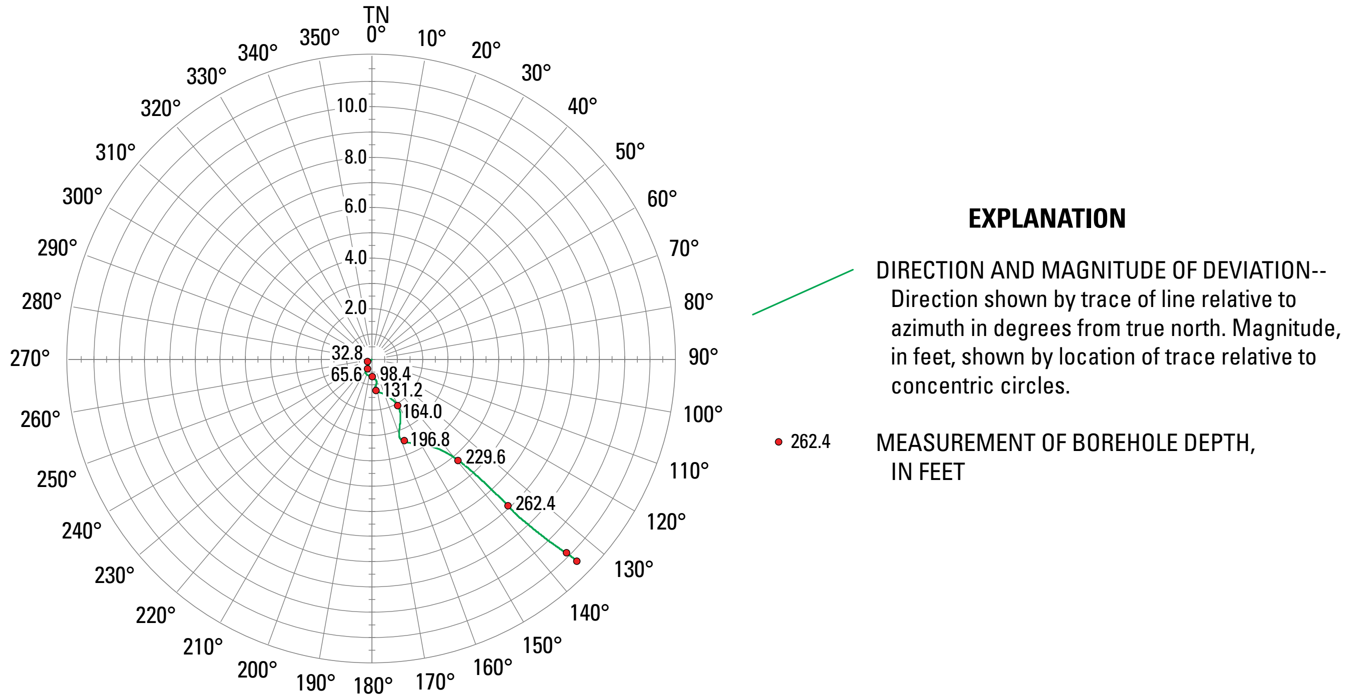


Figure 31 Magnitude and direction of deviation from vertical of borehole MG-2090 (RI-5D). Points show depth of deviation measurement. The borehole deviates from vertical about 11.5 feet toward the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below about 195 feet below land surface.

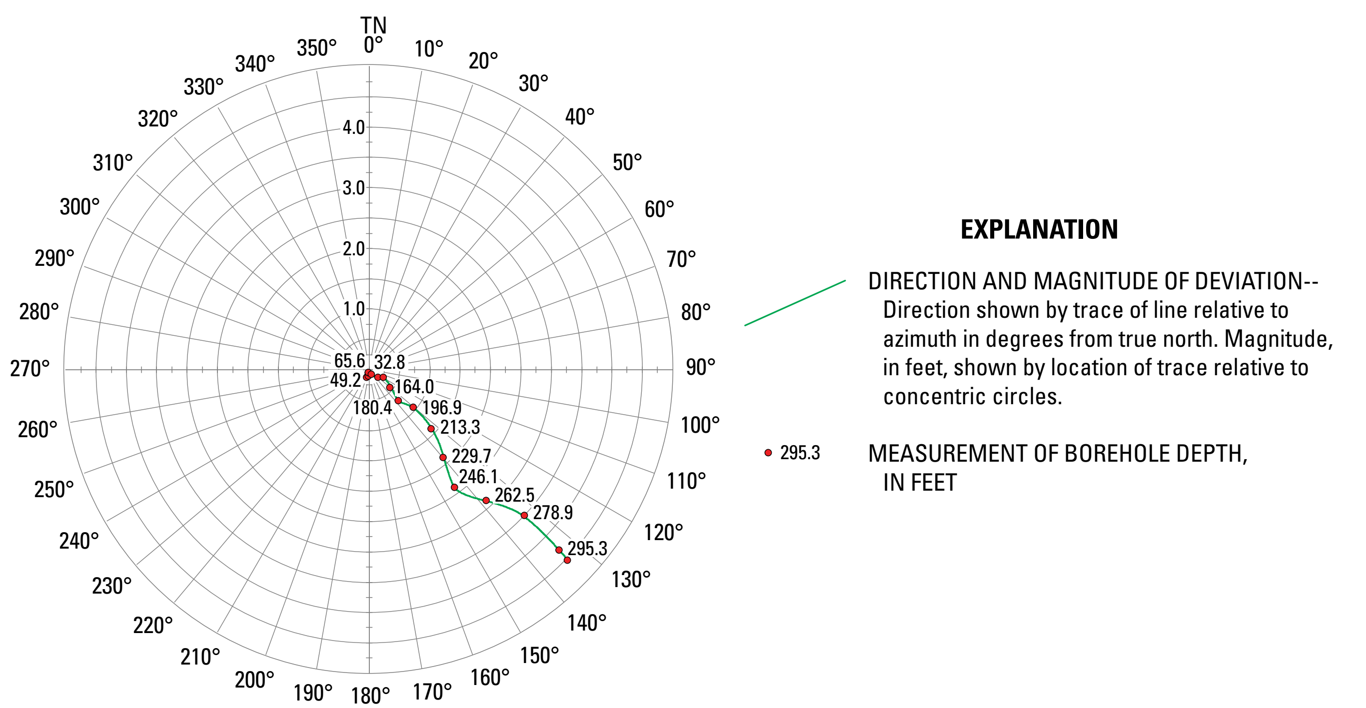


Figure 32. Magnitude and direction of deviation from vertical of borehole MG-2093 (RI-6D). Points show depth of deviation measurement. The borehole deviates from vertical about 4.6 feet to the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below about 105 feet below land surface.

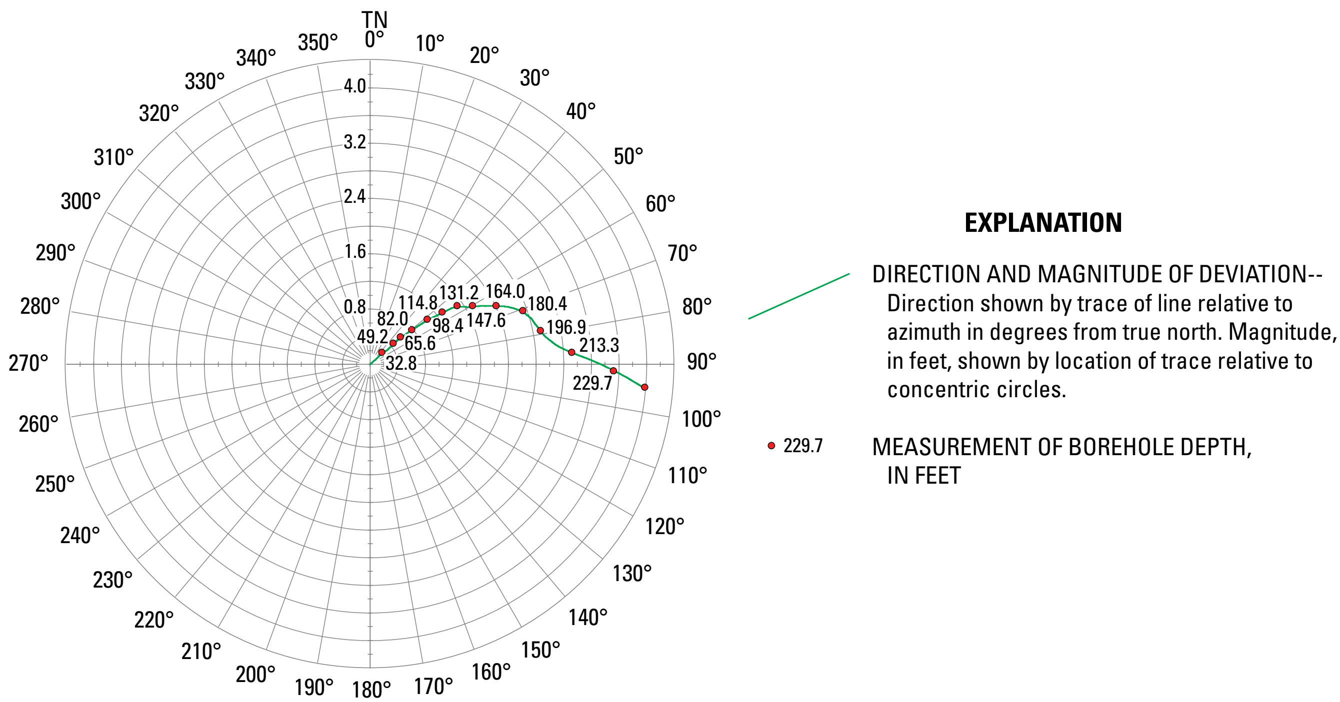


Figure 33 Magnitude and direction of deviation from vertical of borehole MG-2095 (RI-7D). Points show depth of deviation measurement. The borehole deviates from vertical about 4 feet generally toward the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below about 105 feet below land surface.

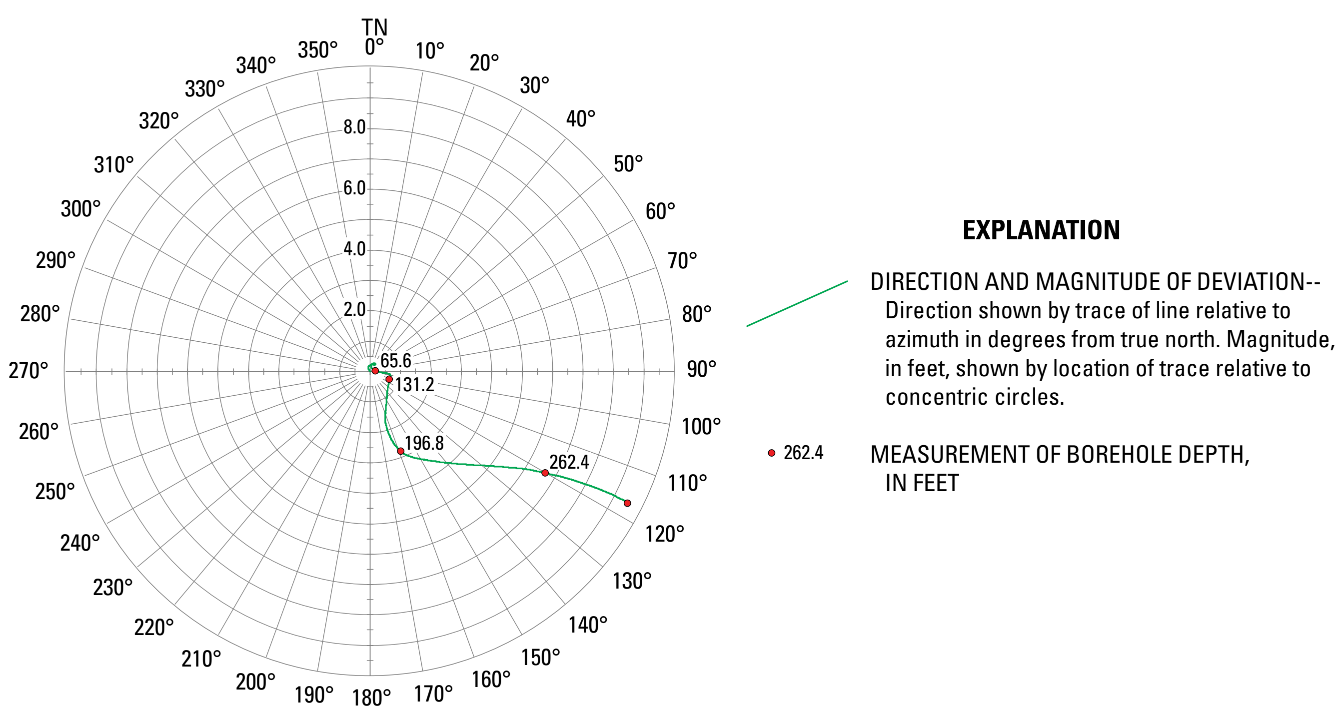


Figure 34. Magnitude and direction of deviation from vertical of borehole MG-2097 (RI-8D). Points show depth of deviation measurement. The borehole deviates from vertical about 9.5 feet generally toward the east over the length of the borehole, and the amount of deviation with depth increases consideraably below about 180 feet below land surface.

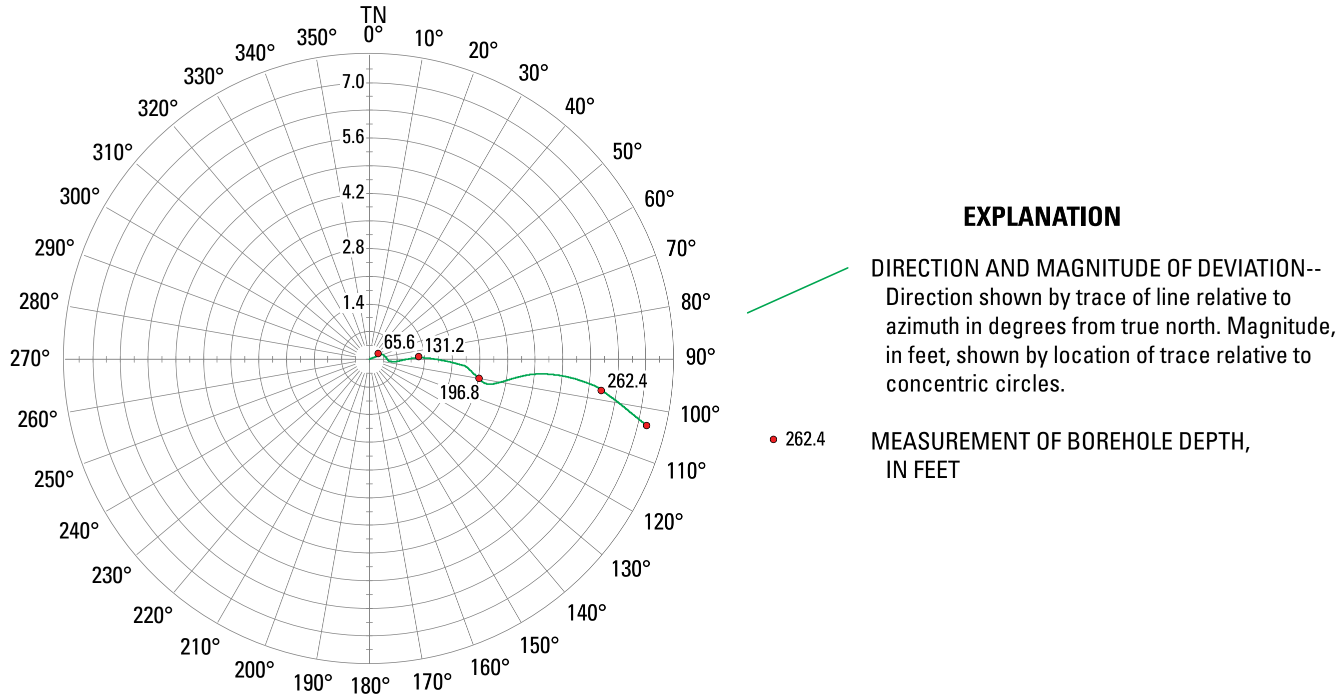


Figure 35 Magnitude and direction of deviation from vertical of borehole MG-2100 (RI-9D). Points show depth of deviation measurement. The borehole deviates from vertical about 7.4 feet generally toward the east over the length of the borehole, and the amount of deviation with depth increases considerably below about 180 feet below land surface.

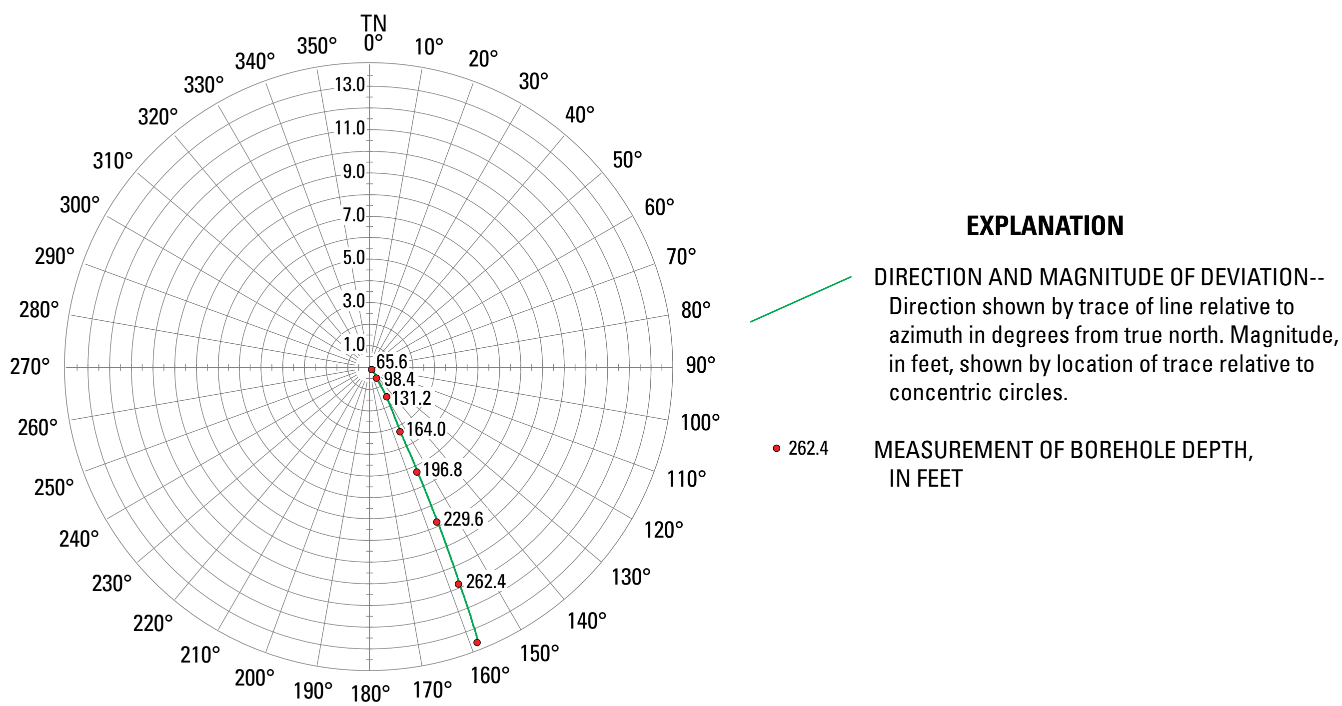


Figure 36. Magnitude and direction of deviation from vertical of borehole MG-2119 (RI-10D). Points show depth of deviation measurement. The borehole deviates from vertical about 13.5 feet toward the southeast over the length of the borehole, and the trend of the deviation is consistent over the length of the borehole.

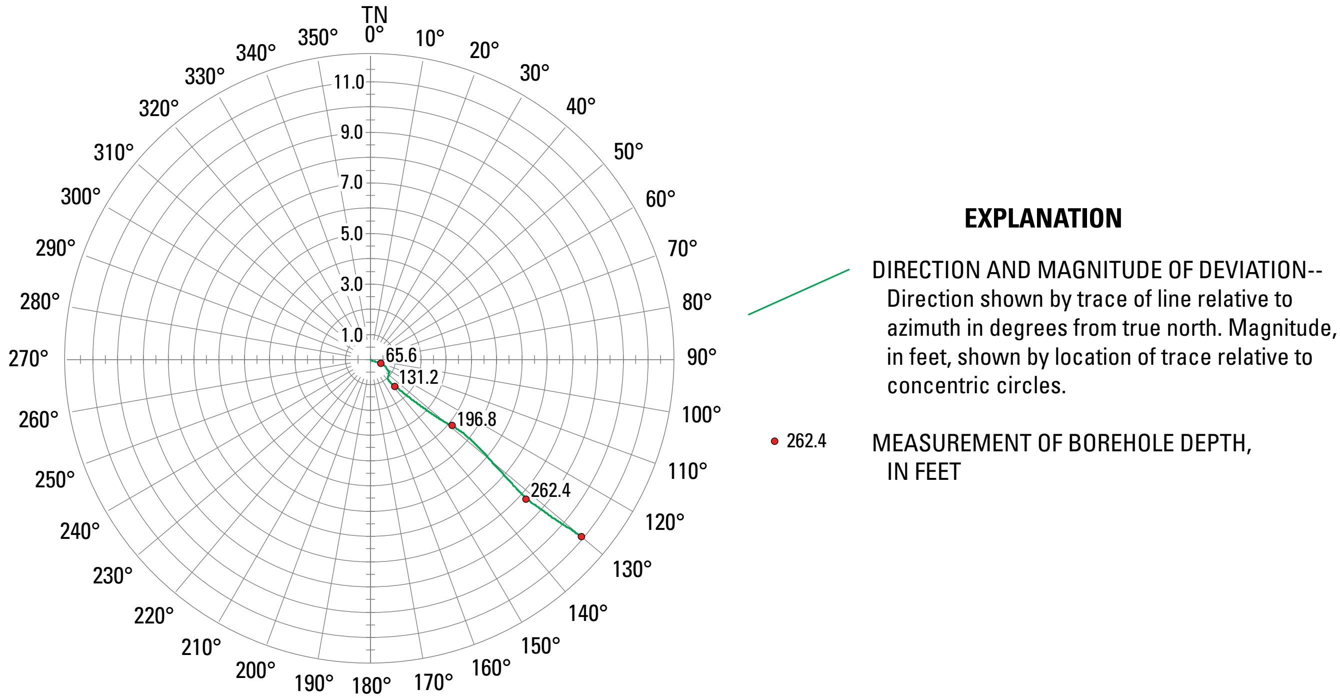


Figure 37 Magnitude and direction of deviation from vertical of borehole MG-2122 (RI-11D). Points show depth of deviation measurement. The borehole deviates from vertical about 11 feet generally toward the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below about 120 feet below land surface.

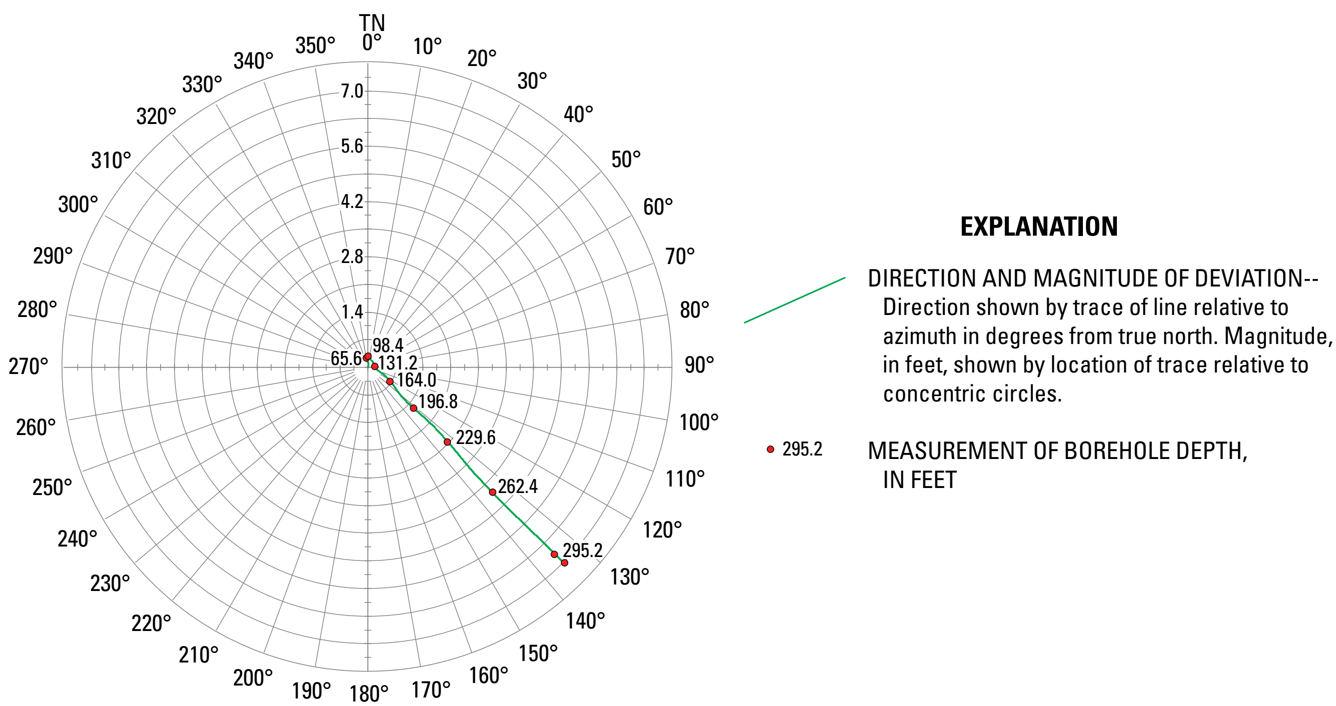


Figure 38. Magnitude and direction of deviation from vertical of borehole MG-2125 (RI-12D). Points show depth of deviation measurement. The borehole deviates from vertical about 7 feet generally toward the southeast over the length of the borehole, and the amount of deviation with depth increases considerably below 100 feet below land surface.

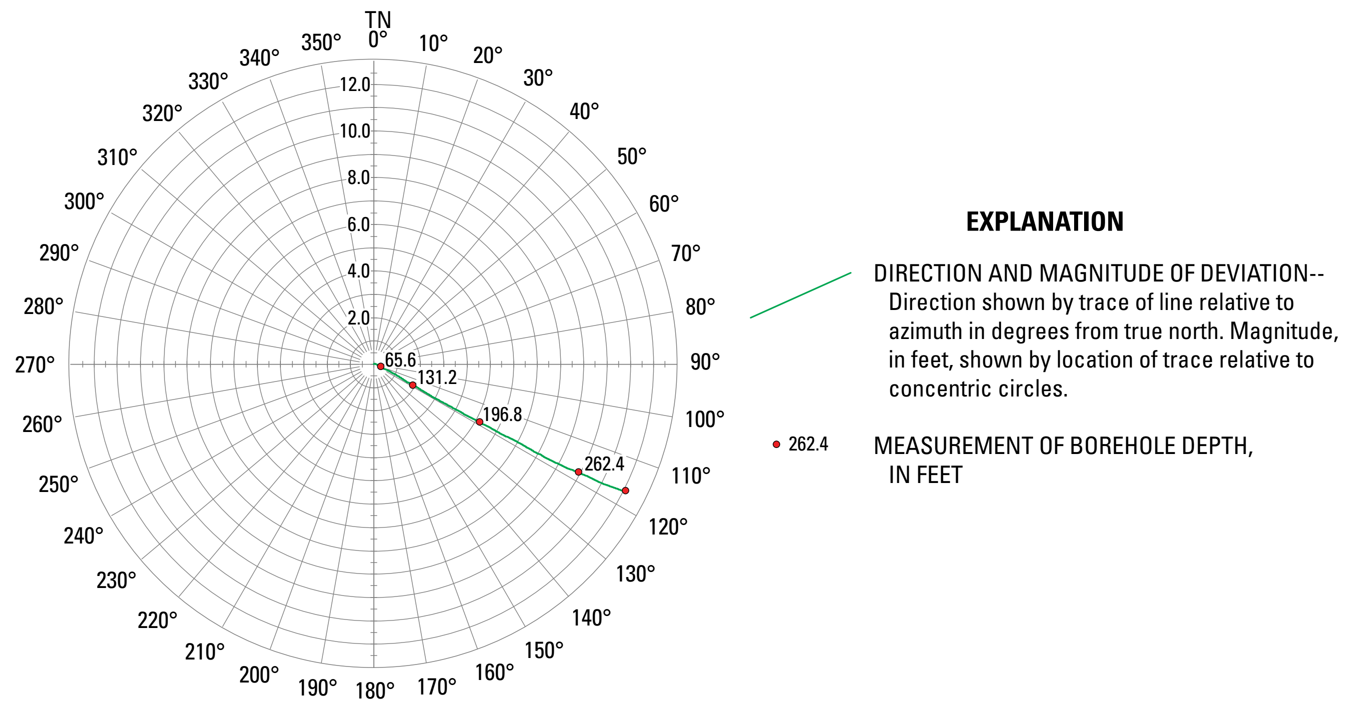


Figure 39 Magnitude and direction of deviation from vertical of borehole MG-2126 (RI-13D). Points show depth of deviation measurement. The borehole deviates from vertical about 12 feet toward the southeast over the length of the borehole, and the amount of deviation with depth increases consistenly over the length of the borehole.

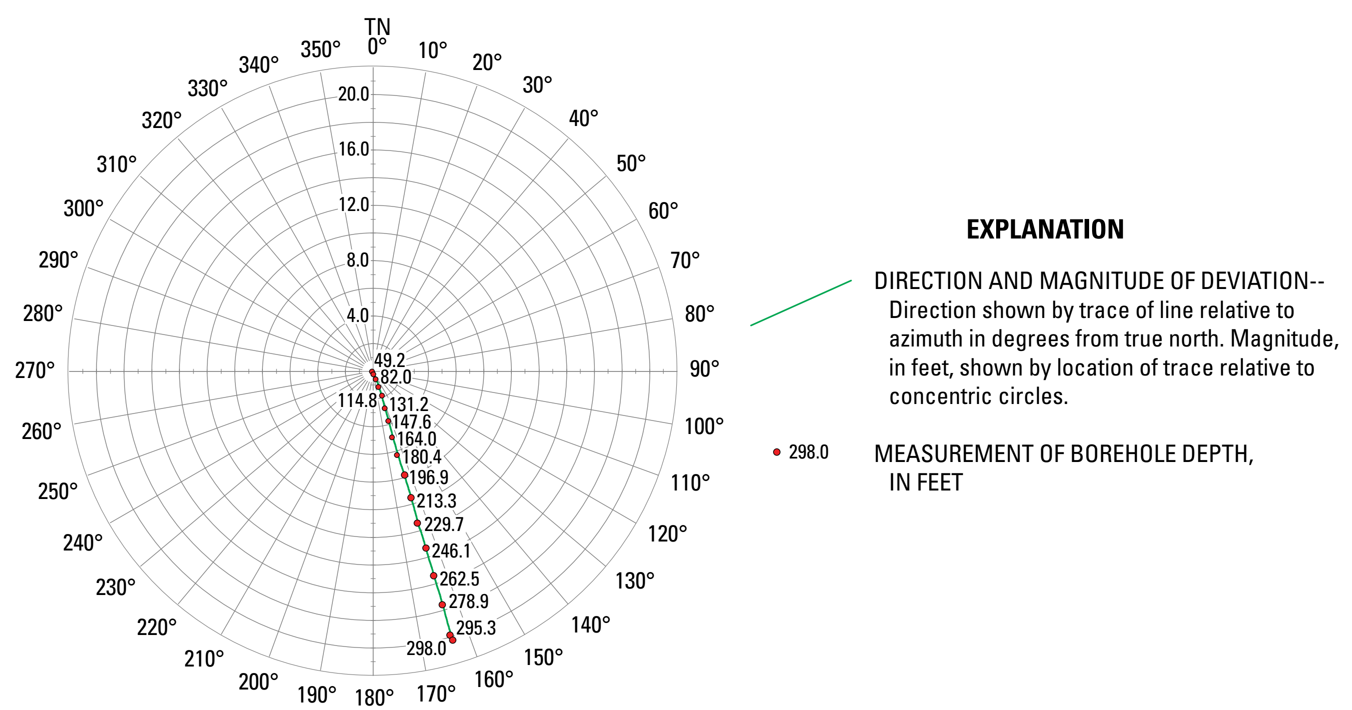


Figure 40. Magnitude and direction of deviation from vertical of borehole MG-2129 (RI-14D). Points show depth of deviation measurement. The borehole deviates from vertical about 20 feet toward the south-southeast over the length of the borehole, and the trend of the deviation is consistent.

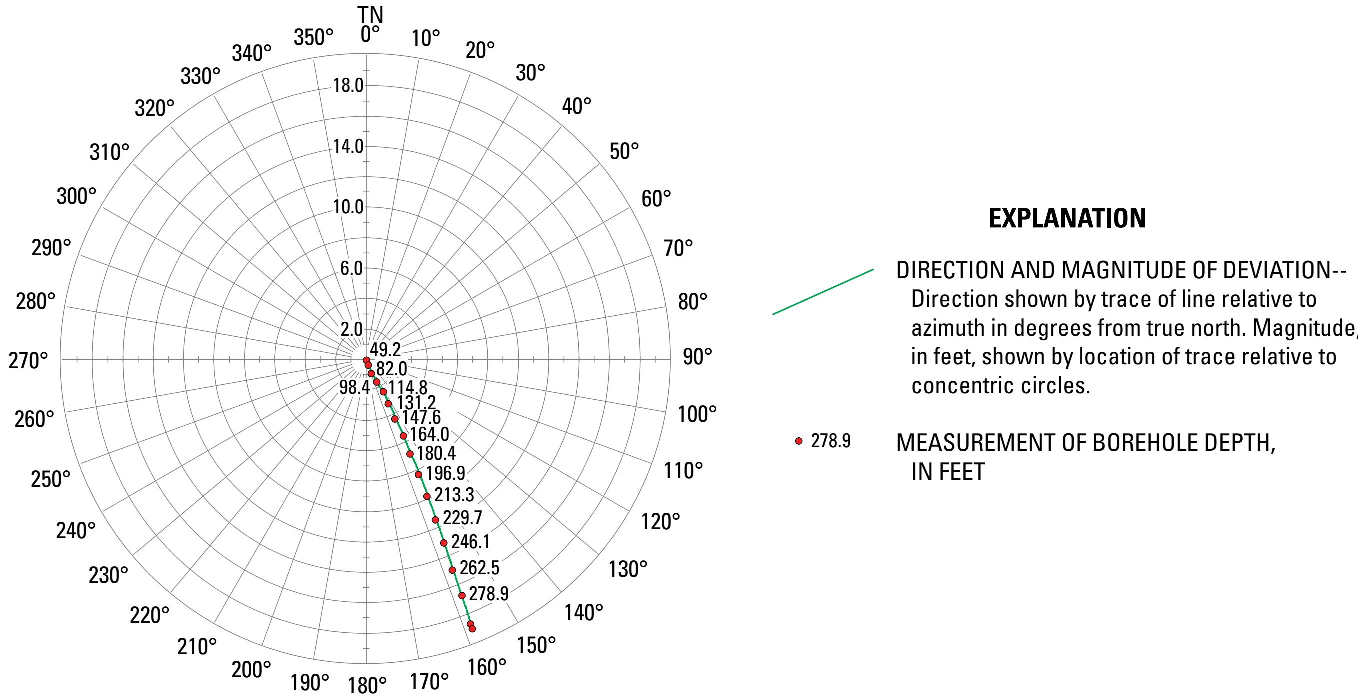


Figure 41. Magnitude and direction of deviation from vertical of borehole MG-2131 (RI-15DD). Points show depth of deviation measurement. The borehole deviates from vertical about 19 feet toward the southeast over the length of the borehole, and the overall deviation is consistent.

The bedding strike inferred from the borehole deviation logs is similar to the strike reported from previous geologic mapping (Longwill and Wood, 1965) and from the log-correlation section of this report. However, the magnitude of the dip inferred by the borehole deviation logs is less than the dip angles of 6 to 12 degrees determined from geologic mapping and log correlation, as discussed above. Because uncertainty is associated with the interpretation of the borehole deviation logs, the resulting bedding orientations should be viewed with caution.

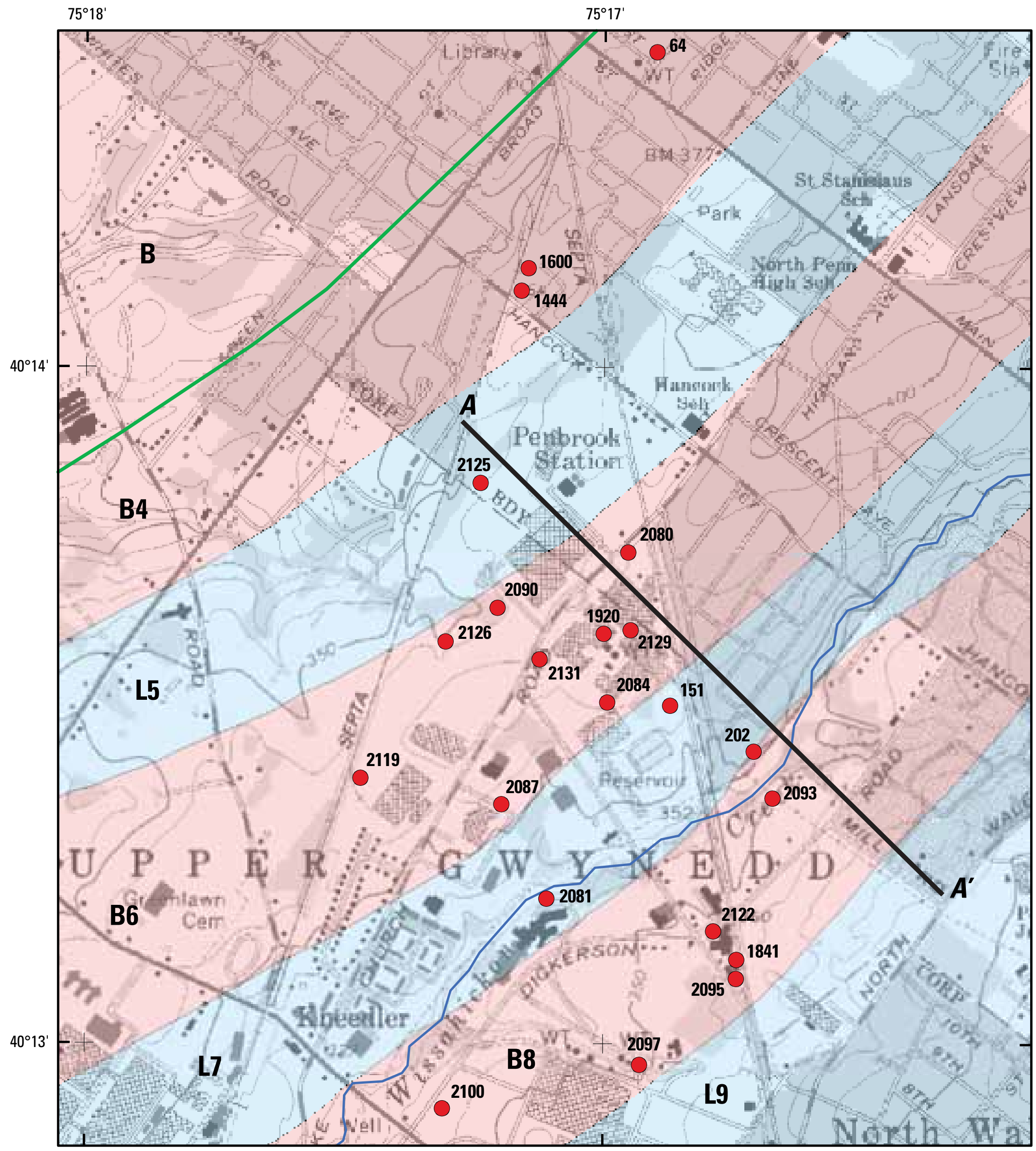
The difference between true vertical depth and drilling depth can be calculated using deviation logs; true vertical depth is less than drilling depth. Even with deviations up to 20 ft from vertical, this difference is relatively small given the depths of the wells. Assuming linear deviation, the difference between true drilling depth and actual drilling depth is less than 1 ft for the 300-ft well with the largest deviation (20 ft from vertical) (MG-2129).

Correlation of Well Logs and Lithology

The natural-gamma-ray activity and single-point-resistance logs commonly show an inverse relation, indicating wells penetrate sequences of alternating relatively finer- and coarser-grained lithologies, grading between shalier and sandier sediments. The prevalence of thicker-bedded sandier units, indicated by elevated single-point resistance, appears to increase in the eastern part of the study area. Notes on lithology collected by CDM during drilling of new monitor wells indicate most drill cuttings appeared to be reddish-brown siltstone, with some reddish-gray sandstone and calcite. Thin beds that were dark gray to black or greenish-gray were reported in wells with elevated natural-gamma activity.

The natural-gamma-ray activity of most sections of the well logs ranged from about 50 to 200 counts per second. In some wells, however, the natural-gamma-ray activity ranged from several hundred to several thousand counts per second, usually in relatively thin sections of 5 to 20 ft in thickness. These zones of elevated natural-gamma activity are sedimentary in origin, usually corresponding to dark gray or black beds noted on drilling logs. By correlating these zones of elevated natural-gamma activity or marker beds in logs of different wells, estimates of bedding orientation were obtained in parts of the study area.

Correlation of natural-gamma logs was possible for several wells in the western part of the study area, including MG-2125 (RI-12D), MG-2126 (RI-13D), MG-2090 (RI-5D), MG-2119 (RI-10D), MG-2131 (RI-15DD), MG-1920 (Ford MW-1), and MG-2129 (RI-14D) (fig. 42). Correlations for the wells across the western area and including some but not all on the former FERCO property were made using three marker beds, at least two of which occur on these logs (fig. 43). The orientation of bedding estimated from these log correlations indicates a strike of about N. 57° NE. and dip of about 9 to 10° NW. The dip angle (about 4°) calculated for correlations with MG-2125 (RI-12D) is shallower than that calculated using the other wells, suggesting possible small displace-



Base from U.S. Geological Survey
Lansdale 1983 contour interval 10 feet
1927 North American Datum

Geology from Berg and others (1980) with nomenclature from Lyttle and Epstein (1987) and additional mapping and lithologic classification from Smoot (unpublished)

EXPLANATION

Nomenclature — Bed code, this report	Lithology
B, B4, B6, B8	Red beds predominant
L5, L7, L9	Gray beds predominant

A——A′ Section line

Lower Brunswick contact with deltaic units

Stream

2119 ● Well and local well number (prefix MG- omitted)

0 500 1,000 2,000 3,000 FEET

0 200 400 800 METERS

Figure 42. Location of selected wells with geophysical logs in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

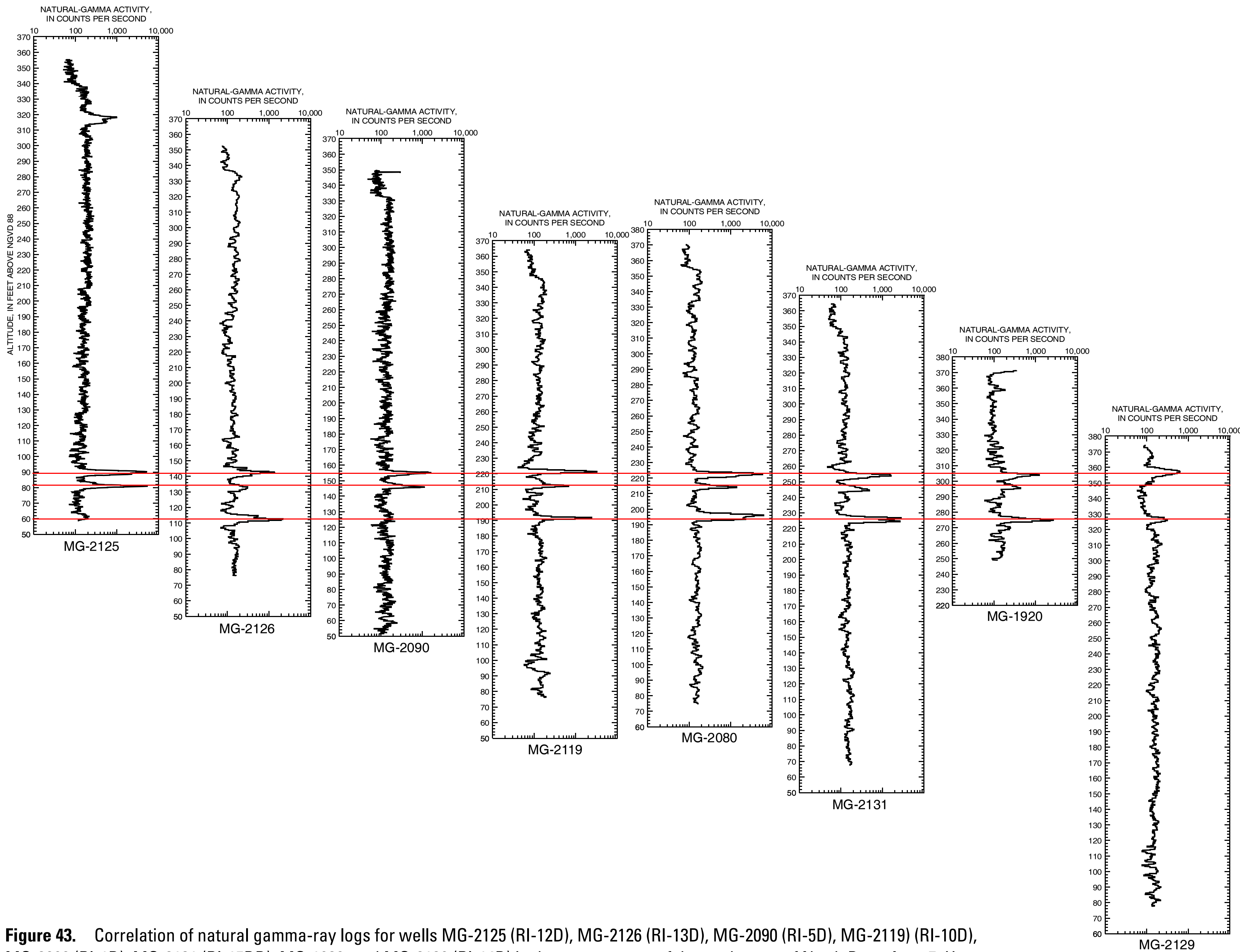


Figure 43. Correlation of natural gamma-ray logs for wells MG-2125 (RI-12D), MG-2126 (RI-13D), MG-2090 (RI-5D), MG-2119) (RI-10D), MG-2080 (RI-1D), MG-2131 (RI-15DD), MG-1920, and MG-2129 (RI-14D) in the western part of the study area of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

ment by faulting in the vicinity of MG-2125 (RI-12D). Fault surfaces were reported in a previous investigation (Black & Veatch, 1999, Appendix) during drilling of well (Rogers 3I) just to the north and nearly along strike from MG-2125 (RI-12D) (fig. 42).

The wells in the western part of the North Penn Area 7 may be further correlated to wells, including MG-64 (fig. 42), that were logged previously for studies of North Penn Area 6 (Conger, 1999) in Lansdale to the north and west of North Penn Area 7, indicating continuity of bedding at depth in that direction. Correlation of a pair of marker beds at about 250 ft below NAVD 88 in well MG-64 to similar beds in MG-2125 (RI-12D) and MG-2090 (RI-5D) (fig. 44) indicates bedding strikes northeast and dips about 11 degrees [using MG-2090 (RI-5D) and MG-2126 (RI-13D)] and about 16 degrees [using MG-2125 (RI-12D) and MG-2126 (RI-13D)]. Marker beds at about 50 and 100 ft above NAVD 88 in well MG-64 (fig. 44) correlate to beds in MG-1444, about 2,500 ft to the southwest (fig. 42), and to other beds in wells several thousand feet approximately along strike to the northeast [see marker beds C and D in Barton and others (2003, p. 15)]. Laterally continuous beds that can be correlated over relatively large distances (miles) have been associated with lake sediments in the Brunswick Group and Lockatong Formation (Olsen and others, 1996).

No marker beds associated with elevated natural-gamma activity (counts greater than 500 per second) occur in any of the existing and new monitor wells that are 300 ft or less in depth in the central part of the study area. Some of this section of rocks corresponds to the lower 400 ft of well MG-64 (fig. 44) that also shows lack of elevated natural-gamma activity. A thin zone of moderately elevated gamma-ray activity (about 500 counts per second) was measured at about 400 ft bls in well MG-151 (Ford #5) on former FERCO property. The sparsity of zones with elevated natural-gamma activity in logs of wells in the central part of the study area appears to be associated with sections of logs with relatively elevated single-point resistance. The zones of elevated resistance, 5 to 20 ft thick, probably indicate relatively sandier sequences of sediments.

Previous logs of wells MG-202 (Senior and others, 2005) and MG-76 (Conger, 1999) near Wissahickon Creek show some zones of elevated natural-gamma activity not readily correlated to each other or other wells, suggesting these marker beds are not laterally continuous over large areas. The four wells that did not have a linear trend to deviation log (table 20) are in the eastern part of the study area, suggesting variable bedding orientations possibly related to interfingering of deltaic deposits that would disrupt lateral continuity of beds.The increase in frequency of zones of elevated natural-gamma activity with depth in well MG-202 and in wells drilled east of Wissahickon Creek, including MG-2122 (RI-11D), MG-2097 (RI-8D), MG-2100 (RI-9D), and MG-2095 (RI-7D) (figs. 19, 16, 17, and 15, respectively) probably reflects stratigraphic changes up-dip and down-section from the central part of the study area.

Despite lack of marker-bed correlation in the central and eastern parts of the study area, the general bedding dip determined from correlations in the western part of the study area was assumed to be the same throughout the study area. Bedding contacts from mapped bedrock contacts were projected using a dip of 10 degrees onto the geophysical logs shown later with results of aquifer-isolation tests (see for example, fig. 48). The units are labeled as identified for this report as shown in figs. 4 and 42. The attitude of beds was used to generate a schematic cross section (fig. 45) that shows wells projected onto a line approximately parallel to dip (fig. 42).

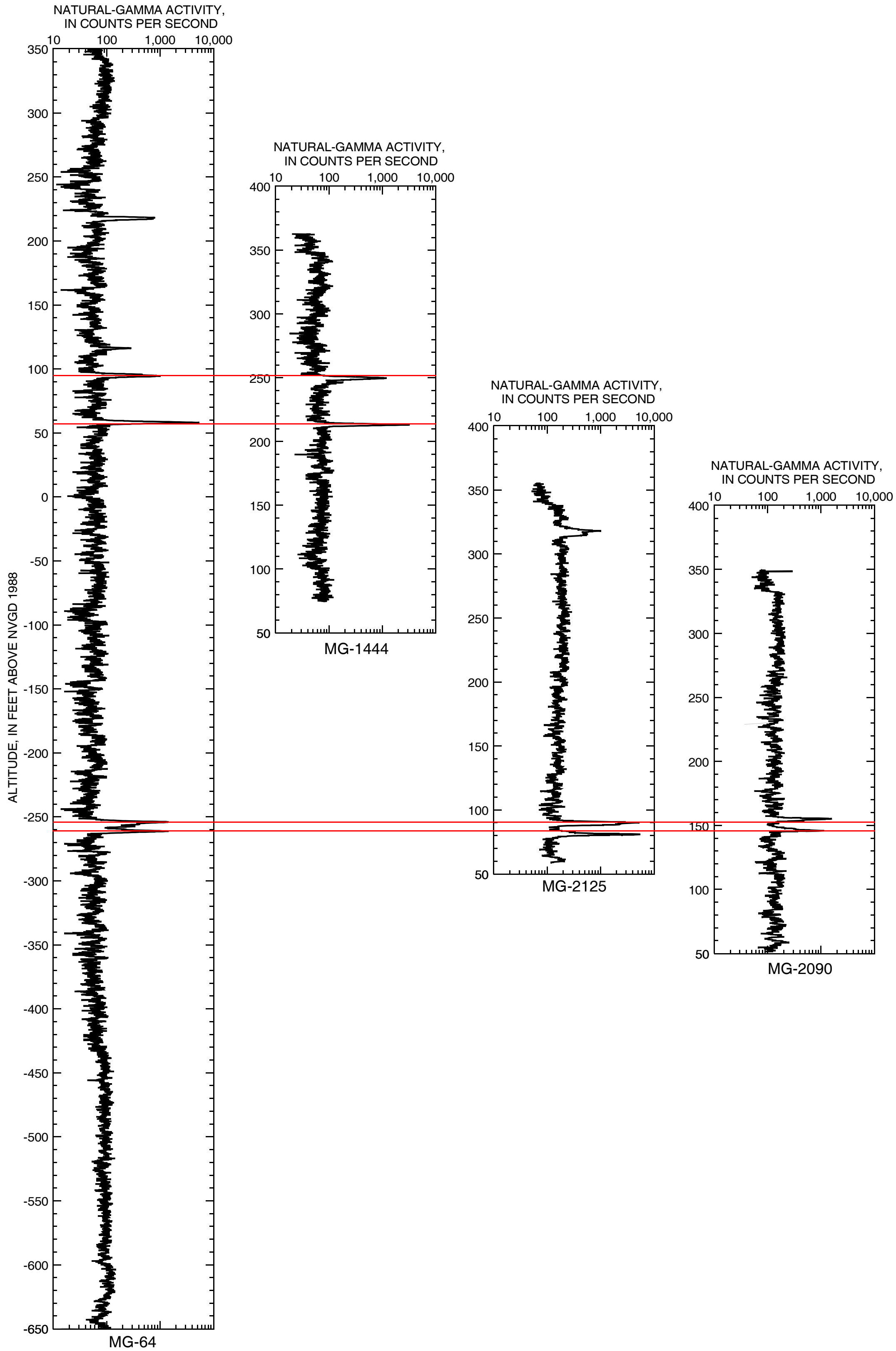


Figure 44. Correlation of natural-gamma-ray logs for wells MG-1225 (RI-12D) and MG-2090 (RI-5D) and wells MG-64 and MG-1444 to the north and west of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

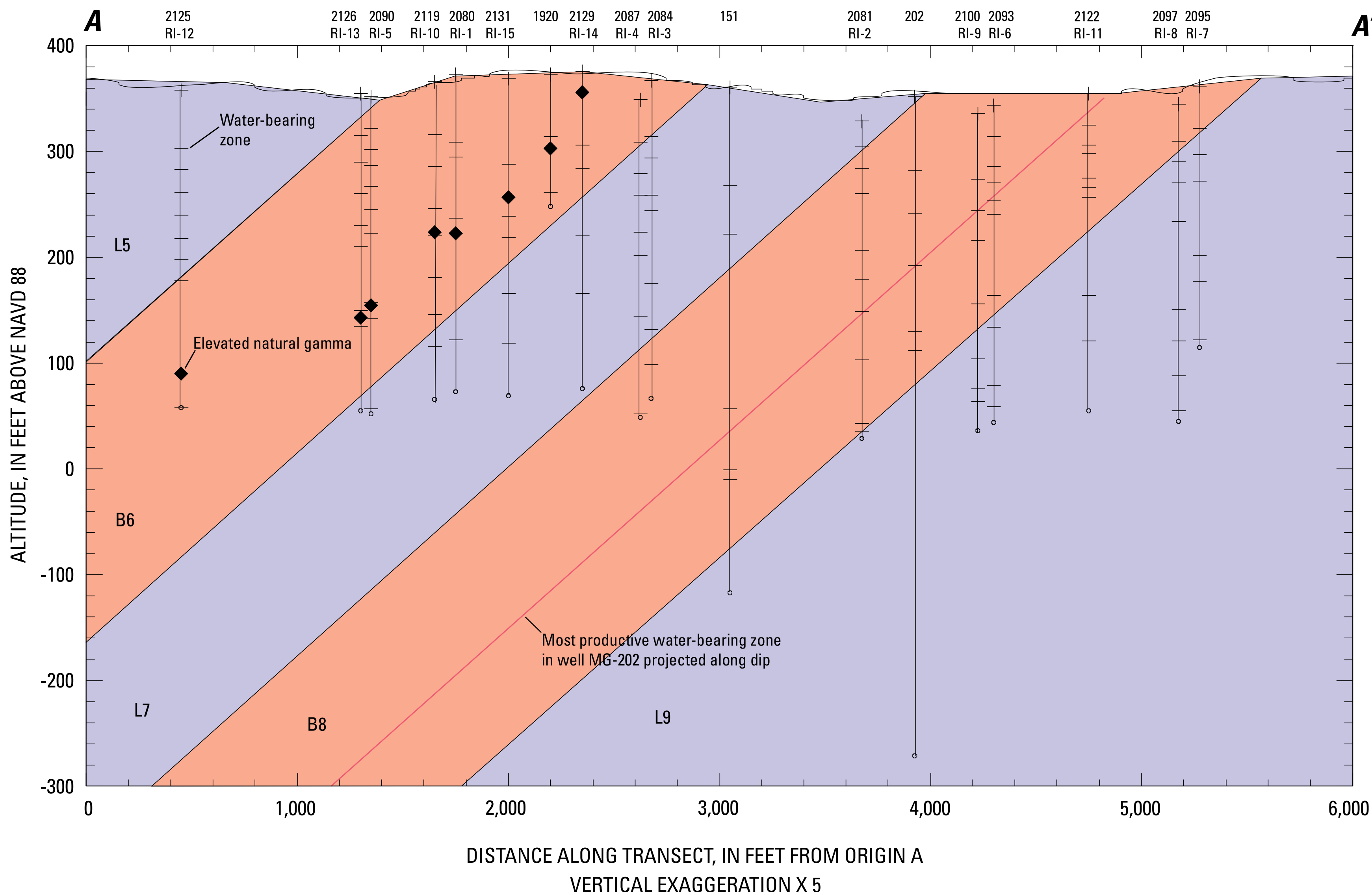


Figure 45. Schematic cross section showing wells projected onto a line approximately parallel to dip in and near North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa. Approximate depth of water-bearing zones and an elevated natural-gamma bed identified from geophysical logging are depicted with extent of beds projected 10 degrees from surface outcrop. See figure 42 for section line, location of wells, and mapped extent of beds (coded L5-L9, B6-B8). Elevated natural-gamma bed shown is the shallowest marker bed on figure 43. Wells are identified by local well number (prefix MG- omitted) and well name.

Aquifer Tests

Hydraulic conductivity and storage are properties of aquifers that may vary spatially because of geologic heterogeneity. Estimation of these properties allows quantitative prediction of the hydraulic response of the aquifer to recharge and pumping. Storage coefficients are important for understanding hydraulic response to transient stresses on aquifers. These properties can be estimated on a local scale by analysis of data from single-well or multiple-well aquifer tests or on a regional scale by a numerical simulation of ground-water flow using a computer-based model. The local scale typically ranges from tens to hundreds of feet. The regional scale is characterized by lengths of thousands of feet or more. Transmissivity, the hydraulic conductivity multiplied by the saturated thickness of the aquifer, represents a vertical average of hydraulic conductivities that may vary with depth. Many of the analytical techniques used to estimate the hydraulic properties of aquifers were developed for porous media, such as unconsolidated sediments. These techniques may provide reasonable estimates of hydraulic properties in fractured rocks when the hydraulic response of the fractured-rock aquifers approximates porous media at the scale of interest.

In a review of aquifer-test data collected prior to this study (pre-1995), Goode and Senior (1998) summarized the range of estimated transmissivity and storage coefficients. Estimates of transmissivity ranged from 0 to about 5,400 ft^2/d; estimates from most tests ranged from 108 to 1,080 ft^2/d. Estimates of storage coefficients ranged from 0.00001 to 0.26; most estimates ranged from 0.0001 to 0.007.

As part of this study, two types of aquifer tests were conducted by the USGS and others in the vicinity of North Penn Area 7 from March 2004 to August 2005. Single-well, aquifer-interval-isolation tests were done by USGS in 17 boreholes and 1 multiple-well test (single pumping well and multiple observation wells) was done by the USGS in cooperation with the NPWA. During phase 1 from September 2001 to May 2002, single-well, aquifer-interval-isolation tests were done by the USGS in eight boreholes and one multiple-well test was conducted.

Single-Well, Aquifer-Interval-Isolation Tests

Water enters open-hole wells through discrete openings, or zones, in fractured-rock aquifers. Because most ground-water flow and contaminant movement at the site are through distinct water-bearing zones comprised of one or more fracture(s), the hydraulic and chemical characteristics of each water-bearing zone can differ. By isolating these discrete zones with inflatable packers, hydraulic properties of individual zones and the extent of vertical hydraulic connection between zones can be determined. This determination provides data on the vertical distribution of hydraulic properties.

The USGS performed a total of 122 single-well, aquifer-interval-isolation tests in 17 wells (table 21). Many of the wells were near known sources of soil contamination with VOCs or were in areas where transport of contamination potentially affected ground water. The objectives of the single-well, interval-isolation tests were to (1) provide information on hydraulic heads and specific capacities of discrete vertical intervals and the hydraulic connection between intervals, and (2) provide water samples from discrete water-bearing zones to allow the USEPA to characterize the vertical extent of contamination in each well.

Inflatable packers were set to isolate selected water-bearing (producing or receiving) zones. The number and depths of intervals to be tested in each open-hole well were based on an analysis of the borehole geophysical logs. The likelihood of obtaining a seal by the packers was considered in the selection of intervals. The spacing between packers, calculated from midpoints of the 5-ft inflatable bladders in the straddle packer assembly, commonly was about 20 ft but ranged up to 31 ft (table 21). The seal of the packer against the borehole wall is critical for isolating the interval and can be affected by roughness or changes in borehole diameter related to presence of fractures, lithology, or drilling methods.

A set of straddle packers was used to isolate three intervals and a single packer was used to isolate two intervals in the open-hole wells. Two types of packers were utilized depending on borehole diameter. Tests of boreholes smaller than 8 in. in diameter used a packer with a 2-ft rubber bladder that, when inflated, sealed off approximately 1 ft of the borehole between two intervals. Tests of boreholes with diameters of 8 in. or larger used a packer with a 5.9-ft rubber bladder that, when inflated, sealed off approximately 4 ft of the borehole between two intervals. The actual length of borehole wall sealed by any packer is largely dependant on actual borehole diameter, borehole condition, and inflation pressure. Water levels in each isolated zone were measured before and after packer inflation using electric tapes. The reference measuring point for water levels and all logged depths was land surface. Water levels were measured continuously in all zones by pressure transducers before, during, and after pumping. Pumping duration and rate were dependent on aquifer properties. Pumping duration was as short as 4 minutes in a very tight zone (low permeability) but was typically 1 to 2 hours in each zone tested. Attempts were made to maintain constant pumping rates for each test. Pumping rates commonly were 1 to 2 gal/min and ranged from about 0.25 to 12.4 gal/min for all intervals tested. Pumping duration partly was determined by the estimated time to evacuate at least three volumes of water from the isolated interval.

Evaluation of the packer seal and hydraulic connections between isolated intervals followed packer inflation. Head separation (difference in water levels) after packer inflation indicates little or no hydraulic connection between isolated intervals and the presence of vertical gradients. Conversely, little or no head separation after packer inflation indicates a hydraulic connection between isolated intervals that may be caused by an incomplete packer seal or hydraulic connection through fractures outside the borehole. Examples of

Table 21. List of wells tested using aquifer-interval-isolation methods and resulting estimated transmissivities in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 2004 through August 2005.

U.S. Geological Survey local well number	Owner well name	Depth of well, in feet	Number of isolated intervals tested	Spacing between packer mid-points, in feet	Transmissivity, in feet squared per day		
					Minimum of any interval	Maximum of any interval	Total for all intervals
MG-151	Ford #5	477	8	20	1.20	721	1,100
MG-1920	Ford MW-1	125	3	20	3.51	44.5	47.0
MG-2080	RI-1D	299	6	20	32.4	265	707
MG-2081	RI-2D	300	8	28	78.0	1,130	2,690
MG-2084	RI-3D	300	10	20	5.82	886	1,780
MG-2087	RI-4D	300	7	23	3.75	1,500	3,090
MG-2090	RI-5D	300	9	20	8.85	1,010	1,900
MG-2093	RI-6D	300	9	22	3.93	893	1,520
MG-2095	RI-7D	246	6	26	136	856	2,590
MG-2097	RI-8D	300	9	23	48.4	1,210	4,510
MG-2100	RI-9D	286	8	26	4.60	1,120	3,520
MG-2119	RI-10D	289	7	25	3.80	1,430	3,310
MG-2122	RI-11D	299	6	31	32.9	178	600
MG-2125	RI-12D	300	8	20	2.84	283	515
MG-2126	RI-13D	279	7	20	23.6	2,290	6,080
MG-2129	RI-14D	299	4	24	3.61	399	761
MG-2131	RI-15DD	299	7	22	6.29	364	1,120

water-level response after packer inflation showing different magnitudes of head separation are shown in figures 46 and 47. Pumping was started when water levels stabilized after packer inflation. The extent of hydraulic connection between isolated intervals is indicated by the extent of head separation and response to pumping in the various isolated intervals. A noted response to pumping stress in an adjacent interval generally indicates a hydraulic connection between isolated intervals, and no response to pumping stress in adjacent zones indicates low, or no, hydraulic connection between isolated intervals. Examples of water-level responses in isolated pumped interval and adjacent intervals also are shown in figures 46 and 47.

The tests of most isolated intervals were characterized by head separation after packer inflation and little to no response in adjacent intervals to pumping in the isolated interval. Head separations after packer inflation commonly ranged from 0.5 to 4 ft but were as high as 19.34 ft; the largest separations were observed in wells MG-2081 (RI-2D), MG-2093 (RI-6D), and MG-2100 (RI-9D). Water-level responses above, below, and in the isolated pumped interval for all tested intervals are shown for each well in appendix 3 (figs. 3-1 to 3-64). Where responses were observed in adjacent intervals, the apparent hydraulic connection of that effect on calculated specific capacity and transmissivity values is noted in the discussion of the tests of the well. Water-level responses above and below the pumped isolated interval were absent or negligible in about 90 percent of the isolated-interval tests.

Specific capacities and estimated transmissivity for each isolated zone were calculated. These results are compared to additional data, where available, on specific capacities of the open-hole wells determined from pumping rates and drawdowns during pumping for heatpulse flowmeter logs. The estimated transmissivity (T) was calculated using the Thiem equation (Bear, 1979), assuming steady-state conditions, as follows:

$$T = \frac{Q}{2\pi\Delta h}\ln\frac{r_o}{r_w} \qquad (1)$$

where

Q is pumping rate,
Δh is change in head,
r_o is radius of influence of pumping, and
r_w is radius of well.

For analysis of data from single-well, interval-isolation tests in the 17 wells, r_o was assumed to equal 328 ft (100 m). This method of estimating transmissivity is similar to that used by Shapiro and Hsieh (1998) for short-term, low-injection-rate, single-well, interval-isolation tests in low-permeability fractured rocks. For the tests by Shapiro and Hsieh (1998), r_o was assumed to equal 9.8 ft (3 m). The rate and duration of pumping of tests for the present study were greater than in the tests by Shapiro and Hsieh (1998), and it is reasonable to

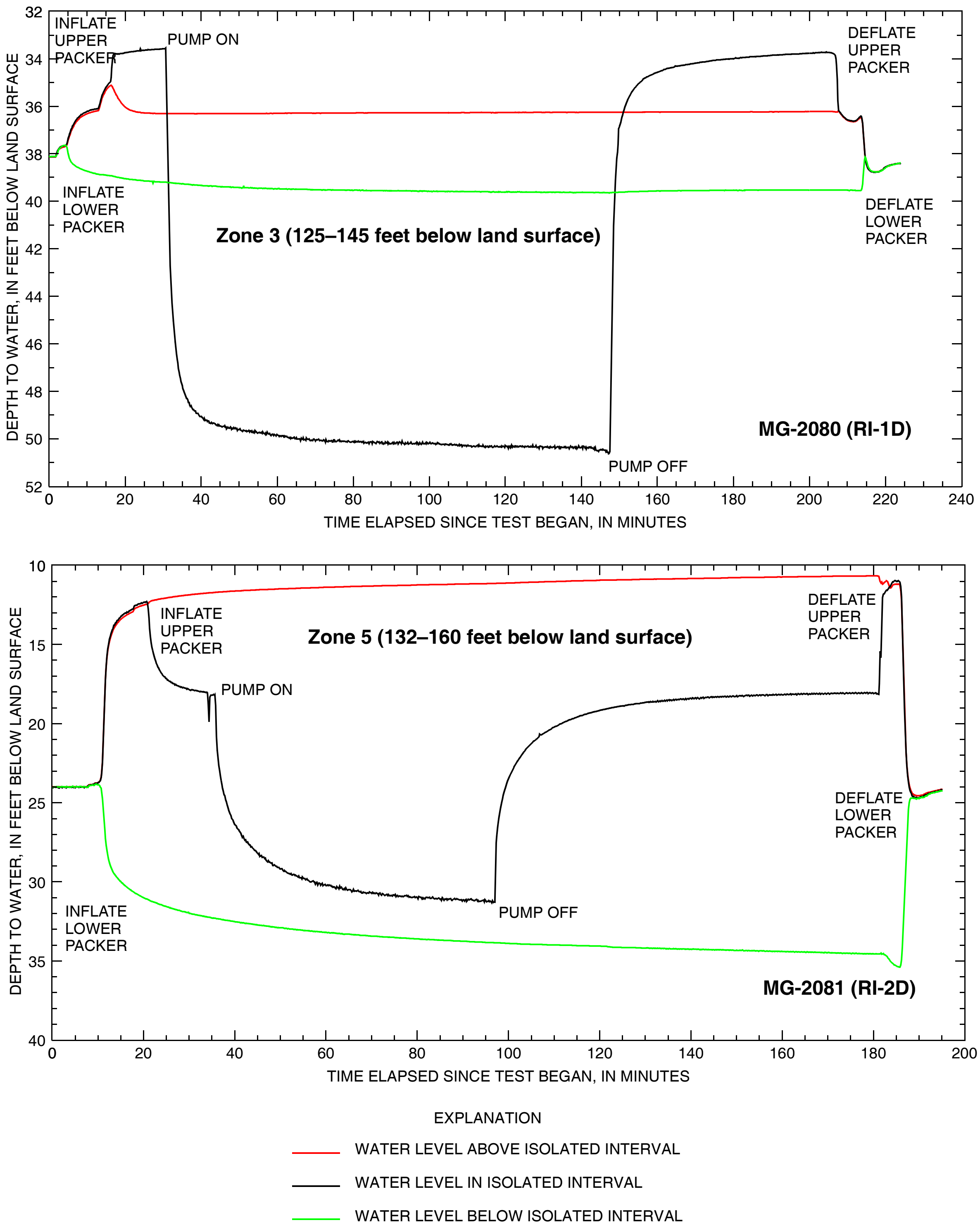


Figure 46. Water-level response in isolated and adjacent intervals after packer inflation showing head separation, indicating presence of vertical gradients in the borehole, and through pumping test when drawdown is measured only in the isolated pumped interval, indicating lack of hydraulic connection between the isolated intervals in tests of two zones. Head separation in zone 5 of well MG-2081 (RI-2D) (bottom) is among the largest observed, whereas head separation of zone 3 of well MG-2080 (RI-1D) (top) is more typical in the vicinity of North Penn Area 7, Montgomery County, Pa.

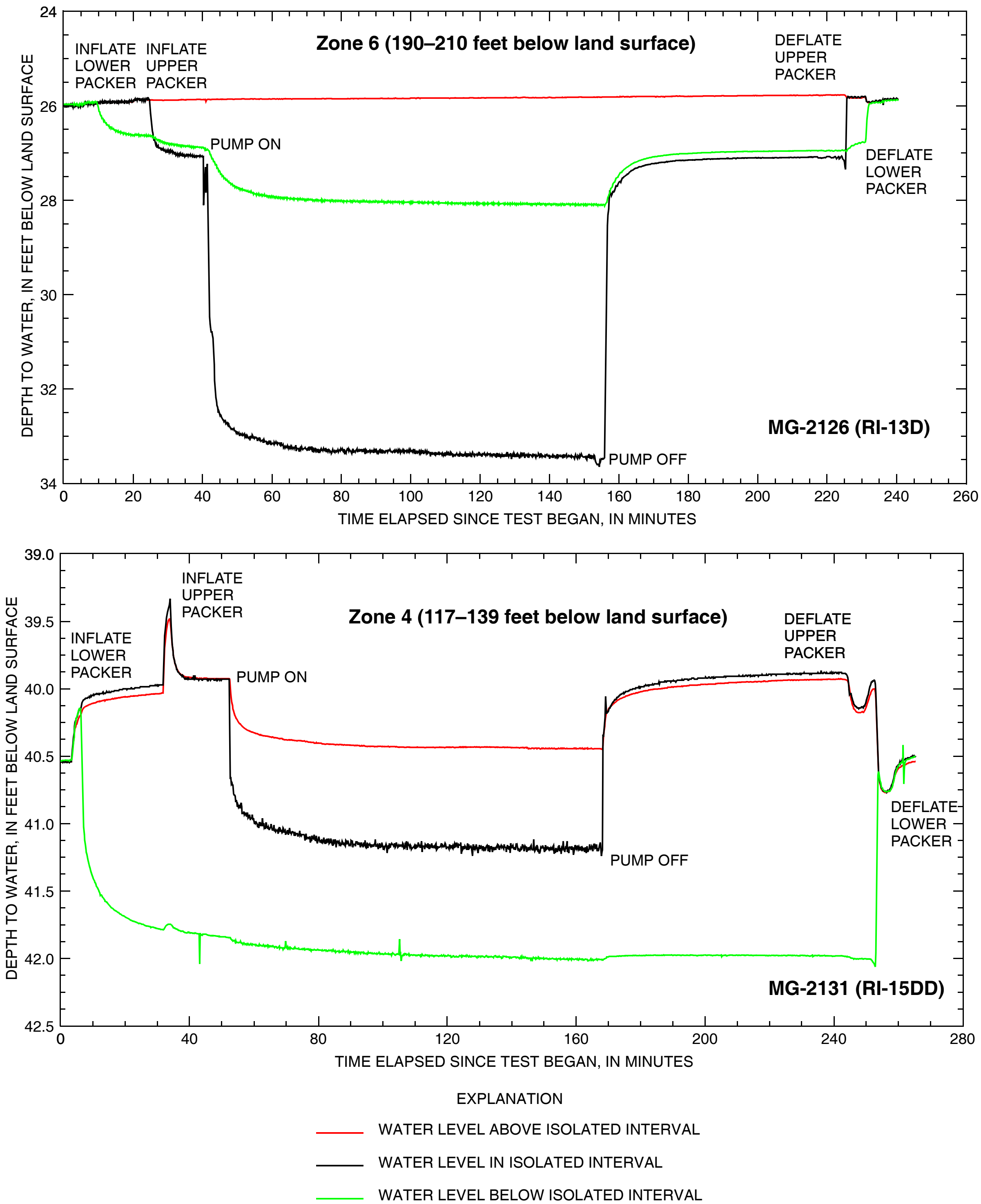


Figure 47. Water-level response in isolated and adjacent intervals after packer inflation showing little to no head separation between the isolated interval and one adjacent interval, indicating small or absent vertical gradients between those zones in the borehole, and during pumping when drawdown is measured in the isolated pumped interval and, to a lesser extent, in one adjacent interval, indicating hydraulic connection between the intervals in tests of the zones. Lack of head separation and strong hydraulic connections between isolated zones were not common in tests of wells in the vicinity of North Penn Area 7, Montgomery County, Pa.

assume that r_o would be greater than 9.8 ft (3 m). Although the radius of influence is unknown, it likely to range between these two distances (about 10 to 300 ft or 3 to 100 m). In addition, the effect of the magnitude of r_o on estimated T is relatively small and should be considered part of the uncertainty of the estimate. Using the r_o of 328 ft (100 m) would result in an estimated T that is about twice that estimated using 9.8 ft (3 m).

The chemical and physical properties of borehole discharge were measured at various times by the USGS during pumping using temperature-compensated pH and specific-conductance meters. After physical and chemical properties stabilized or after three test-interval volumes of borehole water were pumped, water samples were collected for field measurement of pH, specific conductance, temperature, alkalinity, and concentrations of dissolved oxygen and selected inorganic constituents. Samples for VOC analysis were collected by the USGS and forwarded to the USEPA contractor, CDM, for analysis. The pH and specific conductance were measured by USGS using standard methods (U.S. Geological Survey, variously dated). Concentration of dissolved oxygen was measured with a probe and verified in the field by chemical analysis [azide modification of the Winkler titration method (American Public Health Association and others, 1976)] of a sample. Alkalinity was determined using methods outlined in Wood (1976) and USGS (variously dated). Concentrations of sulfide, ferrous and total iron, and sulfate were measured in the field by spectrometric methods (HACH Company, 1997) and should be considered estimates only.

MG-151 (Ford # 5)

Eight intervals (table 22) in the 477-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Geophysical logging indicated numerous water-bearing zones, and under non-pumping conditions, the heatpulse-flowmeter measurements identified the fracture zone at 137–140 ft bls as the most productive.

Results of the packer tests (table 22; fig. 48) confirm observations from the geophysical logging. The fractures at 137–140 ft bls are the most productive (calculated transmissivity of more than 720 ft^2/d). Also, the distribution of hydraulic heads (static water levels in isolated intervals) agrees with previously measured borehole flow where water entered the borehole through fractures at 137–140, 301, and 360–364 ft bls, moved upward and downward, and exited the borehole through fractures at 87–99, 301–307, and 371 ft bls. Water levels in the deepest isolated interval (zone 8, below 274 ft bls) were about 12 ft lower than the intervals above (zones 1-7, table 22; fig. 48), indicating a strong downward vertical gradient in that part of the borehole.

The inorganic chemical constituents and properties showed little difference among water samples from the isolated intervals, although the shallower-interval samples had slightly higher specific conductance and concentration of alkalinity than deeper-interval samples (table 23). No water samples were collected in zones 6 and 7 because of very low yield. PCE and toluene were the main VOCs detected and only in samples from the four shallowest intervals tested. The highest concentrations of PCE (12 to 15 µg/L) were in water from intervals 148 to 191.5 ft bls (zones 4 and 5) (table 24).

Table 22 Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 30-April 2, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Drawdown (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Transmissivity (ft^2/d)
Zone 1 (82–102 ft bls) tested March 30, 2004										
above 82	25.62	24.84	335.89	0.78	25.14	0.30				
82–102 (pumped)	25.61	26.93	333.80	-1.32	29.56	2.63	1.28	130	0.487	106
below 102	25.62	25.39	335.34	.23	25.46	.07				
Zone 2 (102–122 ft bls) tested March 31, 2004										
above 102	25.09	26.64	334.09	-1.55	27.29	.65				
102–122 (pumped)	25.08	25.99	334.74	-.91	32.83	6.84	2	90	.292	63.4
below 122	25.09	24.76	335.97	.33	24.83	.07				
Zone 3 (124–144 ft bls) tested March 31, 2004										
above 124	25.03	26.35	334.38	-1.32	26.75	.40				
124–144 (pumped)	25.04	23.90	336.83	1.14	24.55	.65	2.16	82	3.323	721
below 144	25.04	29.63	331.10	-4.59	29.91	.28				
Zone 4 (148–168 ft bls) tested April 1, 2004										
above 148	24.83	24.21	336.52	.62	24.39	.18				
148–168 (pumped)	24.81	23.81	336.92	1.00	30.13	6.32	1.97	94	.312	67.6
below 168	24.81	24.09	336.64	.72	24.19	.10				
Zone 5 (171.5–191.5 ft bls) tested April 1, 2004										
above 171.5	24.83	24.03	336.70	.80	24.17	.14				
171.5–191.5 (pumped)	24.85	23.68	337.05	1.17	72.70	49.02	1.26	125	.026	5.58
below 191.5	24.81	24.02	336.71	.79	24.10	.08				
Zone 6 (202–222 ft bls) tested April 1, 2004										
above 202	25.22	24.35	336.38	.87	24.17	.08				
202–222 (pumped)	25.25	23.49	337.24	1.76	131.77	108.28	.6	30	.006	1.20
below 222	25.20	37.82	322.91	-12.62	37.57	.25				
Zone 7 (222–242 ft bls) tested April 2, 2004										
above 222	25.17	24.33	336.40	.84	24.34	.01				
222–242 (pumped)	25.27	22.88	337.85	2.39	129.50	106.62	.71	17	.007	1.44
below 242	25.21	36.90	323.83	-11.69	37.61	.71				
Zone 8 (273.8–477 ft bls) tested April 2, 2004										
above 273.8	24.69	24.06	336.67	.63	24.02	-.04				
273.8–477 (pumped)	24.66	36.24	324.49	-11.58	50.16	13.92	2.97	66	.213	46.3

[1]Land-surface altitude surveyed near well head was about 369 feet above North American Vertical Datum of 1988 (NAVD 88) at time of packer test.

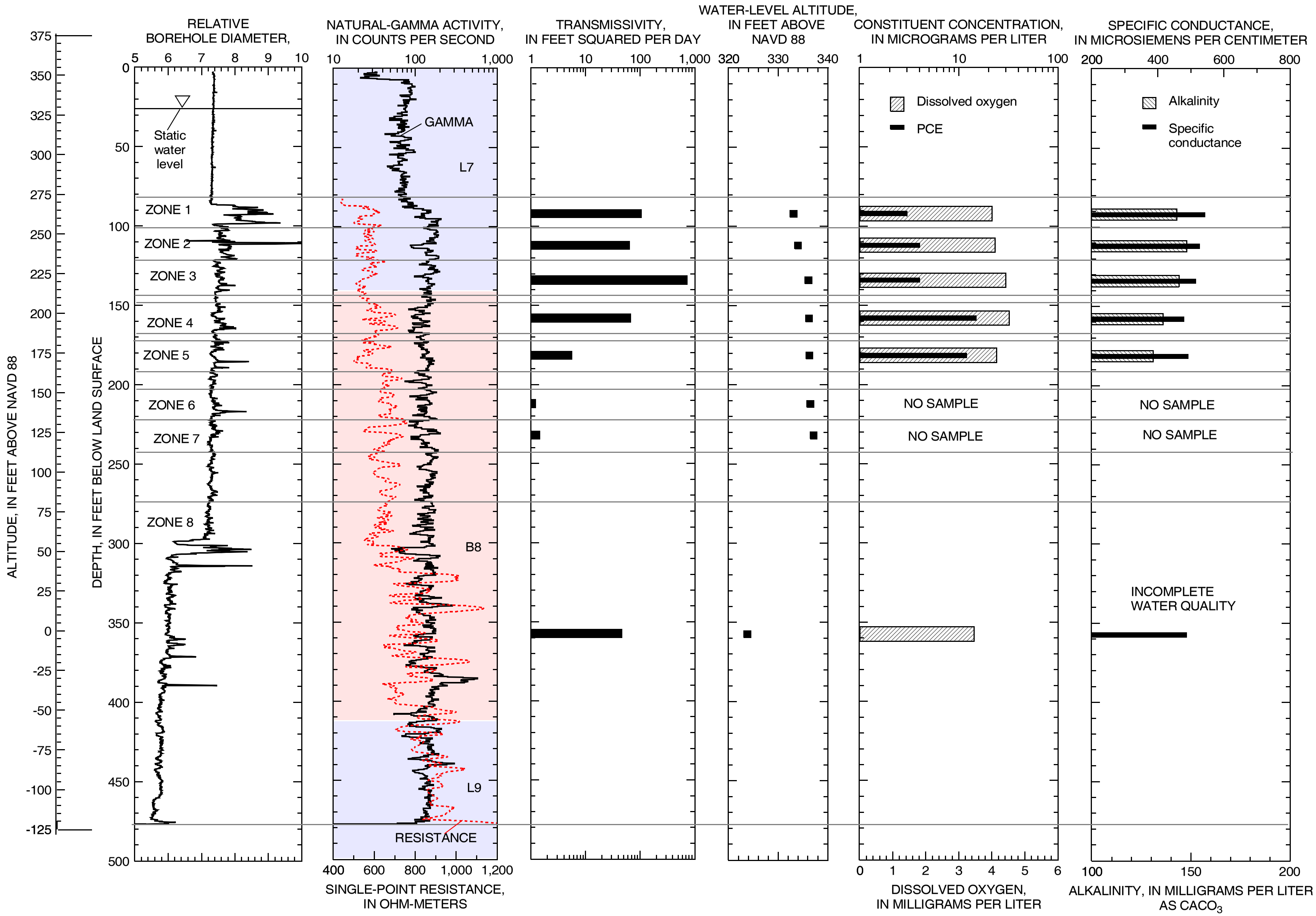


Figure 48. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-151 (Ford #5), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 30-April 2, 2004.

Table 23. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-151 (Ford #5), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 30-April 2, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	82–102	3/30/04	15:19	11.82	7.49	4.01	542	143	0.001	0.02	0.21	28	1.8
2	102–122	3/31/04	10:30	13.32	7.50	4.10	526	148	<.001	.01	.09	25	1.6
3	124–144	3/31/04	14:20	13.47	7.51	4.43	515	144	.002	.01	.09	26	2.0
4	148–168	4/1/04	11:30	13.24	7.59	4.53	478	136	<.001	.01	.14	28	1.9
5	171.5–191.5	4/1/04	17:15	13.54	7.63	4.15	491	131	<.001	.01	.21	25	1.9
6	202–222	4/1/04	no sample										
7	222–242	4/2/04	no sample										
8	273.8–477	4/2/04	11:24	12.96	7.60	3.46	487	no sample					

Table 24. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-151 (Ford #5), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 30-April 1, 2004.

[ft bls, feet below land surface; PCE, tetrachloroethylene; µg/L, micrograms per liter; nd, not detected; J, analyte present but reported value may not be accurate or precise; dup, duplicate sample]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	PCE (µg/L)	Toluene (µg/L)
1	82–102	3/30/2004	15:19	3J	9J
2	102–122	3/31/2004	10:30	4J	4J
3	124–144	3/31/2004	14:20	4J	3J
4	148–168	4/1/2004	11:30	15	nd
5	171.5–191.5	4/1/2004	17:15	12	5J
6	202–222	no sample			
7	222–242	no sample			
8	273.8–477	no sample			

MG-1920 (Ford MW-1)

Three intervals (table 25) in the 125-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the mid-points of the straddle packers was 20 ft. Geophysical logging indicated several probable water-bearing zones from 50 to 123 ft bls, and under non-pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zone at 81–84 ft bls as the most productive.

Results of the packer tests (table 25; fig. 49) confirm only some observations from the geophysical logging. In the packer tests, the fractures in the interval 69–85 ft bls are the most productive. Transmissivities for zone 1 (above 98 ft bls) and zone 2 (69–98 ft bls) were nearly identical. However, the distribution of hydraulic heads (static water levels in isolated intervals) does not agree with previously measured borehole flow where water entered the borehole through fractures at 50–55 and 123 ft bls, moved downward and upward, and exited the borehole through a series of vertical fractures seen on the camera log at 81–84 ft bls, perhaps because of changes in nearby pumping or other external hydraulic conditions. Water levels in the isolated intervals were nearly identical to those in adjacent intervals, differing by only up to 0.3 ft (table 25; fig. 49), indicating little to no vertical gradient in the 125-ft borehole. Drawdown was observed in the interval above and below zone 2, indicating hydraulic connection between isolated and adjacent intervals, which is consistent with the lack of vertical gradients observed.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals; the deepest interval tested (zone 3, below 98 ft bls) had the lowest concentrations of dissolved oxygen, nitrate, and sulfate (table 26). The presence of ferrous iron in concentrations greater than 1 mg/L and the low concentrations of dissolved oxygen in water from all zones tested indicates reducing conditions. TCE and its breakdown product *cis*-1,2-DCE, toluene, and freon-113 (1,1,2-trichloro-1,2,2-trifluoroethane) were the VOCs detected in the highest concentrations, with maximum concentrations of 33, 14, 28, and 18 µg/L, respectively (table 27). Other VOCs detected at lower concentrations included 1,1-DCE, 1,1-DCA, 1,1,1-TCA, and freon-11 (trichlorofluromethane). Concentrations of VOCs were similar in water from all zones tested (table 27).

Table 25 Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 21-22, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallon per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 98 ft bls) tested April 22, 2004										
above 98 (pumped)	40.51	40.39	332.55	0.12	55.85	15.46	3.0	99	0.194	43.6
below 98	40.46	40.39	332.55	.07	52.84	12.45				
below 98	40.48	40.38	332.56	.10	48.21	7.83				
Zone 2 (69–89 ft bls) tested April 22, 2004										
above 69	40.29	40.07	332.87	.22	47.83	7.76				
69–89 (pumped)	40.28	40.07	332.87	.21	49.51	9.44	1.87	63	.198	44.5
below 89	40.28	40.06	332.88	.22	48.54	8.48				
Zone 3 (below 98 ft bls) tested April 21, 2004										
above 98	40.12	40.12	332.82	.00	40.21	.09				
below 98 (pumped)	40.10	40.12	332.82	-.02	72.1	31.98	.5	312	.016	3.51

[1]Land-surface altitude surveyed near well head was 372.94 feet above North American Vertical Datum of 1988 (NAVD 88).

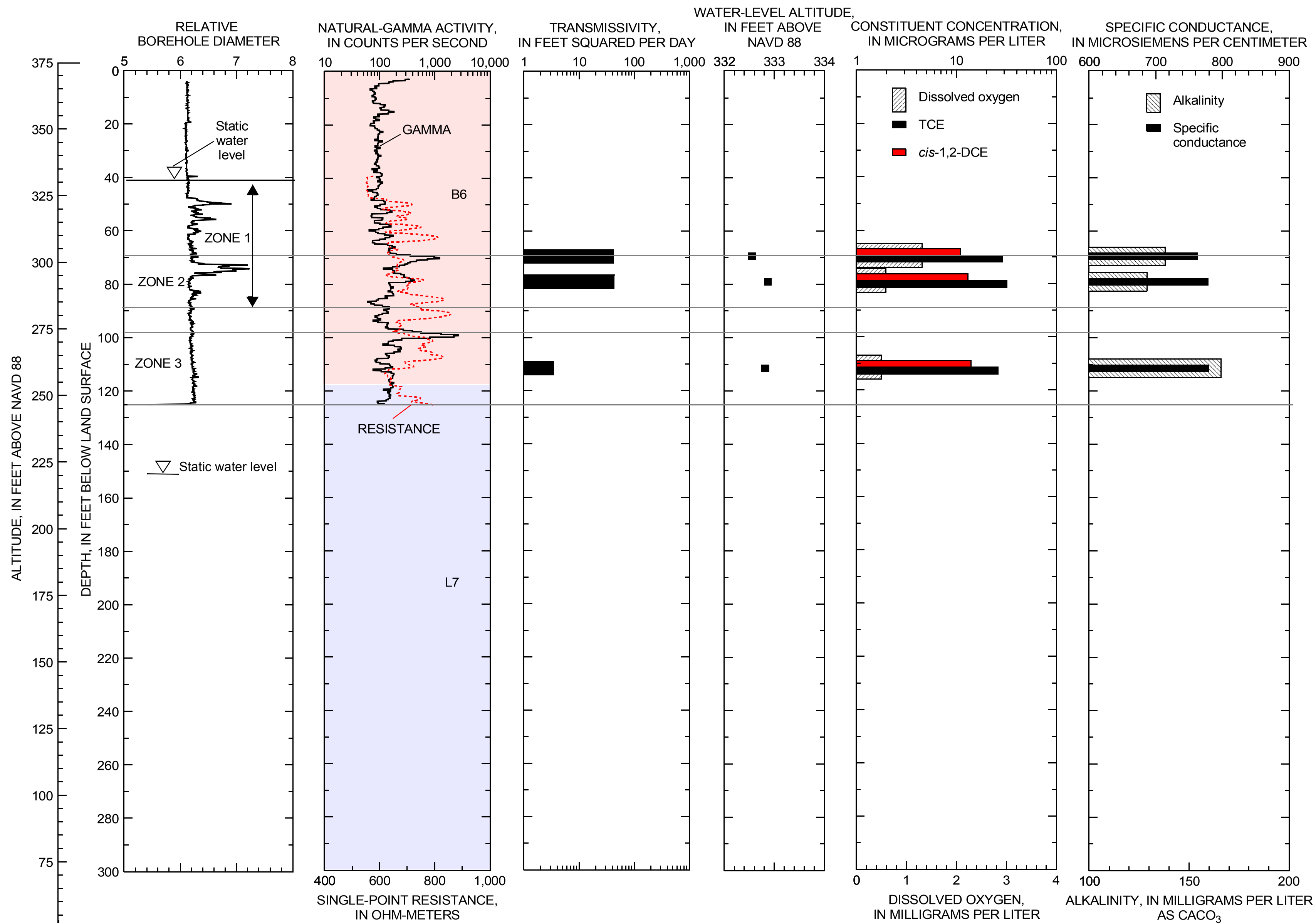


Figure 49. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 21-22, 2004.

Table 26 Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 21-22, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; > greater than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 98	4/22/2004	16:50	16.64	6.44	1.31	762	138	0.013	0.77	2.12	>range	1.4
2	69–89	4/22/2004	13:28	18.54	6.35	.59	778	129	.029	2.07	>range	>range	1.6
3	below 98	4/21/2004	17:03	17.81	6.56	.49	779	166	.001	1.26	1.87	>70	.3

Table 27 Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 21-22, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; freon-11, trichlorofluromethane; 1,1-DCE. 1,1-dichloroethylene; 1,1-DCA, dichloroethane; 1,1,1-TCA, 1,1,1-trichloroethane; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; dup, duplicate sample; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Toluene (µg/L)	Freon-113 (µg/L)	Freon-11 (µg/L)	1,1-DCE (µg/L)	1,1-DCA (µg/L)	1,1,1-TCA (µg/L)	Acetone (µg/L)
1	above 98	4/22/2004	16:50	11	29	12	14	3J	6J	4J	4J	
2	69–89	4/22/2004	13:27	13	32	27	16	3J	7J	5J	4J	3J
2 dup	69–89	4/22/2004	10:10	14	33	28	18	4J	8J	5J	4J	
3	below 98	4/21/2004	17:03	14	26	10	9J		8J	5J	3J	

MG-2080 (RI-1D)

Six intervals (table 28) in the 299-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Geophysical logging indicated probable water-bearing zones from 62 to 285 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zone at 76–79 ft bls as the most productive.

Results of the packer tests (table 28; fig. 50) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 145–165 and 242–262 ft bls are the most productive, having transmissivity values (265 and 239 ft^2/d, respectively) almost four times greater than the value for the interval 76–79 ft bls identified by geophysical logging as the most productive. The distribution of hydraulic heads (static water levels in isolated intervals) generally agrees with previously measured borehole flow where water entered the borehole through fractures at 62–65, 76–79, and 130–142 ft bls, moved downward, and exited the borehole through fractures at 150 and 246–256 ft bls. In the packer tests, the highest hydraulic head was measured in the isolated interval 125–145 ft bls (zone 3, table 28). Water levels in the isolated intervals were up to 6 ft different than those in adjacent intervals (table 28; fig. 50), indicating an overall downward vertical gradient, except near the bottom where the gradient is up.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Water samples from the deeper intervals tested (zones 3-6, all deeper than 125 ft bls) have the lowest concentrations of dissolved oxygen (less than 1 mg/L) and specific conductance (table 29). Toluene and freon-113 were the only VOCs detected; the highest concentrations were in water from the shallowest interval (zone 1, above 70 ft bls) (table 30).

Table 28. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 1-7, 2005.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 70 ft bls) tested June 1, 2005										
above 70 (pumped)	38.01	36.50	336.15	1.51	42.19	5.69	1.64	158	0.288	62.5
below 70	38.01	38.20	334.45	-.19	38.35	.15				
below 70	38.01	38.17	334.48	-.16	38.42	.25				
Zone 2 (70–90 ft bls) tested June 2, 2005										
above 70	38.30	36.35	336.30	1.95	36.89	.54				
70–90 (pumped)	38.32	36.35	336.30	1.97	44.22	7.87	2.56	69	.325	70.6
below 90	38.29	38.81	333.84	-.52	38.94	.13				
Zone 3 (125–145 ft bls) tested June 2, 2005										
above 125	38.13	36.30	336.35	1.83	36.25	-.05				
125–145 (pumped)	38.13	33.56	339.09	4.57	50.51	16.95	2.53	130	.149	32.4
below 145	38.11	39.20	333.45	-1.09	39.64	.44				
Zone 4 (145–165 ft bls) tested June 3, 2005										
above 145	38.16	36.06	336.59	2.10	36.04	-.02				
145–165 (pumped)	38.15	39.57	333.08	-1.42	42.87	3.30	4.03	37	1.221	265
below 103	38.14	38.67	333.98	-.53	39.17	.50				
Zone 4A (145–165 ft bls) tested June 3, 2005										
above 145	38.68	36.11	336.54	2.57	36.10	-.01				
145–165 (pumped)	38.69	39.90	332.75	-1.21	43.30	3.40	4.03	30	1.185	257
below 103	38.68	39.07	333.58	-.39	39.41	.34				
Zone 5 (242–262 ft bls) tested June 3, 2005										
above 242	38.10	37.89	334.76	.21	39.04	.41				
242–262 (pumped)	38.12	38.96	333.69	-.84	41.03	2.07	2.28	126	1.101	239
below 262	38.10	37.96	334.69	.14	39.05	1.09				
Zone 6 (270–300 ft bls) tested June 7, 2005										
above 270	38.22	38.22	334.43	.00	38.56	.34				
below 270 (pumped)	38.23	37.95	334.70	.28	49.04	11.09	1.90	179	.171	37.2

[1]Land-surface altitude surveyed near well head was 372.65 feet above North American Vertical Datum of 1988 (NAVD 88).

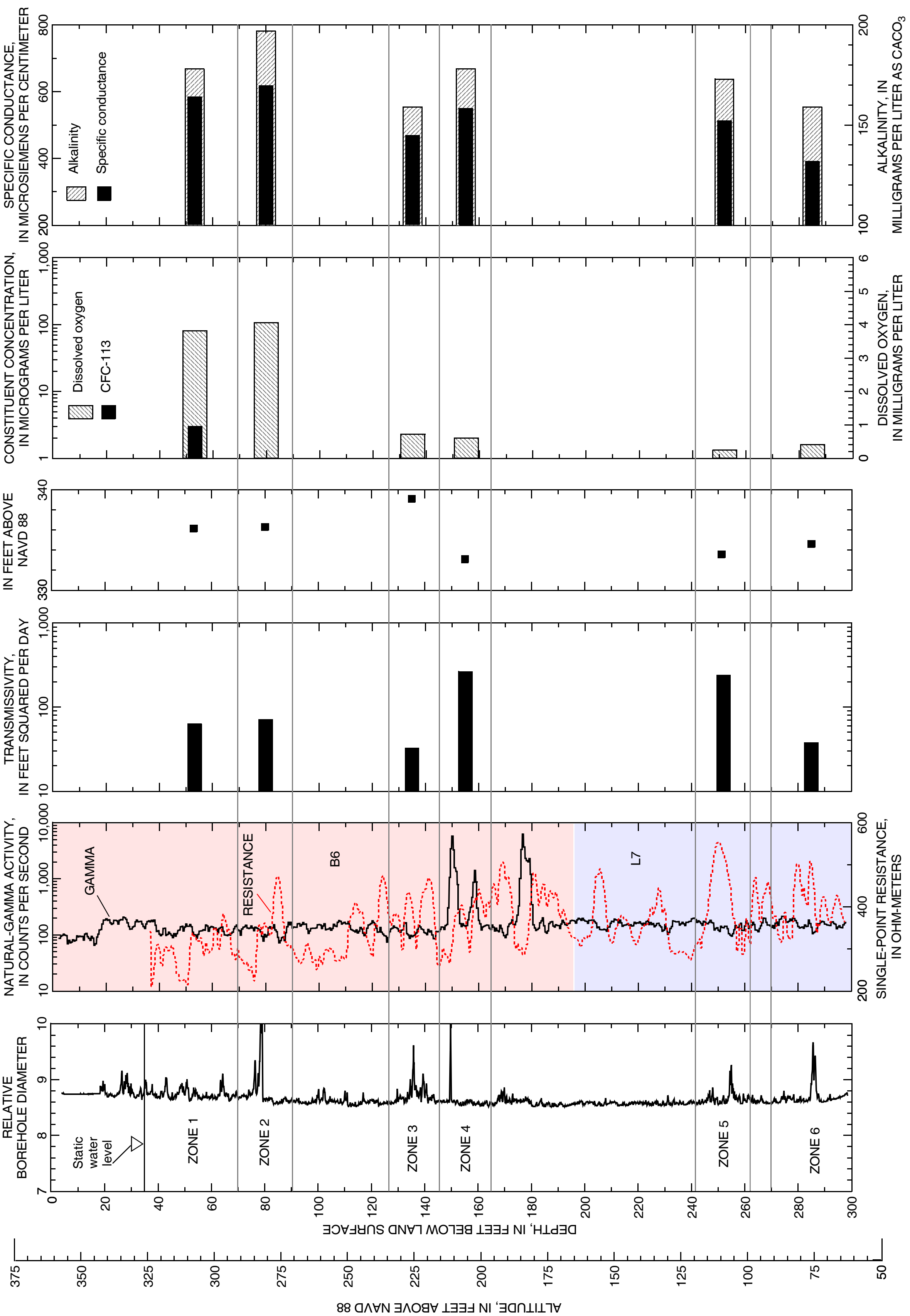


Figure 50. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 1-7, 2005.

Table 29 Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2080 (RI-1D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June1-7, 2005.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; --, no data]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temp-erature (°C)	pH	Dis-solved oxygen (mg/L)	Specific conduc-tance (µS/cm)	Alka-linity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 70	6/1/2005	18:00	17.0	7.52	3.82	584	178	0.032	0.05	0.11	--	1.1
2	70–90	6/2/2005	12:15	15.9	7.52	4.07	618	197	.010	.06	.12	43	1.6
3	125–145	6/2/2005	16:50	15.4	7.82	.72	468	159	.035	.04	.08	43	1.3
4	145–165	6/3/2005	11:17	14.9	7.61	.60	549	178	.016	.01	.11	43	1.9
5	242–262	6/3/2005	17:42	14.7	7.70	.24	512	173	.005	.01	.25	38	2.0
6	below 270	6/7/2005	8:50	17.9	7.85	.41	391	159	.003	.09	.28	24	.1

Table 30 Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2080 (RI-1D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 1-7, 2005.

[ft bls, feet below land surface; µg/L, micrograms per liter; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected]

Zone	Depth of iso-lated interval (ft bls)	Date of sample	Time of sample	Toluene (µg/L)	Freon-113 (µg/L)
1	above 70	6/1/2005	18:00	18	3J
2	70–90	6/2/2005	12:15	1J	
3	125–145	6/2/2005	16:50		
4	145–165	6/3/2005	11:17	1J	
5	242–262	6/3/2005	17:42	4J	
6	below 270	6/7/2005	8:50		

MG-2081 (RI-2D)

Eight intervals (table 31) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 28 ft. Geophysical logging indicated probable water-bearing zones in the intervals between 19 and 294 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones at 19–28 and 170–186 ft bls as the most productive.

Results of the packer tests (table 31; fig. 51) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 19–28 and 170–186 ft bls are the most productive; zone 1 (above 38 ft bls) and zone 4 (160–188 ft bls) had the largest transmissivity values (1,128 and 458 ft^2/d, respectively) of zones tested in the borehole. The intervals tested in zone 2 (38–66 ft bls) and zone 3 (47–75 ft bls) overlapped by about 9 ft and were open to different fractures (43–45 and 70 ft bls, respectively) and the same fractures (52–54 ft bls). The estimated transmissivities for these two zones were similar in magnitude, making it likely that the transmissivities of the different fractures (43–45 and 70 ft bls) are similar but difficult to quantify. Water levels in the isolated intervals were more than 20 ft different than those in adjacent intervals (table 31; fig. 51), indicating an overall downward vertical gradient in the 300-ft borehole and especially between zones 1-4 (above 103 ft bls) and zones 5-8 (below 132 ft bls). The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees only partially with previously measured borehole flow where in one set of measurements all flow was downward, but in another set, water entered the borehole through fractures at 19–28, 170–186, and 294 ft bls, moved downward and upward, and exited the borehole at 43–45 ft bls. Variable nearby pumping conditions are thought to affect gradients in well MG-2080 (RI-2D).

The inorganic chemical constituents and properties showed few differences among water samples from the isolated intervals. Concentrations of dissolved oxygen generally decreased with depth of isolated interval. Except for the sample from zone 7 that had a questionable value of dissolved oxygen, water from the shallowest interval tested (zones 1, above 38 ft bls) had the highest concentration of dissolved oxygen (1.1 mg/L) and lowest specific conductance and concentration of alkalinity and was thus the most oxygenated and dilute (table 32). Toluene and TCE at low concentrations were the only VOCs detected; TCE was detected at about 2 μg/L in water from only the deepest interval tested (zone 8, 257–300 ft bls) (table 33).

Table 31. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 15-20, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 38 ft bls) tested July 15, 2004										
above 38 (pumped)	28.97	12.35	316.95	16.62	13.36	1.01	5.25	63	5.198	1,128
below 38	28.95	32.76	296.54	-3.81	32.93	.17				
below 38	28.96	31.95	297.35	-2.99	31.95	.00				
Zone 2 (38–66 ft bls) tested July 16, 2004										
above 38	28.01	11.31	317.99	16.70	10.54	-.77				
38–66 (pumped)	28.03	11.23	318.07	16.80	15.68	4.45	4.47	59	1.004	218
below 66	28.02	30.42	298.88	-2.40	30.44	.02				
Zone 3 (47–75 ft bls) tested July 16, 2004										
above 47	28.78	11.10	318.20	17.68	10.38	-.72				
47–75 (pumped)	28.78	13.08	316.22	15.70	17.44	4.36	4.50	60	1.032	224
below 75	28.78	33.65	295.65	-4.87	34.18	.53				
Zone 4 (75–103 ft bls) tested July 16, 2004										
above 75	27.35	11.17	318.13	16.18	11.00	-.17				
75–103 (pumped)	27.34	12.83	316.47	14.51	18.33	5.50	5.03	46	.915	198
below 103	27.35	35.11	294.19	-7.76	35.53	.42				
Zone 5 (132–160 ft bls) tested July 19, 2004										
above 132	23.99	11.72	317.58	12.27	11.14	-.58				
132–160 (pumped)	24.03	18.20	311.10	5.83	31.28	13.08	4.70	62	.359	78
below 160	24.01	32.29	297.01	-8.28	33.85	1.56				
Zone 6 (160–188 ft bls) tested July 19, 2004										
above 160	23.53	11.58	317.72	11.95	10.85	-.73				
160–188 (pumped)	23.50	34.38	294.92	-10.88	36.63	2.25	4.75	76	2.111	458
below 188	23.50	33.27	296.03	-9.77	35.53	2.26				
Zone 7 (212–240 ft bls) tested July 20, 2004										
above 212	22.78	21.59	307.71	1.19	21.82	.23				
212–240 (pumped)	22.79	29.50	299.80	-6.71	33.58	4.08	4.65	79	1.140	247
below 240	22.80	33.71	295.59	-10.91	34.28	.57				
Zone 8 (257–300 ft bls) tested July 20, 2004										
above 257	22.87	22.31	306.99	.56	22.37	.06				
257–300 (pumped)	22.90	35.67	293.63	-12.77	42.75	7.08	4.56	105	.644	140

[1]Land-surface altitude surveyed near well head was 329.3 feet above North American Vertical Datum of 1988 (NAVD 88).

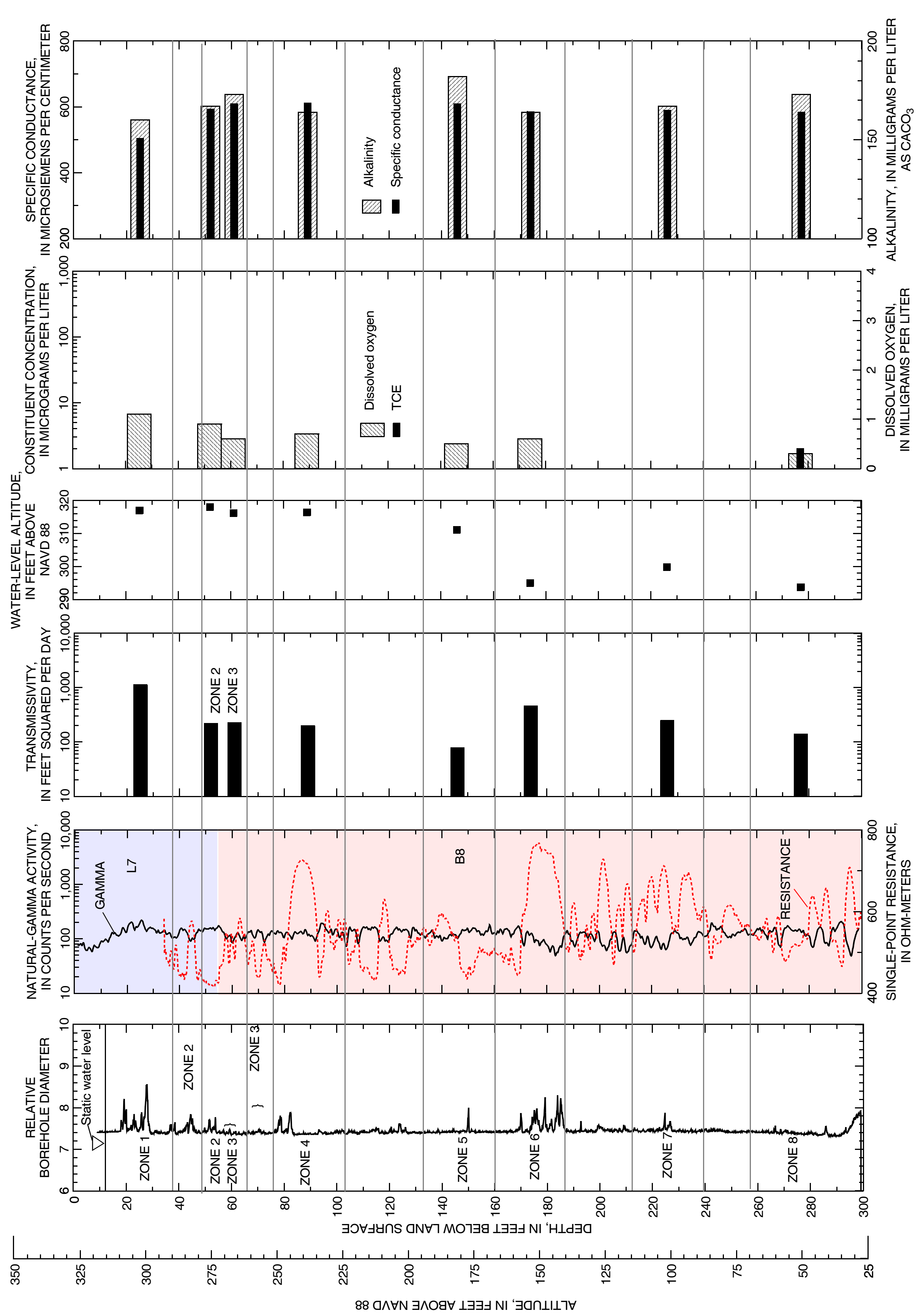


Figure 51. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 15-20, 2004.

Table 32. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2081 (RI-2D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 15-20, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; --, no data; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temp-erature (°C)	pH	Dis-solved oxygen (mg/L)	Specific conduc-tance (µS/cm)	Alka-linity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 38	7/15/2004	16:30	12.6	6.73	1.1	504	160	0.020	0.11	0.16	37	0.3
2	38–66	7/16/2004	10:35	13.0	7.10	.9	593	167	.025	.05	.07	41	1.0
3	47–75	7/16/2004	13:08	13.3	7.25	.6	609	173	.014	.01	.16	32	.9
4	75–103	7/16/2004	16:15	13.0	7.30	.7	611	164	--	.02	.06	32	.3
5	132–160	7/19/2004	11:29	13.1	7.45	.5	609	182	<.001	.01	.09	32	.3
6	160–188	7/19/2004	15:42	13.0	7.04	.6	585	164	.007	.10	.10	34	low
7	212–240	7/20/2004	11:00	13.4	7.03	[1]<1.8	590	167	.006	.01	.19	32	low
8	257–300	7/20/2004	14:50	14.4	7.13	.3	584	173	.008	.20	.26	28	low

[1]Sample appears to have been aerated as indicated by bubbles; dissolved oxygen value is questionable.

Table 33. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2081 (RI-2D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 15-20, 2004.

[ft bls, feet below land surface; TCE, trichloroethylene; TIC, tentatively identified compound; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	TCE (µg/L)	Toluene (µg/L)	unknown or TIC (µg/L)
1	above 38	7/15/2004	16:30		3J	
2	38–66	7/16/2004	10:35		2J	
3	47–75	7/16/2004	13:08		1J	
4	75–103	7/16/2004	16:15			
5	132–160	7/19/2004	11:29			
6	160–188	7/19/2004	15:42		1J	
7	212–240	7/20/2004	11:00			8J trimethylsilanol
8	257–300	7/20/2004	14:50	2J		

MG-2084 (RI-3D)

Ten intervals (table 34) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Because of limitations of packer configuration, two overlapping intervals below 260 ft bls (zones 9 and 10) were tested to allow inclusion of the borehole below 280 ft bls. Geophysical logging indicated numerous probable water-bearing zones from about 73 to 265 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fractures at or near 73–75, 109, and 123 ft bls as the most productive.

Results of the packer tests (table 34; fig. 52) confirm some observations from the geophysical logging. The packer tests indicated the most productive intervals were identified by geophysical logs as water-bearing zones but not necessarily as the most productive; zone 4 (115–135 ft bls), zone 5 (162–182 ft bls), and zone 6 (182–202 ft bls) had the largest transmissivity values (311, 340, and 385 ft^2/d, respectively) of zones tested in the borehole. Transmissivity for the interval from 280–300 ft bls, calculated by subtracting the transmissivity of zone 9 (260–280 ft bls) from that of zone 10 (260–300 ft bls), is low at 3.04 ft^2/d.

Water levels in the isolated intervals were up to about 5 ft different than those in adjacent intervals (table 34; fig. 52), indicating an overall slight downward vertical gradient in the upper part (above 182 ft bls) and an upward gradient in the lower part of the 300-ft borehole. The interval between 182–202 ft bls (zone 6) had the lowest hydraulic head. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees only partially with previously measured borehole flow where flow was downward in the upper part of borehole, upward in the lower part of borehole, and exited through fractures at 190–193 ft bls. Effects of nearby pumping are especially pronounced on water levels in packer tests of zone 4 (115–135 ft bls), zone 5 (162–182 ft bls), and zone 6 (182–202 ft bls) (see appendix 3, figs. 3-15 and 3-16). From geophysical-logging results, the observed flow patterns suggested the borehole may be interconnected through the fractures at 190–193 ft bls with nearby well(s) that is (are) pumped at variable rates. Interconnection with a pumping well is also suggested by the measured hydraulic head in intervals below 260 ft bls (zones 9 and 10) (table 34). MG-2084 (RI-3D) is near two active production wells at the Precision Tube facility.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Concentrations of dissolved oxygen and alkalinity and specific conductance of water samples decreased with depth (fig. 52, table 35). The shallowest interval (zone 1, above 60 ft bls) had very high specific conductance (925 µS/cm). PCE, TCE, *cis*-1,2-DCE, toluene, and freon-113 were the main VOCs detected; TCE was measured at the highest concentration of 190 µg/L in the shallowest interval tested (zone 1 above 60 ft bls) (table 36). *Cis*-1,2-DCE was only detected in water samples from the two shallowest intervals (zones 1 and 2), which also had the highest concentrations of TCE and freon-113. The highest concentrations of PCE were measured in water samples from isolated intervals ranging in depth from 60 to 202 ft bls (zones 2-6); the maximum concentration of 37 µg/L was in water from the interval 115–135 ft bls (zone 4) (table 36).

Table 34. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 5-12, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft²/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 60 ft bls) tested March 5, 2004										
above 60 (pumped)	38.26	38.04	328.74	0.22	39.83	1.79	0.6	130	0.335	72.7
below 60	38.25	38.15	328.63	.10	38.1	-.05				
below 60	38.21	38.15	328.63	.06	38.13	-.02				
Zone 2 (60–80 ft bls) tested March 8, 2004										
above 60	38.09	37.78	329.00	.31	37.66	-.12				
60–80 (pumped)	38.11	37.32	329.46	.79	40.27	2.95	1	114	.339	73.6
below 80	38.11	37.92	328.86	.19	37.98	.06				
Zone 3 (95–115 ft bls) tested March 8, 2004										
above 95	37.76	37.39	329.39	.37	37.38	-.01				
95–115 (pumped)	37.77	37.07	329.71	.70	42.93	5.86	1.8	102	.307	66.6
below 115	37.76	37.67	329.11	.09	37.76	.09				
Zone 4 (115–135 ft bls) tested March 9, 2004										
above 115	38.73	38.46	328.32	.27	38.37	-.09				
115–135 (pumped)	38.70	38.31	328.47	.39	39.53	1.22	1.75	91	1.434	311
below 135	38.74	38.92	327.86	-.18	38.94	.02				
Zone 5 (162–182 ft bls) tested March 9, 2004										
above 162	38.41	37.87	328.91	.54	37.94	.07				
162–182 (pumped)	38.57	38.41	328.37	.16	39.43	1.02	1.6	96	1.569	340
below 182	38.56	38.52	328.26	.04	38.8	.28				
Zone 6 (182–202 ft bls) tested March 10, 2004										
above 182	38.74	38.63	328.15	.11	38.55	-.08				
182–202 (pumped)	38.80	39.11	327.67	-.31	40.09	.98	4	58	4.082	886
below 202	38.78	35.09	331.69	3.69	34.75	-.34				
Zone 7 (220–240 ft bls) tested March 10, 2004										
above 220	38.72	38.74	328.04	-.02	38.67	-.07				
220–240 (pumped)	38.68	33.02	333.76	5.66	47.5	14.48	.71	128	.049	10.6
below 240	38.71	35.72	331.06	2.99	35.22	-.50				
Zone 8 (240–260 ft bls) tested March 11, 2004										
above 240	38.48	38.40	328.38	.08	38.34	-.06				
240–260 (pumped)	38.47	32.64	334.14	5.83	55.60	22.96	.83	116	.036	7.84
below 260	38.49	36.68	330.10	1.81	37.59	.91				
Zone 9 (260–280 ft bls) tested March 11, 2004										
above 260	38.40	38.39	328.39	.01	38.20	-.19				
260–280 (pumped)	38.34	33.90	332.88	4.44	71.17	37.27	1	77	.027	5.82
below 280	38.40	38.34	328.44	.06	38.21	.13				
Zone 10 (260–300 ft bls) tested March 12, 2004										
above 260	38.90	38.83	327.95	.07	38.50	-.33				
260–300 (pumped)	38.77	37.72	329.06	1.05	72.98	35.26	1.44	196	.041	8.86

[1]Land-surface altitude surveyed near well head was 366.78 feet above North American Vertical Datum of 1988 (NAVD 88).

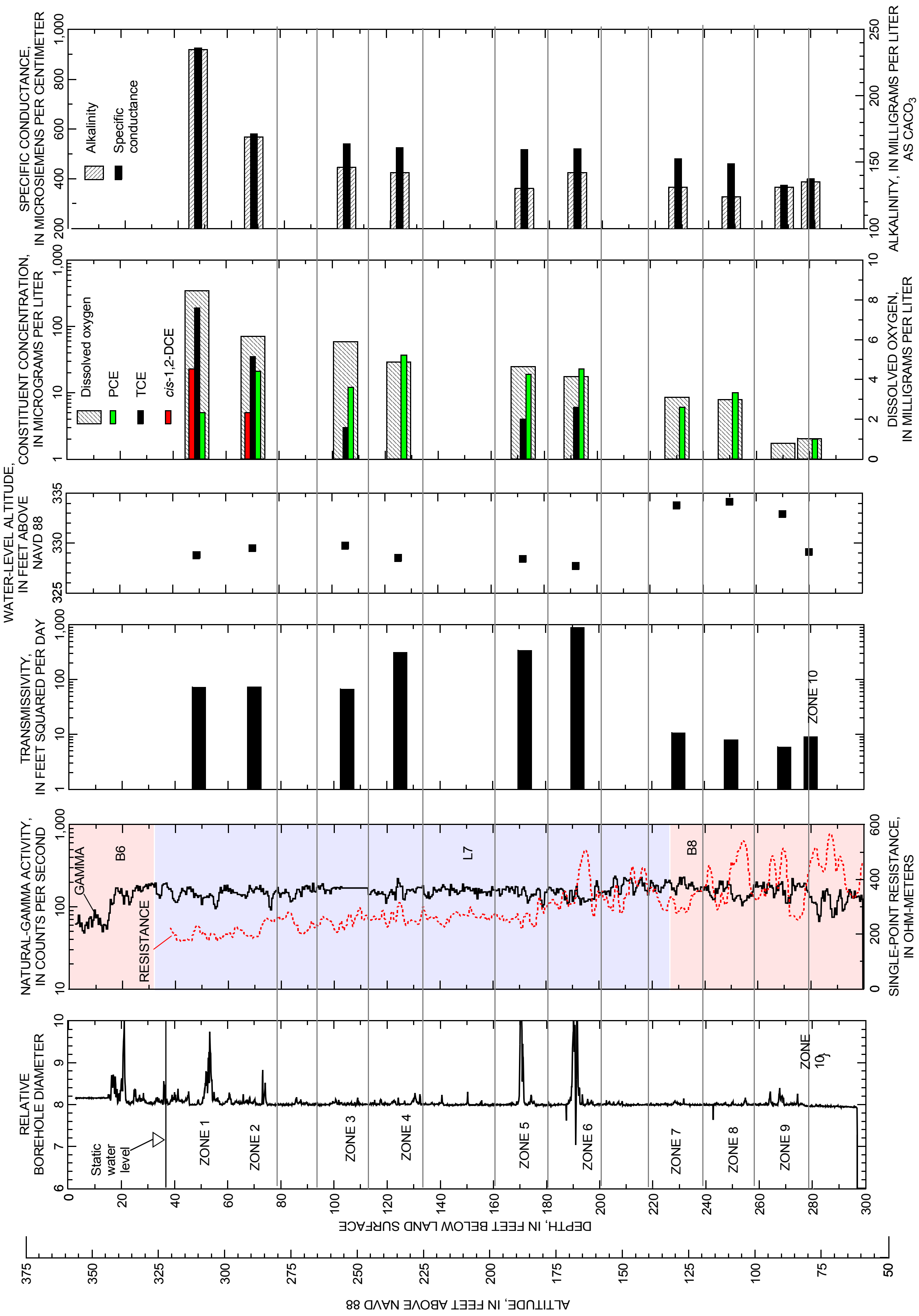


Figure 52. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2084 (RI-3D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 5-12, 2004.

Table 35. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2084 (RI-3D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 5-12, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 60	3/5/2004	14:20	15.01	7.20	8.47	925	235	0.014	0.06	0.21	9	1.1
2	60–80	3/8/2004	11:00	14.20	7.47	6.16	580	169	.005	.02	.21	19	1.6
3	95–115	3/8/2004	16:10	13.87	7.57	5.89	540	146	.017	<.01	.12	16	1.3
4	115–135	3/9/2004	10:50	14.15	7.66	4.88	524	142	.005	<.01	.12	20	1.6
5	162–182	3/9/2004	15:35	13.71	7.67	4.64	517	130	.002	.02	.18	20	1.9
6	182–202	3/10/2004	10:30	14.58	7.64	4.15	520	142	.003	<.01	.06	17	1.7
7	220–240	3/10/2004	15:45	13.72	7.92	3.10	480	131	.008	.03	.35	18	1.6
8	240–260	3/11/2004	11:50	15.79	7.93	2.99	460	124	.005	.01	.32	18	1.3
9	260–280	3/11/2004	17:30	14.13	8.02	.78	373	131	<.001	.03	.23	13	.1
10	260–300	3/12/2004	11:50	14.51	7.98	1.03	399	135	.012	.03	.22	13	.5

Table 36. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2084 (RI-3D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 5-12, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; µg/L, micrograms per liter; nd, not detected; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	Freon-113 (µg/L)
1	above 60	3/5/2004	14:20	23	190	5J	11	38
2	60–80	3/8/2004	11:00	5J	35	21	2J	24
3	95–115	3/8/2004	16:10	nd	3J	12	nd	8J
4	115–135	3/9/2004	10:50	nd	nd	37	nd	nd
5	162–182	3/9/2004	15:35	nd	4J	19	1J	1J
6	182–202	3/10/2004	10:30	nd	6J	23	3J	4J
7	220–240	3/10/2004	15:45	nd	nd	6J	1J	nd
8	240–260	3/11/2004	11:50	nd	nd	10	1J	nd
9	260–280	3/11/2004	17:30	nd	nd	nd	nd	nd
10	260–300	3/12/2004	11:50	nd	1J	2J	1J	nd

MG-2087 (RI-4D)

Seven intervals (table 37) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 23 ft. Geophysical logging indicated numerous probable water-bearing zones from about 60 to 291 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fractures at 86–90, 94–97, and 146 ft bls as the most productive.

Results of the packer tests (table 37; fig. 53) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 58–81 and 80–103 ft bls are the most productive; zone 2 (58–81 ft bls) and zone 3 (80–103) had the largest transmissivity values (1,140 and 1,500 ft^2/d, respectively) of zones tested in the borehole. Water levels in the isolated intervals were less than 1 ft different than those in adjacent intervals (table 37; fig. 53), indicating an overall slight downward vertical gradient to zone 6 (198–122 ft bls) and a slight upward gradient from zone 7 (265–300 ft bls). The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees only partially with previously measured borehole flow where water entered the borehole at 60, 145, 203–209, and 291 ft bls, moved downward (from fractures near 60 ft bls) and upward (from other fractures), and exited the borehole through the fractures at 86–90, 94–97, and 123 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Concentrations of dissolved oxygen and specific conductance generally decreased somewhat with depth. Water from the deepest interval tested (zone 7, 260–300 ft bls) had the lowest concentrations of dissolved oxygen and nitrate and the highest concentrations of ferrous iron, indicating relatively reducing conditions (table 38). PCE, TCE, *cis*-1,2-DCE, toluene, 1,1-DCE, 111-TCA, and freon-113 were the main VOCs detected; TCE was measured at the highest concentrations. Water from the two shallowest intervals (zone 1, above 58 ft bls and zone 2, 58–81 ft bls) and from a deep interval (zone 6, 198–221 ft bls) had the highest concentrations of TCE (about 500, 200, and 170 µg/L, respectively) (table 39).

Table 37. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 26-29, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 58 ft bls) tested April 26, 2004										
above 58 (pumped)	23.34	22.91	325.89	0.43	46.13	23.22	2	45	0.086	[2]18.7
below 58	23.31	23.19	325.61	.12	23.14	-.05				
Zone 2 (58–81 ft bls) tested April 27, 2004										
above 58	22.77	21.85	326.95	.92	22.47	.62				
58–81 (pumped)	22.74	22.03	326.77	.71	22.41	.38	2	109	5.263	1,140
below 81	22.74	22.78	326.02	-.04	22.83	.05				
Zone 3 (80–103 ft bls) tested April 27, 2004										
above 80	22.72	22.05	326.75	.67	22.15	.10				
80–103 (pumped)	22.76	22.85	325.95	-.09	23.30	.45	3.11	80	6.911	1,500
below 103	22.72	22.60	326.20	.12	22.65	.05				
Zone 4 (109–132 ft bls) tested April 28, 2004										
above 109	23.19	23.19	325.61	.00	23.30	.11				
109–132 (pumped)	23.20	23.11	325.69	.09	31.50	8.39	1.97	106	.235	50.9
below 132	23.18	23.01	325.79	.17	23.04	.03				
Zone 5 (140–163 ft bls) tested April 28, 2004										
above 140	23.19	23.22	325.58	-.03	23.25	.03				
140–163 (pumped)	23.16	22.82	325.98	.34	50.80	27.98	1.54	126	.055	11.9
below 163	23.12	23.14	325.66	-.02	23.17	.03				
Zone 6 (198–221 ft bls) tested April 29, 2004										
above 198	23.31	23.30	325.50	.01	23.38	.08				
198–221 (pumped)	23.30	23.24	325.56	.06	24.71	1.47	2.49	90	1.694	368
below 221	23.30	23.20	325.60	.10	23.39	.19				
Zone 7 (260–300 ft bls) tested April 29, 2004										
above 265	23.33	23.31	325.49	.02	23.31	.00				
265–300 (pumped)	23.32	22.92	325.88	.40	57.06	34.14	.59	70	.017	3.75

[1]Land-surface altitude surveyed near well head was 3448.8 feet above North American Vertical Datum of 1988 (NAVD 88).

[2]Water mostly from storage, transmissivity overestimated.

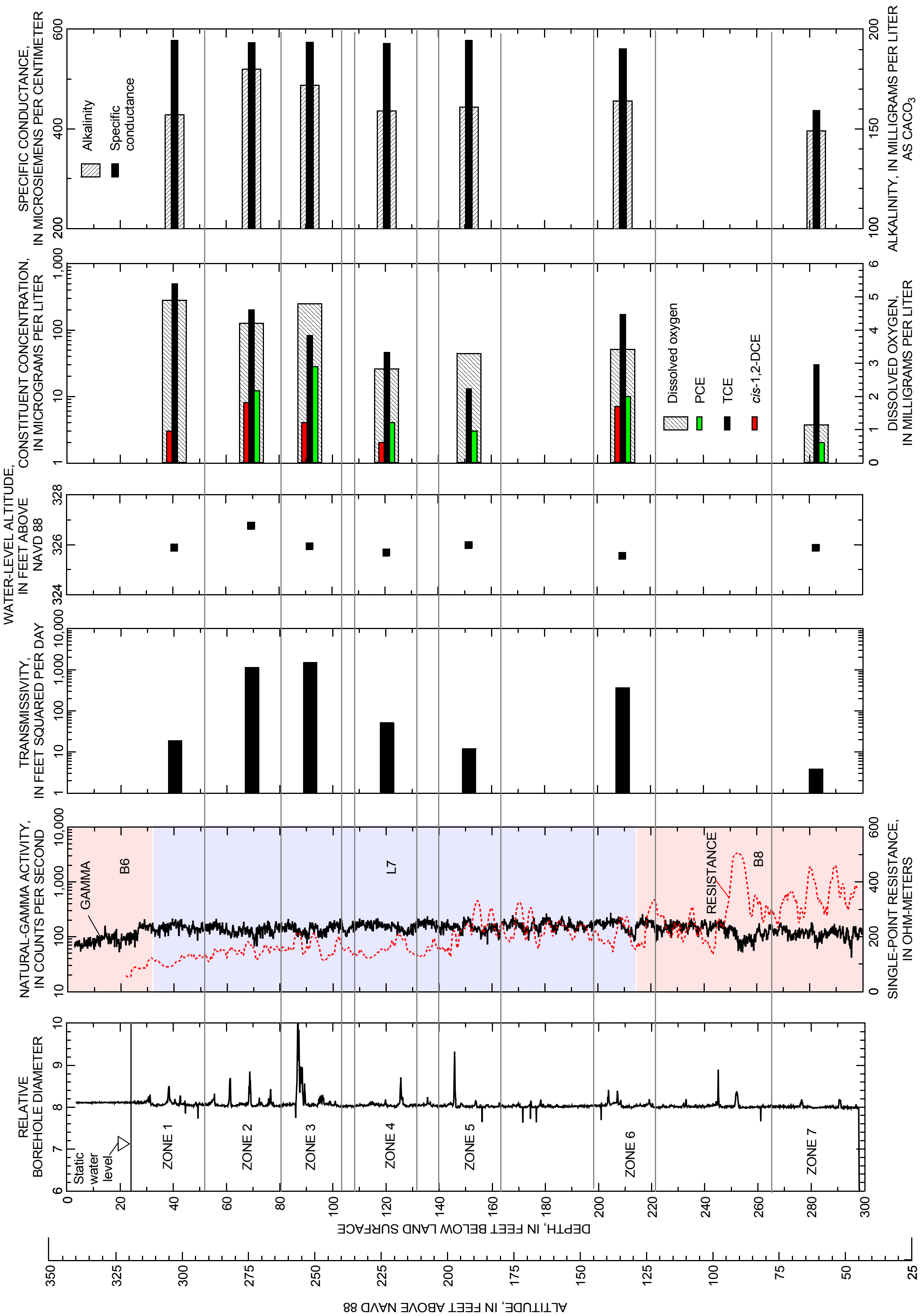


Figure 53. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 26-29, 2004.

Table 38. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2087 (RI-4D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 26-29, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 58	4/26/2004	16:55	14.60	7.36	4.90	578	157	0.003	0.03	0.23	21	0.6
2	58–81	4/27/2004	11:35	16.30	7.37	4.20	573	180	.007	.03	.14	21	1.1
3	80–103	4/27/2004	15:10	14.50	7.39	4.80	574	172	.001	.02	.05	19	1.5
4	109–132	4/28/2004	11:30	14.59	7.49	2.82	572	159	.003	.02	.15	22	1.3
5	140–163	4/28/2004	15:45	15.50	7.50	3.30	578	161	.003	.01	.17	21	1.6
6	198–221	4/29/2004	10:25	14.99	7.44	3.42	561	164	<.001	.01	.20	21	1.3
7	265–300	4/29/2004	18:25	16.35	7.67	1.14	437	149	.003	.11	.70	16	.4

Table 39. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2087 (RI-4D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 26-29, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; 1,1-DCE. 1,1-dichloroethylene; 1,1,1-TCA, 1,1,1-trichloroethane; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; E, estimated; blank in column indicates compound was not detected; B, in blank]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	1,1-DCE (µg/L)	1,1,1-TCA (µg/L)	Freon-113 (µg/L)
1	above 58	4/26/2004	16:55	3J	410		15	26	10	3J
2	58–81	4/27/2004	11:35	8J	200	12	3J	9J	2J	33
3	80–103	4/27/2004	15:10	4J	83	28	3J	5J		71
4	109–132	4/28/2004	11:30	2J	46	4J	2J	3J		15
5	140–163	4/28/2004	15:45		13	3J	2J			
6	198–221	4/29/2004	10:25	7J	170	10	2J	9J	2J	31
7	265–300	4/29/2004	18:25		30	2J	11	2J		

MG-2090 (RI-5D)

Nine intervals (table 40) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Geophysical logging indicated numerous probable water-bearing zones from about 47 to 296 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fractures at 66–68 and 80–84 ft bls as the most productive.

Results of the packer tests (table 40; fig. 54) confirm some observations from the geophysical logging. The packer tests indicated the interval between 75–95 ft bls was the most productive; this interval (zone 4) had the largest transmissivity value (1,010 ft^2/d) of zones tested in the borehole. Water levels in the isolated intervals were up to about 3 ft different than those in adjacent intervals (table 40; fig. 54), indicating an overall downward vertical gradient in the 300-ft borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees with previously measured borehole flow where water entered the borehole at 48, 65, and 80–84 ft bls, moved downward, and exited the borehole through the fractures at 172–178, 190–199, 272, and 296 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Water from all zones tested had unusually elevated specific conductance but moderate concentrations of alkalinity and sulfate (table 41), indicating presence of dissolved salts. Specific conductance was highest in water from the intervals 40–95 ft bls (zones 2-4) and below 260 ft bls (zone 9). Concentrations of dissolved oxygen were lowest and less than 1 mg/L in water from intervals 180–220 (zones 7 and 8). PCE, TCE, *cis*-1,2-DCE, toluene, and freon-11 were the main VOCs detected; TCE was measured at the highest concentrations (table 42). TCE concentrations ranged from 130 to 440 µg/L; the highest concentrations were in the deepest and three shallowest intervals tested (zone 9, below 260 ft bls and zones 1-3, all above 75 ft bls).

Table 40. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 17-21, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 40 ft bls) tested May 18, 2004										
above 40 (pumped)	20.47	20.18	331.82	0.29	33.98	13.80	2.44	14	0.177	[2]38.4
below 40	20.47	20.46	331.54	.01	20.46	.00				
Zone 2 (40–60 ft bls) tested May 17, 2004										
above 40	[3]32.07		352.00	.00	31.48	.00				
40–60 (pumped)	[3]20.47	19.40	332.60	-19.40	30.11	10.71	2.44	76	.228	49.4
below 60	[3]20.48	20.45	331.55	-20.45	20.42	-.03				
Zone 3 (55–75 ft bls) tested May 18, 2004										
above 55	20.34	19.03	332.97	1.31	19.23	.20				
55–75 (pumped)	20.32	19.84	332.16	.48	28.71	8.87	2.04	96	.230	49.9
below 75	20.33	20.32	331.68	.01	20.41	.09				
Zone 4 (75–95 ft bls) tested May 18, 2004										
above 75	20.28	19.61	332.39	.67	19.7	.09				
75–95 (pumped)	20.27	19.96	332.04	.31	20.64	.68	3.15	63	4.632	1,010
below 95	20.28	20.59	331.41	-.31	20.71	.12				
Zone 5 (95–115 ft bls) tested May 19, 2004										
above 95	20.35	19.97	332.03	.38	20.09	.12				
95–115 (pumped)	20.34	20.29	331.71	.05	21.49	1.20	2.6	83	2.167	470
below 115	20.33	21.21	330.79	-.88	21.48	.27				
Zone 6 (115–135 ft bls) tested May 19, 2004										
above 115	20.39	20.10	331.90	.29	20.15	.05				
115–135 (pumped)	20.39	20.10	331.90	.29	25.01	4.91	1.97	104	.401	87.1
below 135	20.38	21.65	330.35	-1.27	21.95	.30				
Zone 7 (180–200 ft bls) tested May 20, 2004										
above 180	20.55	20.31	331.69	.24	20.31	.00				
180–200 (pumped)	20.52	21.49	330.51	-.97	55.82	34.33	1.4	148	.041	8.85
below 200	20.52	21.72	330.28	-1.20	22.57	.85				
Zone 8 (200–220 ft bls) tested May 20, 2004										
above 200	20.54	20.26	331.74	.28	20.25	-.01				
200–220 (pumped)	20.54	21.43	330.57	-.89	28.71	7.28	2.41	85	.331	71.8
below 220	20.54	22.25	329.75	-1.71	23.15	.90				
Zone 9 (260–300 ft bls) tested May 21, 2004										
above 260	20.37	20.19	331.81	.18	20.15	-.04				
260–300 (pumped)	20.36	23.32	328.68	-2.96	30.2	6.88	3.88	159	.564	122

[1]Land-surface altitude surveyed near well head was 352 feet above North American Vertical Datum of 1988 (NAVD 88).

[2]Specific capacity and transmissivity probably overestimated.

[3]Test 2 began after test 1 with upper packer still inflatedthese “open-hole” water levels were measured with upper packer inflated. Water levels in interval above 40 ft bls were still recovering from test of zone 1.

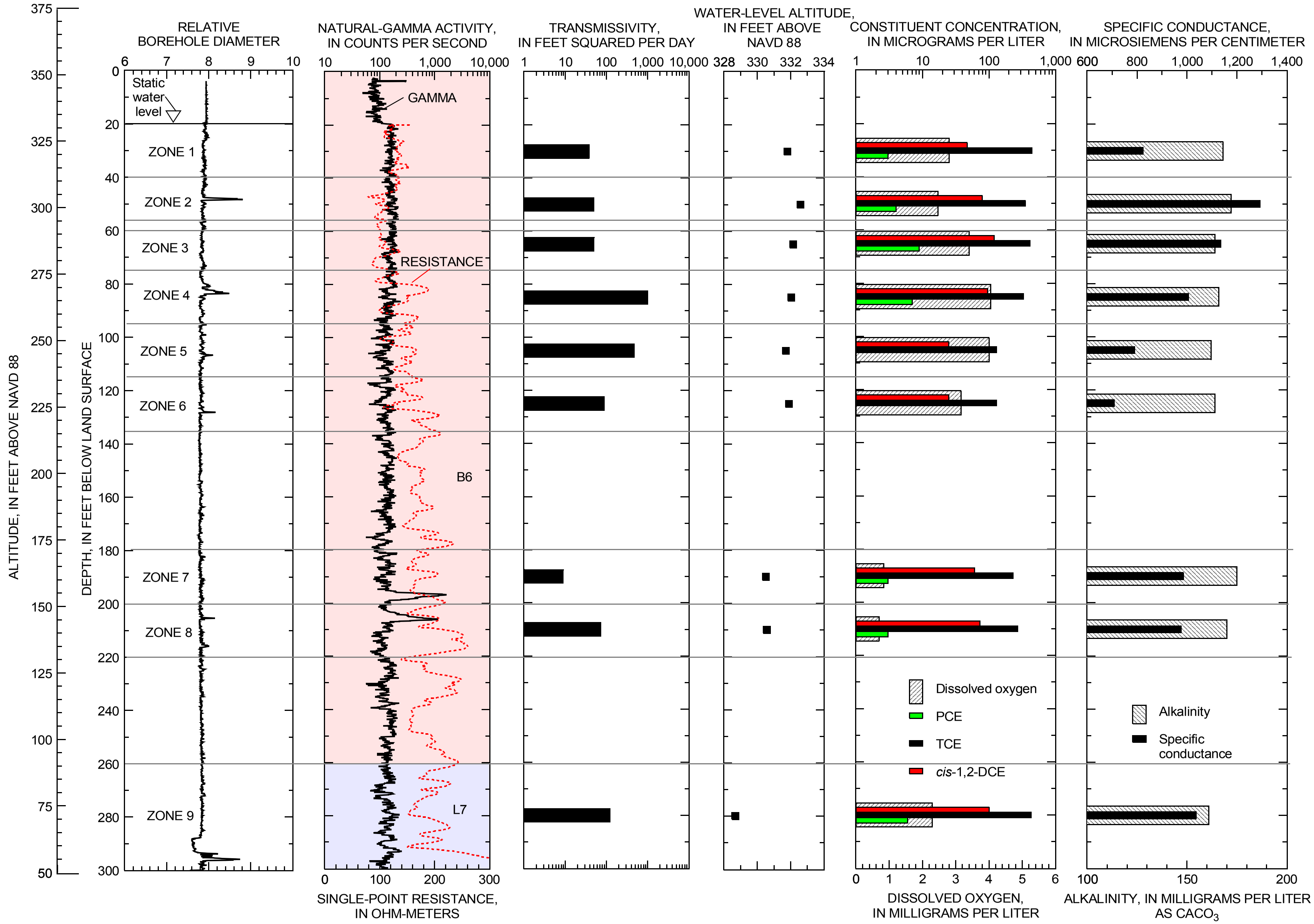


Figure 54. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 17-21, 2004.

Table 41. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2090 (RI-5D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 17-21, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 40	5/18/2004	09:00	19.07	7.35	2.80	824	168	0.025	0.07	1.28	20	0.8
2	40–60	5/17/2004	14:30	17.63	7.01	2.50	1,293	172	.005	.05	.13	26	1.0
3	55–75	5/18/2004	12:10	17.78	7.27	3.60	1,135	164	<.001	.05	.16	20	.8
4	75–95	5/18/2004	15:00	17.12	7.30	3.80	1,006	166	.001	.01	.08	31	.7
5	95–115	5/19/2004	11:15	16.32	7.40	3.80	790	162	<.001	.02	.12	27	1.2
6	115–135	5/19/2004	14:45	16.03	7.51	3.16	707	164	.001	.04	.21	29	.9
7	180–200	5/20/2004	12:00	17.85	7.44	.70	985	175	.001	.04	.18	27	1.1
8	200–220	5/20/2004	15:30	15.79	7.38	.70	977	170	.002	.05	.18	28	1.1
9	260–300	5/21/2004	11:55	15.23	7.26	2.30	1,036	161	.001	.09	.20	27	.6

Table 42. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2090 (RI-5D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 17-21, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; freon-11, trichlorofluromethane; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected; E, estimated]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	Freon-11 (µg/L)	Unknown
1	above 40	5/18/2004	09:00	47	400		200		
2	40–60	5/17/2004	14:30	79	320	4J	7J	6J	
3	55–75	5/18/2004	12:10	120	350		6J	9J	
4	75–95	5/18/2004	15:00	95	320			7J	
5	95–115	5/19/2004	11:15	25	130			3J	
6	115–135	5/19/2004	14:45	25	130			4J	
7	180–200	5/20/2004	12:00	61	240	3J	4J	4J	
8	200–220	5/20/2004	15:30	73	250	3J	4J	5J	61J
9	260–300	5/21/2004	11:55	100	420	6J	7J	4J	

MG-2093 (RI-6D)

Nine intervals (table 43) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 22 ft. Because of limitations of packer configuration and low yields of the deepest intervals, two overlapping intervals below 249 ft bls (zone 8, 249–271 ft bls and zone 9, 249–300 ft bls) were tested to allow inclusion of the borehole below 271 ft bls. Geophysical logging indicated numerous probable water-bearing zones from about 22 to 287 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 56 ft bls as the most productive.

Results of the packer tests (table 43; fig. 55) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 43–65 and 75–97 ft bls were the most productive; these intervals (zones 2 and 4) had the largest transmissivity values (545 and 893 ft^2/d, respectively) of zones tested in the borehole. Transmissivity for the interval between 271–300 ft bls, calculated by subtracting the transmissivity of zone 8 (249–271 ft bls) from that of zone 9 (249–300 ft bls), is very low at 0.19 ft^2/d. Water levels in the isolated intervals in the upper 200 ft of the borehole were less than 3 ft different than those in adjacent intervals (table 43; fig. 55), indicating an overall downward vertical gradient in that part of the 300-ft borehole. However, water-level differences between the isolated and adjacent intervals were greater (up to 20 ft) below 220 ft bls, with hydraulic head rising above land surface in the interval 249–271 ft bls (zone 8) and a predominantly upward vertical gradient. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees with previously measured borehole flow where water entered the borehole at 23, 54, 102, and 287 ft bls, moved downward and upward, and exited the borehole through the fractures at 85–95 ft bls. The interval between 75–97 ft bls (zone 4) had the lowest hydraulic head and was likely affected by nearby pumping in production well MG-202 (L-22).

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Concentrations of dissolved oxygen and alkalinity and specific conductance in water samples generally decreased with depth (table 44). Concentrations of dissolved oxygen were less than 0.5 mg/L in water from the three deepest zones with samples (zones 5-7, 97–219 ft bls). Yields from the two intervals tested below 249 ft bls (zones 8 and 9) were too small to allow borehole purging and sample collection. Toluene at low concentrations (less than 5 µg/L) and are unknown compound were the only VOCs detected and were in samples from the intervals above 119 ft bls (zones 1-5) (table 45).

Table 43. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 24-28, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft²/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Drawdown (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Transmissivity (ft²/d)
Zone 1 (above 43 ft bls) tested May 24, 2004										
above 43 (pumped)	12.07	9.79	334.41	2.28	26.88	17.09	1.71	167	0.100	21.7
below 43	12.00	12.00	332.20	.00	12.05	.05				
Zone 2 (43–65 ft bls) tested May 24, 2004										
above 43	12.04	9.16	335.04	2.88	9.53	.37				
43–65 (pumped)	11.97	9.43	334.77	2.54	10.88	1.45	3.64	58	2.510	545
below 65	11.96	12.29	331.91	-.33	12.41	.12				
Zone 3 (60–82 ft bls) tested May 25, 2004										
above 60	12.12	9.64	334.56	2.48	9.56	-.08				
60–82 (pumped)	12.10	10.98	333.22	1.12	34.9	23.92	.64	213	.027	5.80
below 82	12.08	12.59	331.61	-.51	12.75	.16				
Zone 4 (75–97 ft bls) tested May 25, 2004										
above 75	12.10	9.60	334.60	2.50	9.52	-.08				
75–97 (pumped)	12.07	12.64	331.56	-.57	13.84	1.20	4.94	47	4.117	893
below 97	12.08	10.16	334.04	1.92	10.42	.26				
Zone 5 (97–119 ft bls) tested May 26, 2004										
above 97	12.10	12.10	332.10	.00	12.16	.06				
97–119 (pumped)	12.09	11.55	332.65	.54	36.4	24.85	.71	186	.029	6.20
below 119	12.10	9.79	334.41	2.31	9.69	-.10				
Zone 6 (166–188 ft bls) tested May 26, 2004										
above 166	12.11	12.12	332.08	-.01	12.12	.00				
166–188 (pumped)	12.04	10.55	333.65	1.49	23.88	13.33	2	113	.150	32.6
below 188	12.04	8.33	335.87	3.71	8.71	.38				
Zone 7 (197–219 ft bls) tested May 27, 2004										
above 197	12.07	12.06	332.14	.01	12.11	.05				
197–219 (pumped)	12.10	9.50	334.70	2.60	49.77	40.27	1.7	137	.042	9.16
below 219	12.07	3.93	340.27	8.14	1.93	-2.00				
Zone 8 (249–271 ft bls) tested May 27, 2004										
above 249	12.13	12.10	332.10	.03	12.103	.00				
249–271 (pumped)	12.01	-7.33	351.53	19.34	69.88	77.21	1.4	9	.018	3.93
below 271	12.00	8.30	335.90	3.70	8.18	-.12				
Zone 9 (249–300 ft bls) tested May 28, 2004										
above 249	12.13	12.09	332.11	.04	12.11	.02				
249–300 (pumped)	12.01	3.51	340.69	8.50	77.32	73.81	1.4		.019	4.12

[1]Land-surface altitude surveyed near well head was 344.2 feet above North American Vertical Datum of 1988 (NAVD 88).

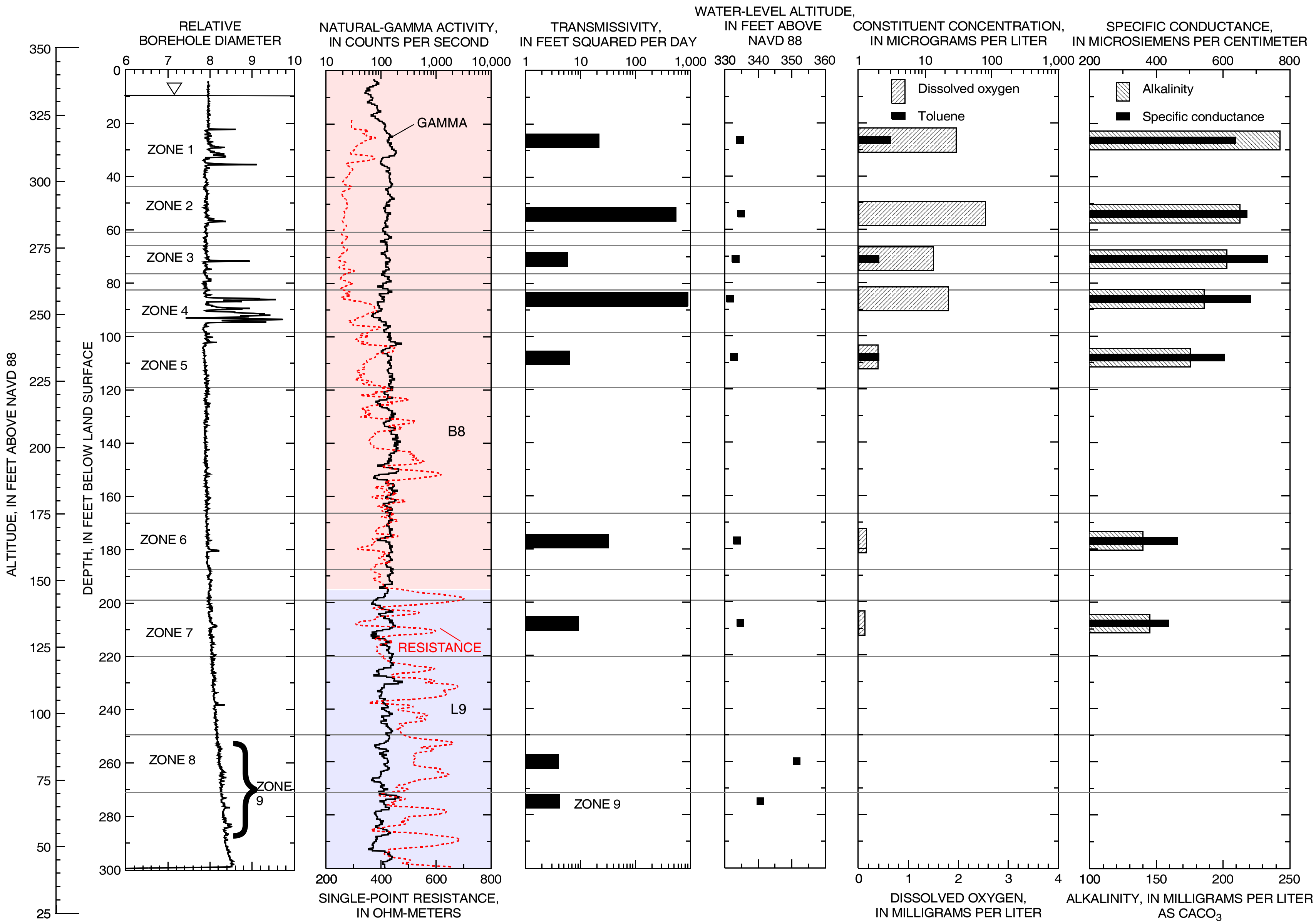


Figure 55. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2093 (RI-6D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 24-28, 2004.

Table 44. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2093 (RI-6D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 24-28, 2004

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 43	5/24/2004	13:55	14.35	7.10	1.95	637	243	0.011	0.03	0.43	36	0.7
2	43–65	5/24/2004	17:20	13.53	7.13	2.54	672	213	.001	.03	.09	34	.7
3	60–82	5/25/2004	13:06	17.52	7.14	1.50	735	203	.004	.19	1.04	30	1.0
4	75–97	5/25/2004	16:07	13.10	7.08	1.80	683	186	.002	.03	.12	31	.8
5	97–119	5/26/2004	12:46	14.11	7.50	.39	605	176	.001	.05	.23	30	.1
6	166–188	5/26/2004	16:50	13.10	7.70	.16	463	140	.003	.11	.27	31	<.1
7	197–219	5/27/2004	11:30	13.74	7.64	.13	436	145	<.001	.12	.15	24	.1
8	249–271	5/27/2004	no sample										
9	271–300	5/28/2004	no sample										

Table 45. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2093 (RI-6D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., May 24-28, 2004.

[ft bls, feet below land surface; TIC, tentatively identified compound; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Toluene (µg/L)	Methylene chloride (µg/L)	TIC (µg/L)
1	above 43	5/24/2004	13:55	3J		
2	43–65	5/24/2004	17:20			39
3	60–82	5/25/2004	13:06	2J		
4	75–97	5/25/2004	16:07	1J		
5	97–119	5/26/2004	12:46	2J	1J	
6	166–188	5/26/2004	16:50			
7	197–219	5/27/2004	11:30			
8	249–271	5/27/2004	no sample			
9	271–300	5/28/2004	no sample			

MG-2095 (RI-7D)

Six intervals (table 46) in the 246-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the mid-points of the straddle packers was 26 ft. The interval between 210–236 (zone 6) was tested but yielded almost no water, so the test for zone 6 was abandoned. Geophysical logging indicated numerous probable water-bearing zones from about 37 to 242 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones at 183–187 ft bls as the most productive.

Results of the packer tests (table 46; fig. 56) confirm some observations from the geophysical logging. The packer tests indicated the interval between 77–103 ft bls was the most productive; this interval (zone 3) had the largest transmissivity value (856 ft^2/d) of zones tested in the borehole. Water levels in the isolated intervals were up to 3 ft different than those in adjacent intervals (table 46; fig. 56), indicating an overall upward vertical gradient in the 246-ft borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests agrees with previously measured borehole flow where water entered the borehole near 160, 183–187, and 242 ft bls, moved upward, and exited the borehole through the fractures at 37, 68, 83–85, and 99–101 ft bls. Water levels were also monitored in the nearby well MG-175, which was constructed as an open hole 103 ft in depth with 14 ft of casing (Senior and others, 2005) at the time of the packer test. Water levels in well MG-175 showed little response to pumping in the isolated intervals of borehole MG-2095 (RI-7D) but declined up to 0.6 ft after packer inflation in tests of intervals deeper than 77 ft bls (zones 3-7) (table 46), indicating limited hydraulic connection between the two holes.

The inorganic chemical constituents and properties showed few differences among water samples from the isolated intervals. Water from all zones tested had low concentrations of dissolved oxygen; intervals deeper than 51 ft bls had less than 1 mg/L (table 47). Water from the shallowest interval tested (zone 1, above 51 ft bls) had the highest concentrations of dissolved oxygen (1.3 mg/L) and sulfate. TCE, *cis*-1,2-DCE, vinyl chloride, toluene, and xylenes were the main VOCs detected and were detected only in intervals shallower than 103 ft bls (zones 1-3) (table 48). The highest concentration of any VOC was 31 µg/L for *cis*-1,2-DCE. Vinyl chloride was detected only in water from zone 2 (interval between 51–77 ft bls); water from this interval also had the highest concentration of *cis*-1,2-DCE and toluene (table 48).

Table 46. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 1-4, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 51 ft bls) tested March 1, 2004										
above 51 (pumped)	23.40	24.12	337.48	-0.72	28.91	4.79	3.00	87	0.626	136
5177	23.40	23.14	338.46	.26	23.16	.02				
below 77	23.40	23.03	338.57	.37	23.07	.04				
MG-175 well[2]	23.30	23.28	338.02	.02	23.30	.02				
Zone 2 (51–77 ft bls) tested March 2, 2004										
above 51	23.09	24.06	337.54	-.97	24.46	.40				
51–77 (pumped)	23.08	24.03	337.57	-.95	26.21	2.18	3.00	110	1.376	299
below 77	23.07	22.87	338.73	.20	22.86	-.01				
MG-175 well	23.20	23.13	338.17	.07	23.18	.05				
Zone 3 (77–103 ft bls) tested March 2, 2004										
above 77	23.03	24.08	337.52	-1.05	24.25	.17				
77–103 (pumped)	23.03	24.01	337.59	-.98	24.77	.76	3.00	69	3.947	856
below 103	23.02	21.20	340.40	1.82	21.00	-.20				
MG-175 well	23.16	23.77	337.53	-.61	23.88	.11				
Zone 4 (146–172 ft bls) tested March 3, 2004										
above 146	23.35	24.34	337.26	-.99	24.45	.11				
146–172 (pumped)	23.33	21.47	340.13	1.86	23.11	1.64	3.25	48	1.982	430
below 172	23.33	21.86	339.74	1.47	21.67	-.19				
MG-175 well	23.45	23.88	337.42	-.43	23.96	.08				
Zone 5 (176–202 ft bls) tested March 3, 2004										
above 176	23.35	23.96	337.64	-.61	24.04	.08				
176–202 (pumped)	23.32	21.22	340.38	2.10	23.00	1.78	3.20	99	1.798	390
below 202	23.33	21.82	339.78	1.51	21.80	-.02				
MG-175 well	23.41	23.66	337.64	-.25	23.71	.05				
Zone 7[3] (210–246 ft bls) tested March 4, 2004										
above 210	23.25	23.42	338.18	-.17	23.45	.03				
210–246 (pumped)	23.24	21.61	339.99	1.63	23.23	1.62	3.60	90	2.222	482
MG-175 well	23.33	23.44	337.86	-.11	23.42	-.02				

[1]Land-surface altitude surveyed near well head was 361.6 feet above North American Vertical Datum of 1988 (NAVD 88).

[2]Well MG-175 near MG-2095 (RI-7D) was constructed as an open hole from 14 to 103 ft bls.

[3]Zone 6 (210236ftbls) initially was tested but yielded no water; therefore, test of zone 6 was abandoned.

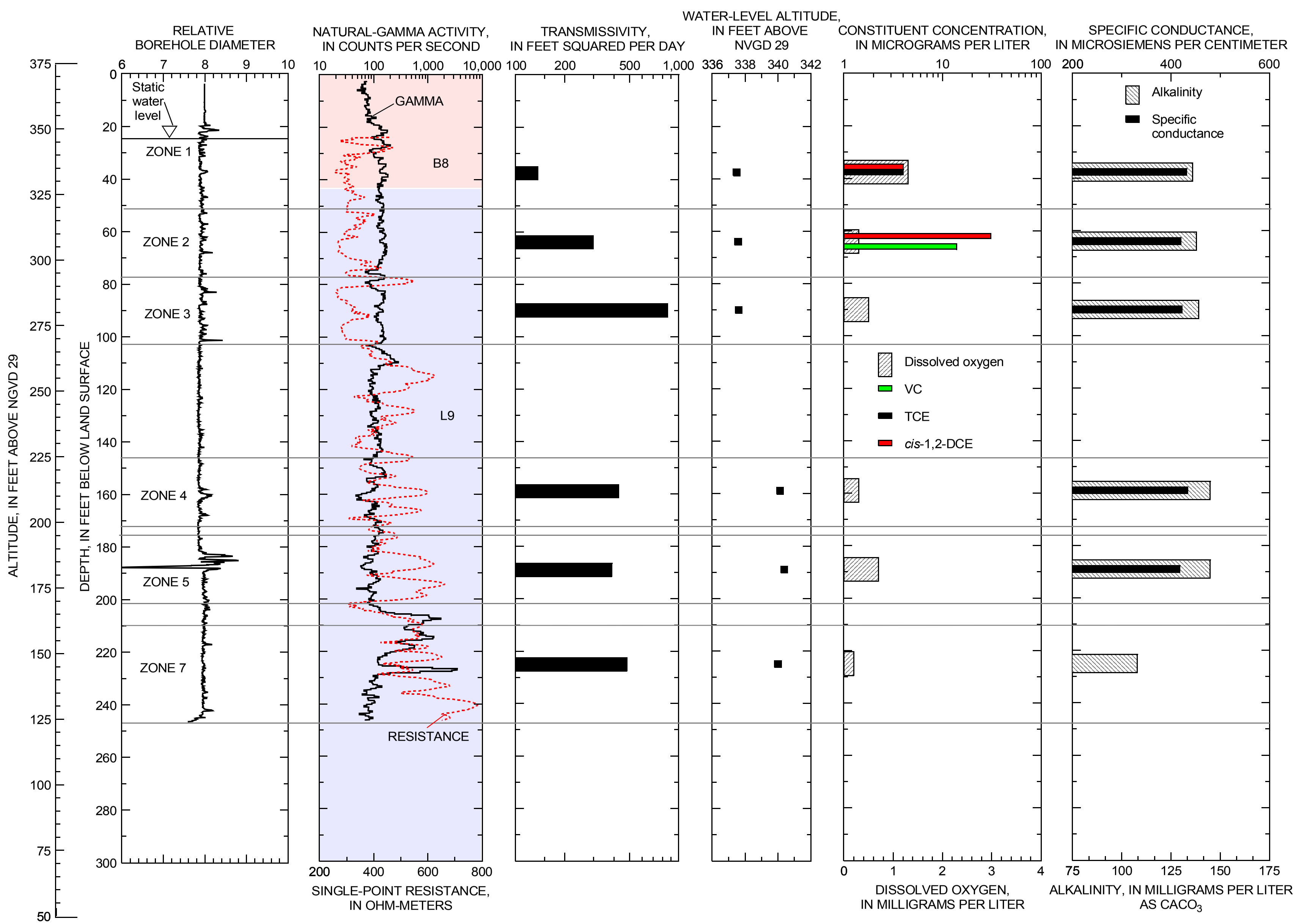


Figure 56. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2095 (RI-7D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 1-4, 2004.

Table 47. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2095 (RI-7D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 1-4, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; --, no data; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temp-erature (°C)	pH	Dis-solved oxygen (mg/L)	Specific conduc-tance (µS/cm)	Alka-linity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 51	3/1/2004	17:30	13.47	7.84	1.30	432	136	0.020	<0.01	0.11	47	0.3
2	51–77	3/2/2004	11:12	13.80	7.94	.30	420	138	.001	.01	.06	30	.1
3	77–103	3/2/2004	17:00	13.53	7.91	.50	422	139	.003	<.01	.07	33	.3
4	146–172	3/3/2004	11:45	14.17	8.02	.30	434	145	.004	<.01	.00	34	.1
5	176–202	3/3/2004	16:25	13.24	7.98	.70	418	145	.001	<.01	.07	30	.1
7	210–246	3/4/2004	13:56	--	8.09	.20	--	108	.002	.02	.10	30	.2

Table 48. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2095 (RI-7D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 1-4, 2004.

[ft bls, feet below land surface; VC, vinyl chloride; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; µg/L, micrograms per liter; blank in column indicates compound was not detected; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	VC (µg/L)	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Toluene (µg/L)	Xylenes (µg/L)
1	above 51	3/1/2004	17:30		4J	4J	4J	
2	51–77	3/2/2004	11:12	14	31	1J	8J	4J
3	77–103	3/2/2004	17:00				1J	
4	146–172	3/3/2004	11:45					
5	176–202	3/3/2004	16:25					
7	210–246	3/4/2004	13:56					

MG-2097 (RI-8D)

Nine intervals (table 49) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the mid-points of the straddle packers was 23 ft. Geophysical logging indicated numerous probable water-bearing zones from 18.5 to 292 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones at 283-292 ft bls as the most productive.

Results of the packer tests (table 49; fig. 57) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 238–261 and 270–300 ft bls were the most productive; these intervals (zone 8 and 9) had the largest transmissivity values (1,210 and 997 ft^2/d, respectively) of zones tested in the borehole. Water levels in the isolated intervals were up to about 3 ft different than those in adjacent intervals (table 49; fig. 57), indicating an overall upward vertical gradient below 70 ft bls and a downward vertical gradient above 70 ft bls in the 300-ft borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees, except in the upper 70 ft of the borehole, with previously measured borehole flow where water entered the borehole at water near 283–292, 257, and possibly 169 ft bls, moved upward, and exited the borehole through the fractures at 109, 74, 52, 59, 25–31, and 18.5 ft bls. Gradients in the upper 70 ft of the borehole may change direction, depending on nearby pumping or other transient hydraulic conditions.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Generally, water from the isolated intervals had low concentrations of dissolved oxygen (mostly less than 0.4 mg/L) and otherwise differed little from interval to interval except for water from zone 1, above 47 ft bls (table 50). Water from the shallowest interval tested (zone 1, above 47 ft bls) had the highest concentration of dissolved oxygen (1.8 mg/L) and specific conductance and lowest concentration of alkalinity of all zones tested. PCE, TCE, *cis*-1,2-DCE, toluene, 1,1-DCE, 1,1,1-TCA, 1,1-DCA, freon-113, freon-11, carbon tetrachloride, and chloroform were the main VOCs detected; the highest concentration measured (90 µg/L) was for TCE (table 51). Water from the shallowest interval tested (zone 1, above 47 ft bls) contained the highest concentrations of all VOCs detected, except for toluene, which was slightly lower than the concentration measured in water from zone 2 (47–70 ft bls). No VOCs except toluene were detected in water from intervals deeper than 70 ft bls (zones 3-9) (table 51).

Table 49. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 2-5, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 47 ft bls) tested August 2, 2004										
above 47 (pumped)	7.22	5.87	338.93	1.35	21.12	15.25	3.4	129	0.223	48.4
below 47	7.19	7.17	337.63	.02	7.16	-.01				
Zone 2 (47–70 ft bls) tested August 3, 2004										
above 47	6.83	6.91	337.89	-.08	7.44	.53				
47–70 (pumped)	6.83	9.32	335.48	-2.49	12.57	3.25	3.42	70	1.052	228
below 70	6.83	6.71	338.09	.12	6.76	.05				
Zone 3 (64–87 ft bls) tested August 3, 2004										
above 64	6.93	9.17	335.63	-2.24	9.52	.35				
64–87 (pumped)	6.93	9.73	335.07	-2.80	11.41	1.68	3.64	66	2.167	470
below 87	6.92	6.64	338.16	.28	6.48	-.16				
Zone 4 (101–124 ft bls) tested August 3, 2004										
above 101	6.86	9.62	335.18	-2.76	9.90	.28				
101–124 (pumped)	6.86	9.07	335.73	-2.21	12.80	3.73	3.98	68	1.067	232
below 124	6.85	6.27	338.53	.58	5.80	-.47				
Zone 5 (151–181 ft bls) tested August 4, 2004										
above 158	6.71	9.25	335.55	-2.54	9.46	.21				
158–181 (pumped)	6.71	5.92	338.88	.79	7.70	1.78	4.15	54	2.331	506
below 181	6.70	6.25	338.55	.45	5.98	-.27				
Zone 6 (181–204 ft bls) tested August 4, 2004										
above 181	6.69	8.40	336.40	-1.71	8.47	.07				
181–204 (pumped)	6.71	5.86	338.94	.85	9.96	4.10	4.15	63	1.012	220
below 204	6.69	6.29	338.51	.40	6.20	-.09				
Zone 7 (205–228 ft bls) tested August 5, 2004										
above 205	6.54	8.01	336.79	-1.47	8.12	.11				
205–228 (pumped)	6.54	5.80	339.00	.74	7.32	1.52	4.15	60	2.730	592
below 228	6.54	6.25	338.55	.29	6.26	.01				
Zone 8 (238–261 ft bls) tested August 5, 2004										
above 238	6.58	7.48	337.32	-.90	7.52	.04				
238–261 (pumped)	6.58	5.80	339.00	.78	6.55	.75	4.2	66	5.600	1,210
below 261	6.57	6.24	338.56	.33	6.30	.06				
Zone 9 (270–300 ft bls) tested August 5, 2004										
above 270	6.55	6.70	338.10	-.15	6.58	-.12				
below 270 (pumped)	6.55	5.94	338.86	.61	7.05	1.11	5.1	66	4.595	997

[1]Land-surface altitude surveyed near well head was 344.8 feet above North American Vertical Datum of 1988 (NAVD 88).

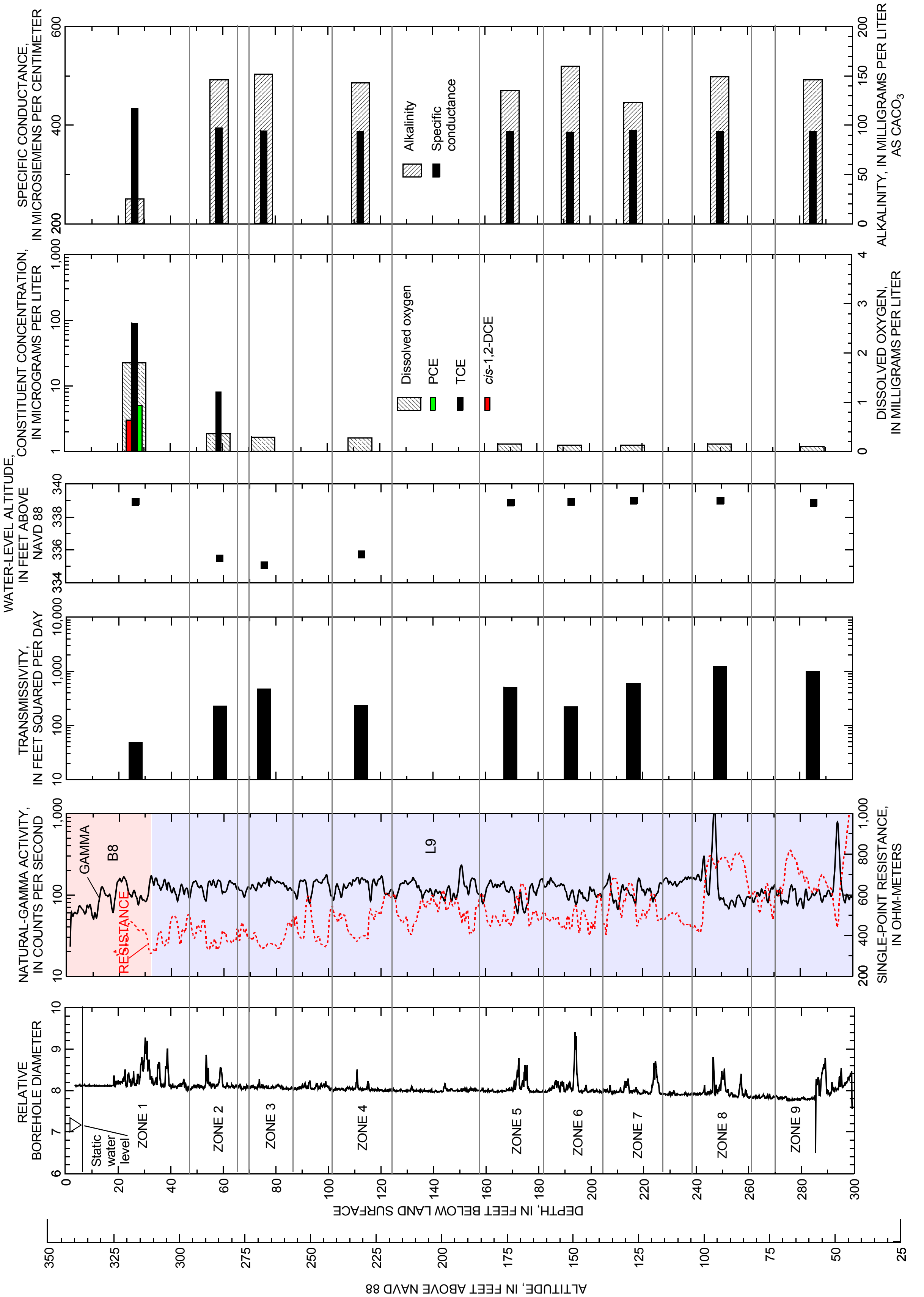


Figure 57. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 2-5, 2004.

Table 50. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2097 (RI-8D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 2-5, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; --, no data; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temp-erature (°C)	pH	Dis-solved oxygen (mg/L)	Specific conduc-tance (µS/cm)	Alka-linity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 47	8/2/2004	14:09	16.50	6.34	1.80	433	25	0.03	0.44	0.88	41	3.1
2	47–70	8/3/2004	10:23	14.95	7.00	.36	394	146	--	--	--	--	--
3	64–87	8/3/2004	13:22	15.79	7.54	.29	388	152	--	--	--	--	--
4	101–124	8/3/2004	16:00	14.47	7.61	.27	387	143	--	--	--	--	--
5	158–181	8/4/2004	11:04	14.90	7.50	.15	387	135	<.001	<.01	<.01	39	<.1
6	181–204	8/4/2004	14:00	15.40	7.60	.13	385	160	<.001	.04	.17	59	.1
7	205–228	8/5/2004	10:24	13.95	7.56	.13	389	123	<.001	<.01	.13	32	.1
8	238–261	8/5/2004	13:05	14.57	7.65	.15	386	149	<.001	.01	.21	27	.2
9	below 270	8/5/2004	15:35	14.00	7.65	.10	386	146	.005	<.01	.20	29	<.1

Table 51. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2097 (RI-8D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 2-5, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; freon-11, trichloroflurомethane; 1,1-DCE. 1,1-dichloroethylene; 1,1-DCA, dichloroethane; 1,1,1-TCA, 1,1,1-trichloroethane; carbon tet., carbon tetrachloride; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	1,1,1-TCA (µg/L)	1,1-DCA (µg/L)	1,1-DCE (µg/L)	Freon-113 (µg/L)	Freon-11 (µg/L)	Carbon tet. (µg/L)	Chloro-form (µg/L)
1	above 47	8/2/2004	14:09	3J	90	5J	19	59	1J	33	50	55	33	5J
2	47–70	8/3/2004	10:23		8J		22	5J			4J	1J	3J	
3	64–87	8/3/2004	13:22				5J							
4	101–124	8/3/2004	16:00				4J							
5	158–181	8/4/2004	11:04				2J							
6	181–204	8/4/2004	14:00				1J							
7	205–228	8/5/2004	10:24				2J							
8	238–261	8/5/2004	13:05				1J							
9	below 270	8/5/2004	15:35											

MG-2100 (RI-9D)

Eight intervals (table 52) in the 286-ft deep borehole were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 26 ft. Geophysical logs indicated probable water-bearing zones from about 62 to 273 ft bls. Under non-pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones at 176–182 and 269–273 ft bls as the most productive.

Results of the packer tests (table 52; fig. 58) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 108–134 and 160–186 ft bls were the most productive; these intervals (zones 4 and 6) had the largest transmissivity values (1,120 and 1,050 ft^2/d, respectively) of zones tested in the borehole. Water levels in the isolated intervals of the upper 80 ft of the borehole were up to 13 ft different than those in adjacent intervals (table 52; fig. 58), indicating a downward vertical gradient in that part of the 286-ft borehole. The lowest hydraulic head was in the interval between 80–106 ft bls (zone 3), such that the gradient was upward below that interval. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole fractures at 62, 180, 262, and 273 ft bls, moved downward and upward, and exited the borehole through the fractures at 90–95, 117–122, 128–132, and 139 ft bls. Water was noted as cascading in upper part of well during tests of zones 1, 3 (after heavy rain), 4, and 7.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Concentrations of dissolved oxygen and specific conductance in water samples generally decreased with depth, with the exception of water from zone 5 (134–160 ft bls) (table 53). Concentrations of dissolved oxygen were less than 1 mg/L in water from all zones except zone 1 (above 54 ft bls) and zone 5 (134–160 ft bls). TCE and toluene at low concentrations were the main VOCs detected; TCE was only detected in water from zone 3 (80–106 ft bls) (table 54). Water from the shallowest interval tested (zone 1, above 54 ft bls) had the highest concentration of toluene of intervals tested.

Table 52. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 26-30, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft²/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft²/d)
Zone 1 (above 54 ft bls) tested July 26, 2004										
above 54 (pumped)	41.32	28.29	307.01	13.03	46.11	17.82	2.78	74	0.156	33.9
below 54	41.31	41.54	293.76	-.23	41.56	.02				
Zone 2 (54–80 ft bls) tested July 27, 2004										
above 54	41.24	28.14	307.16	13.10	27.91	-.23				
54–80 (pumped)	41.19	39.85	295.45	1.34	48.31	8.46	.35	24	.041	8.98
below 80	41.20	41.36	293.94	-.16	41.39	.03				
Zone 3 (80–106 ft bls) tested July 27, 2004										
above 80	41.02	28.83	306.47	12.19	28.08	-.75				
80–106 (pumped)	41.01	42.40	292.90	-1.39	43.36	.96	3.2	85	3.333	723
below 106	41.05	40.96	294.34	.09	41.11	.15				
Zone 4 (108–134 ft bls) tested July 28, 2004										
above 108	40.22	40.78	294.52	-.56	41.06	.28				
108–134 (pumped)	40.21	41.52	293.78	-1.31	42.51	.99	5.1	67	5.152	1,120
below 134	40.22	39.12	296.18	1.10	38.94	-.18				
Zone 5 (134–160 ft bls) tested July 28, 2004										
above 134	40.16	41.26	294.04	-1.10	41.53	.27				
134–160 (pumped)	40.18	41.28	294.02	-1.10	47.08	5.80	2.5	106	.431	93.5
below 160	40.16	38.37	296.93	1.79	38.19	-.18				
Zone 6 (160–186 ft bls) tested July 29, 2004										
above 160	39.40	40.46	294.84	-1.06	40.56	.10				
160–186 (pumped)	39.4	37.12	298.18	2.28	37.89	.77	3.72	64	4.831	1,050
below 186	39.39	38.91	296.39	.48	38.83	-.08				
Zone 7 (224–250 ft bls) tested July 29, 2004										
above 224	39.23	39.45	295.85	-.22	39.46	.01				
224–250 (pumped)	39.21	38.26	297.04	.95	60.89	22.63	.48	108	.021	4.60
below 250	39.24	38.50	296.80	.74	38.23	-.27				
Zone 8 (250–286 ft bls) tested July 30, 2004										
above 250	38.66	39.11	296.19	-.45	39.14	.03				
250–286 (pumped)	38.65	36.95	298.35	1.70	39.63	2.68	6.1	59	2.276	494

[1] Land-surface altitude surveyed near well head was 335.3 feet above North American Vertical Datum of 1988 (NAVD 88).

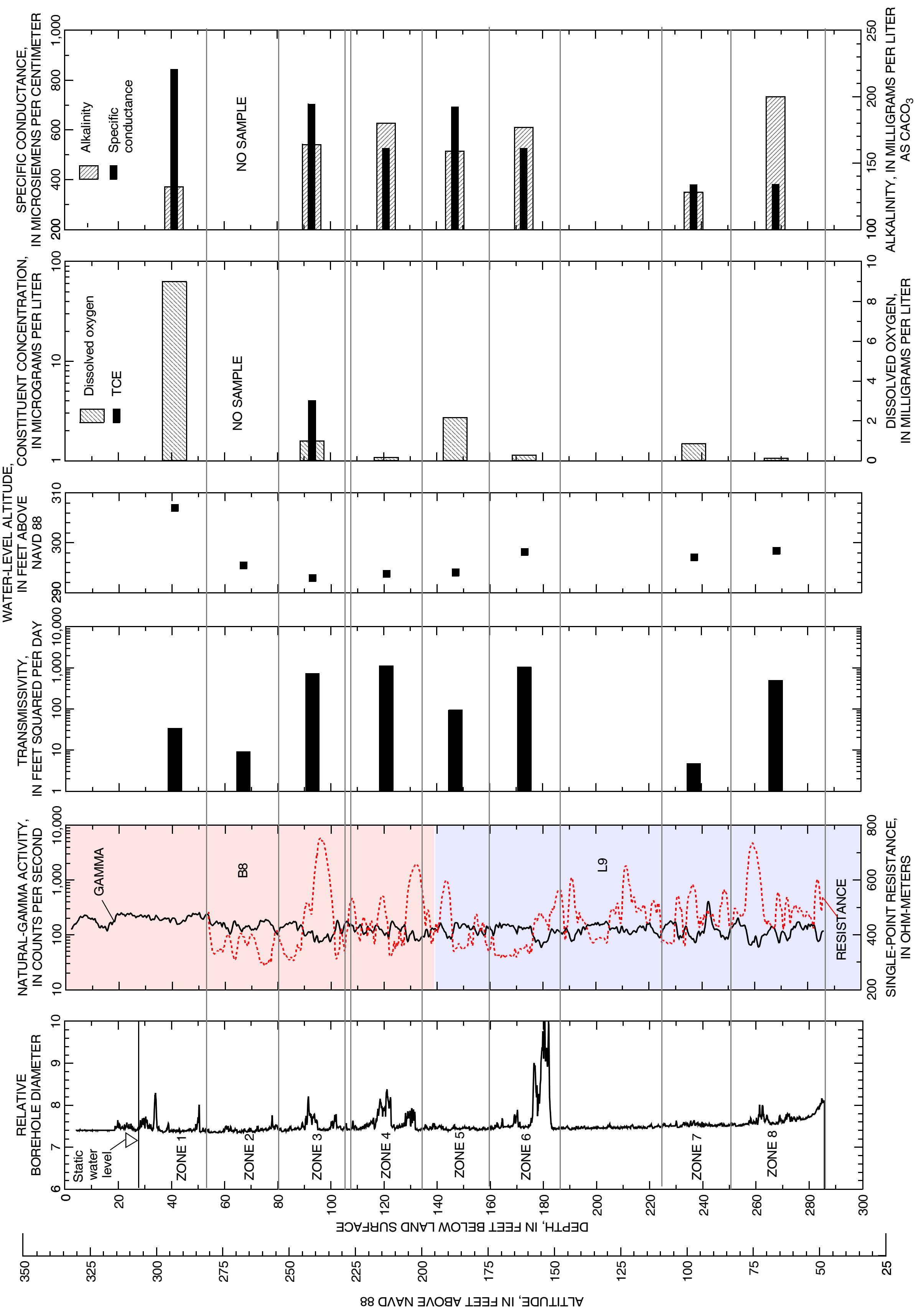


Figure 58. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 26-30, 2004.

Table 53. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2100 (RI-9D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 26-30, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 54	7/26/2004	16:53	16.43	6.88	9.00	842	132	<0.001	0.01	0.08	24	0.7
2	54–80	no sample											
3	80–106	7/27/2004	15:55	16.32	7.27	.97	703	164	.015	.05	.03	25	.5
4	108–134	7/28/2004	10:48	14.5	7.51	.16	525	180	.011	.11	.13	38	.1
5	134–160	7/28/2004	14:20	15.64	7.19	2.15	692	159	.055	.02	.17	28	.8
6	160–186	7/29/2004	10:55	15.15	7.58	.27	524	177	.001	.07	.2	25	.2
7	224–250	7/29/2004	15:30	15.01	7.66	.84	378	128	.011	.12	.93	18	.2
8	250–286	7/30/2004	12:35	14.9	7.46	.12	380	200	.005	.12	.27	23	.1

Table 54. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2100 (RI-9D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 26-30, 2004.

[ft bls, feet below land surface; TCE, trichloroethylene; µg/L, micrograms per liter; blank in column indicates compound was not detected; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	TCE (µg/L)	Toluene (µg/L)	Unknown (µg/L)
1	above 54	7/26/2004	16:53		18	
2	54–80	no sample				
3	80–106	7/27/2004	15:55	4J	8J	14J
4	108–134	7/28/2004	10:48		3J	7J
5	134–160	7/28/2004	14:20		11	
6	160–186	7/29/2004	10:55		2J	
7	224–250	7/29/2004	15:30		7J	
8	250–286	7/30/2004	12:35		1J	

MG-2119 (RI-10D)

Seven intervals (table 55) in the 289-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 25 ft. Geophysical logging indicated numerous probable water-bearing zones from about 60 to 256 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 82 ft bls as the most productive.

Results of the packer tests (table 55; fig. 59) confirm some observations from the geophysical logging. The packer tests indicated the interval between 63–88 ft bls was the most productive; this interval (zone 2) had the largest transmissivity value (1,430 ft^2/d) of zones tested in the borehole. Transmissivity for the interval between 265–289 ft bls (fig. 59) was calculated by subtracting the transmissivity of zone 6 (240–265 ft bls) from that of zone 7 (240–289 ft bls) to be 3.8 ft^2/d. Water levels in the isolated intervals of the upper 170 ft of the borehole were up to 1.8 ft higher than those in adjacent intervals (table 55; fig. 59), indicating an overall downward vertical gradient in the borehole. The lowest hydraulic head was in the interval between 240–265 ft bls (zone 6) and the highest was in the interval between 63–88 ft bls (zone 2). The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole near 82 ft bls, moved upward and downward, and exited the borehole through fractures at 60, 70–77, 185, 189.5, and 225 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Water from the shallowest interval was the most oxygenated and dilute of the intervals tested, having the highest concentrations of dissolved oxygen and lowest specific conductance (table 56). Water quality from other intervals differed little and concentrations of dissolved oxygen were all greater than 2 mg/L. PCE, TCE, *cis*-1,2-DCE, toluene, and freon-11 were the main VOCs detected; TCE was measured at the highest concentrations (up to 530 µg/L) (table 57). Water from the shallowest interval (zone 1, above 63 ft bls) had the lowest concentrations of detected VOCs except toluene, which was measured at the highest concentration of any interval tested.

Table 55. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 23-26, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft²/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft²/d)
Zone 1 (above 63 ft bls) tested March 23, 2004										
above 63 (pumped)	39.36	39.19	326.31	0.17	54.69	15.50	0.7	154	0.045	9.80
below 63	39.36	39.33	326.17	.03	39.29	-.04				
Zone 2 (63–88 ft bls) tested March 23, 2004										
above 63	39.21	38.73	326.77	.48	38.95	.22				
63–88 (pumped)	39.12	38.83	326.67	.29	39.3	.47	3.1	71	6.596	1,430
below 88	39.24	39.69	325.81	-.45	39.72	.03				
Zone 3 (105–130 ft bls) tested March 24, 2004										
above 105	39.38	39.06	326.44	.32	39.04	-.02				
105–130 (pumped)	39.38	39.12	326.38	.26	40.07	.95	3.28	74	3.453	749
below 130	39.36	40.43	325.07	-1.07	40.59	.16				
Zone 4 (170–195 ft bls) tested March 24, 2004										
above 170	39.29	38.99	326.51	.30	38.87	-.12				
170–195 (pumped)	39.24	40.72	324.78	-1.48	41.72	1.00	3.2	66	3.200	694
below 195	39.29	40.01	325.49	-.72	40.25	.24				
Zone 5 (210–235 ft bls) tested March 25, 2004										
above 210	39.36	39.31	326.19	.05	39.33	.02				
210–235 (pumped)	39.31	40.26	325.24	-.95	41.96	1.70	3.2	86	1.882	408
below 235	39.35	39.91	325.59	-.56	40.21	.30				
Zone 6 (240–265 ft bls) tested March 25, 2004										
above 240	39.33	39.32	326.18	.01	39.33	.01				
240–265 (pumped)	39.31	40.88	324.62	-1.57	56.32	15.44	.78	230	.051	11.0
below 265	39.31	39.39	326.11	-.08	39.52	.13				
Zone 7 (240–289 ft bls) tested March 26, 2004										
above 240	39.21	39.25	326.25	-.04	39.27	.02				
240–289 (pumped)	39.21	40.34	325.16	-1.13	66.8	26.46	1.8	200	.068	14.8

[1]Land-surface altitude surveyed near well head was 365.5 feet above North American Vertical Datum of 1988 (NAVD 88).

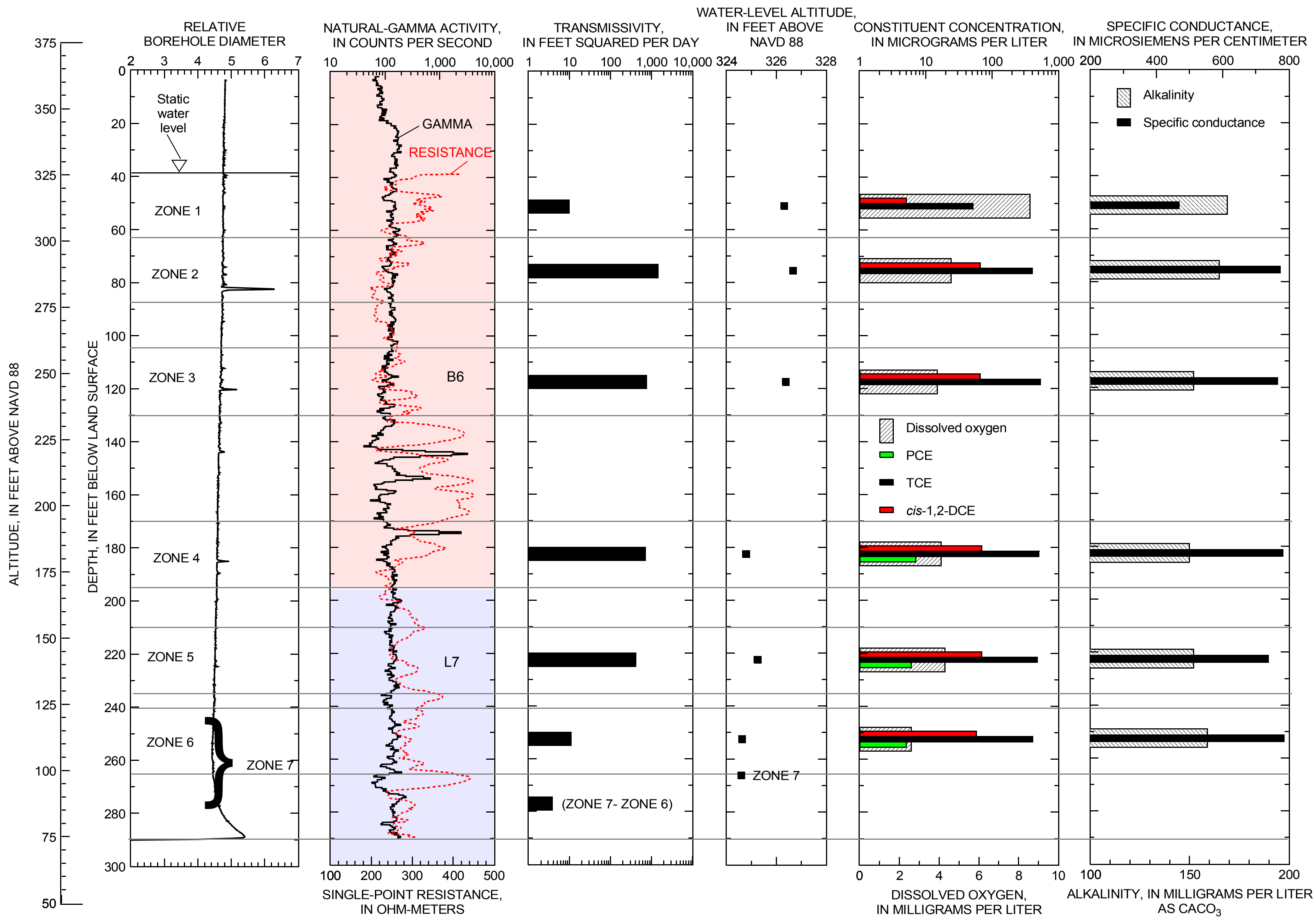


Figure 59. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2119 (RI-10D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 23-26, 2004.

Table 56. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2119 (RI-10D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 23-26, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 63	3/23/2004	13:37	14.00	7.56	8.57	468	169	0.005	0.01	0.15	10	0.9
2	63–88	3/23/2004	15:55	13.25	7.50	4.60	774	165	.004	.02	.08	18	1.1
3	105–130	3/24/2004	10:05	13.70	7.34	3.90	766	152	.003	.01	.11	21	1.0
4	170–195	3/24/2004	13:35	13.90	7.37	4.10	782	150	.001	.02	.13	19	1.2
5	210–235	3/25/2004	10:50	13.25	7.38	4.30	738	152	.001	.04	.18	17	1.2
6	240–265	3/25/2004	17:00	13.22	7.52	2.60	785	159	.013	.01	.46	21	1.3
7	240–289	3/26/2004	11:40	14.64	7.54	2.14	778	152	.013	.01	.30	18	1.2

Table 57. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2119 (RI-10D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., March 23-26, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; freon-11, trichlorofluromethane; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected; E, estimated]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	freon-11 (µg/L)
1	above 63	3/23/2004	13:37	5J	51		38	
2	63–88	3/23/2004	15:55	66	410			
3	105–130	3/24/2004	10:05	66	510			7J
4	170–195	3/24/2004	13:35	70	460	7J	6J	10
5	210–235	3/25/2004	10:50	70	380	6J	5J	11
6	240–265	3/25/2004	17:00	58	360	5J	6J	9J
7	240–289	3/26/2004	11:40	60	400	6J	9J	8J

MG-2122 (RI-11D)

Six intervals (table 58) in the 299-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 31 ft. Geophysical logging indicated numerous probable water-bearing zones from about 28 to 259 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 25–26, 34–36, 49, 54–58, and 250–268 ft bls as the most productive.

Results of the packer tests (table 58; fig. 60) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 73–104 and 178–209 ft bls were the most productive; these interval (zones 3 and 4) had the largest transmissivity values (178 and 158 ft^2/d, respectively) of zones tested in the borehole although an order of magnitude smaller than the largest transmissivity values of most other boreholes. Water levels in the isolated intervals deeper than 209 ft bls were up to 5 ft higher than those in adjacent intervals (table 58; fig. 60), indicating an upward vertical gradient in the borehole. The lowest hydraulic heads were in the intervals above 42 ft bls and between 42–73 ft bls (zones 1 and 2). The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole near fractures at 250–259 and 210–220 ft bls, moved upward, and exited the borehole through fractures at 80–100, 52–58, 45–48, 34–36, and above 28 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Water from the shallowest interval (zone 1, above 42 ft bls) had the lowest pH and the highest concentrations of dissolved oxygen (1.27 mg.L) of intervals tested (table 59). Water quality of other intervals differed little and concentrations of dissolved oxygen were less than 0.3 mg/L in water from all intervals except zone 1, indicating reducing conditions. TCE, *cis*-1,2-DCE, and toluene were the main VOCs detected; toluene measured at the highest concentration (170 µg/L) (table 60) from the shallowest interval (zone 1, above 42 ft bls). Water from the interval between 73–104 ft bls (zone 3) had the highest concentrations of TCE (19 µg/L) and *cis*-1,2-DCE (15 µg/L).

Table 58. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 9-13, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
			Zone 1 (above 42 ft bls) tested July 9, 2004							
above 42 (pumped)	21.91	24.10	331.50	-2.19	35.43	11.33	1.87	33	0.165	35.8
below 42	21.89	21.81	333.79	.08	21.88	.07				
			Zone 2 (42–73 ft bls) tested July 9, 2004							
above 42	still rising		355.60	--		.00				
42–73 (pumped)	22.03	24.06	331.54	-2.03	30.87	6.81	3.9	74	.573	124
below 73	22.18	21.57	334.03	.61	21.60	.03				
			Zone 3 (73–104 ft bls) tested July 9, 2004							
above 73	22.20	24.22	331.38	-2.02	24.74	.52				
73–104 (pumped)	22.21	22.88	332.72	-.67	26.73	3.85	3.16	86	.821	178
below 104	22.19	20.77	334.83	1.42	20.71	-.06				
			Zone 4 (178–209 ft bls) tested July 13, 2004							
above 178	22.00	23.13	332.47	-1.13	23.41	.28				
178–209 (pumped)	22.00	21.81	333.79	.19	25.46	3.65	2.65	127	.726	158
below 209	22.00	19.70	335.90	2.30	19.25	-.45				
			Zone 5 (209–240 ft bls) tested July 13, 2004							
above 209	22.06	22.86	332.74	-.80	22.92	.06				
209–240 (pumped)	22.07	17.87	337.73	4.20	36.00	18.13	2.75	109	.152	32.9
below 240	22.06	19.88	335.72	2.18	19.72	-.16				
			Zone 6 (240–271 ft bls) tested July 12, 2004							
above 240	22.36	22.78	332.82	-.42	22.83	.05				
240–271 (pumped)	22.32	18.06	337.54	4.26	27.58	9.52	3.15	106	.331	71.8
below 271	22.33	22.49	333.11	-.16	22.62	.13				

[1]Land-surface altitude surveyed near well head was 355.6 feet above North American Vertical Datum of 1988 (NAVD 88).

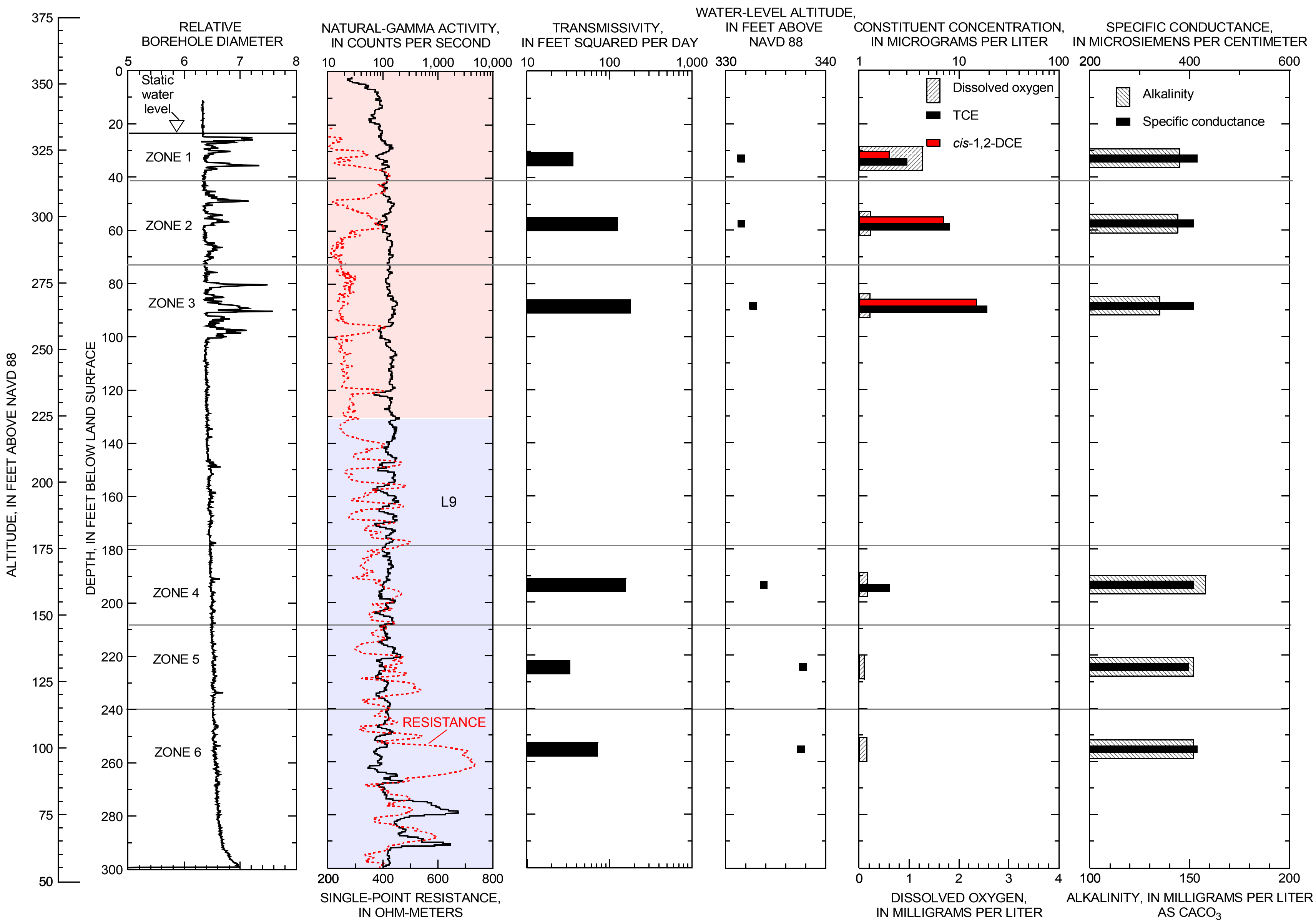


Figure 60. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 9-13, 2004.

Table 59. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2122 (RI-11D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 9-13, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; --, no data; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 42	7/9/2004	09:04	15.46	6.65	1.27	415	145	0.070	0.11	0.66	28	1.1
2	42–73	7/9/2004	11:00	14.99	7.60	.22	407	144	.006	.02	.24	33	<.1
3	73–104	7/9/2004	15:10	14.72	7.62	.21	407	135	.002	.01	.18	36	.1
4	178–209	7/13/2004	16:00	13.80	7.60	.17	408	158	.006	.01	.07	34	.2
5	209–240	7/13/2004	12:23	13.90	7.65	.10	398	152	<.001	.01	.11	37	.2
6	240–271	7/12/2004	12:10	14.31	7.61	.15	415	152	.001	.02	.03	54	--

Table 60. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2122 (RI-11D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 9-13, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; TIC, tentatively identified compound; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Toluene (µg/L)	unknown or TIC (µg/L)
1	above 42	7/9/2004	09:04	3	3J	170	
2	42–73	7/9/2004	11:00	6	8J	15	
3	73–104	7/9/2004	15:10	13	13	4	
4	178–209	7/13/2004	16:00		2J	1J	
5	209–240	7/13/2004	12:23			2J	7J trimethylsilanol
6	240–271	7/12/2004	12:10			2J	6J

MG-2125 (RI-12D)

Eight intervals (table 61) in the 300-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Geophysical logging indicated numerous probable water-bearing zones from about 42 to 176 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 70–75 and possibly 82 ft bls as the most productive.

Results of the packer tests (table 61; fig. 61) confirm some observations from the geophysical logging. The packer tests indicated the interval between 65–85 ft bls was the most productive; this interval (zone 2) had the largest transmissivity value (283 ft^2/d) of zones tested in the borehole although an order of magnitude smaller than the largest transmissivity values of most other boreholes. Water levels in the isolated intervals were up to 2.7 ft different than those in adjacent intervals (table 61; fig. 61). The lowest hydraulic head was in the interval between 144–164 ft bls (zone 6), indicating downward gradient above that interval and upward gradient below that interval. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole through fractures near 42–47, 72–75, and 97 ft bls, moved downward, and exited the borehole through fractures at 111, 149, 158–161, and 176 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Overall, specific conductance of water from all intervals was higher than in water from most other boreholes tested. Water from the shallowest two intervals (zone 1, above 65 ft bls and zone 2, 65–85 ft bls) had specific conductance values over 2,000 µS/cm (table 62), at least twice the value of water from other boreholes. The elevated specific conductance indicates probable presence of dissolved salts, given the moderate sulfate concentrations. Concentrations of alkalinity were also higher than those for water from most other boreholes. The concentrations of dissolved oxygen were less than 2 mg/L in water from all intervals and were less than 1 mg/L in five of the eight intervals tested. Water from the deepest interval tested had 0.10 mg/L of dissolved oxygen and 1.47 mg/L of ferrous iron, indicating reducing conditions. TCE, toluene, and freon-11 at low concentrations were the only VOCs detected; toluene was measured at the highest concentration (14 µg/L) in water from zone 7 (168–188 ft bls) (table 63).

Table 61. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 6-12, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude20 (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 65 ft bls) tested April 6, 2004										
above 65 (pumped)	41.89	41.41	316.49	0.48	48.19	6.78	2	103	0.295	64.0
below 65	41.88	41.94	315.96	-.06	42.23	.29				
Zone 2 (65–85 ft bls) tested April 6, 2004										
above 65	41.79	41.09	316.81	.70	41.48	.39				
65–85 (pumped)	41.79	41.34	316.56	.45	43.09	1.75	2.28	89	1.303	283
below 85	41.79	42.70	315.20	-.91	42.97	.27				
Zone 3 (85–105 ft bls) tested April 7, 2004										
above 85	41.49	41.09	316.81	.40	41.14	.05				
85–105 (pumped)	41.49	41.14	316.76	.35	46.49	5.35	1.33	131	.249	53.9
below 105	41.49	43.15	314.75	-1.66	43.27	.12				
Zone 4 (105–125 ft bls) tested April 7, 2004										
above 105	41.46	40.96	316.94	.50	41.09	.13				
105–125 (pumped)	41.46	43.08	314.82	-1.62	47.98	4.90	1.5	103	.306	66.4
below 125	41.46	43.32	314.58	-1.86	43.45	.13				
Zone 5 (124–144 ft bls) tested April 8, 2004										
above 124	41.52	41.39	316.51	.13	41.33	-.06				
124–144 (pumped)	41.51	43.65	314.25	-2.14	67.13	23.48	1.24	137	.053	11.5
below 144	41.51	43.02	314.88	-1.51	43.18	.16				
Zone 6 (144–164 ft bls) tested April 8, 2004										
above 144	41.56	41.50	316.40	.06	41.43	-.07				
144–164 (pumped)	41.60	44.17	313.73	-2.57	69.19	25.02	1.26	139	.050	10.9
below 164	41.54	42.75	315.15	-1.21	43.06	.31				
Zone 7 (168–188 ft bls) tested April 9, 2004										
above 168	41.68	41.66	316.24	.02	41.73	.07				
168–188 (pumped)	41.66	42.64	315.26	-.98	58.07	15.43	1.6	111	.104	22.5
below 188	41.68	43.52	314.38	-1.84	44.16	.64				
Zone 8 (260–300 ft bls) tested April 12, 2004										
above 260	41.84	41.95	315.95	-.11	42.07	.12				
260–300 (pumped)	41.77	42.00	315.90	-.23	84.00	42.00	.55	301	.013	2.84

[2]Land-surface altitude surveyed near well head was 357.9 feet above North American Vertical Datum of 1988 (NAVD 88).

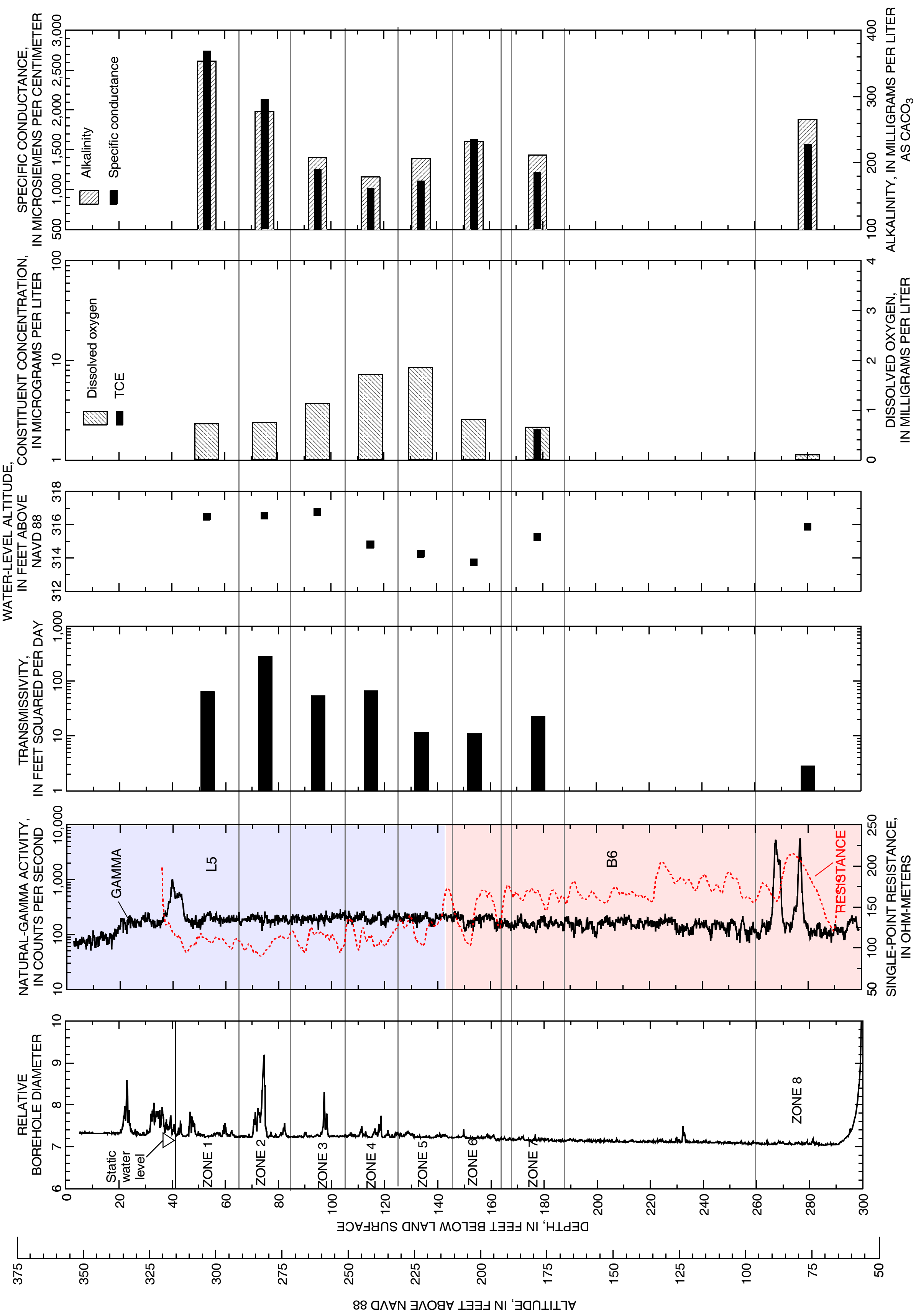


Figure 61. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 6-12, 2004.

Table 62. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2125 (RI-12D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 6-12, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 65	4/6/2004	12:55	13.03	7.02	0.73	2,742	354	0.006	0.09	0.25	54	0.5
2	65–85	4/6/2004	16:15	13.40	7.03	.75	2,126	278	<.001	.14	.27	44	.6
3	85–105	4/7/2004	09:00	15.00	7.06	1.13	1,247	208	<.001	.15	.24	37	.6
4	105–125	4/7/2004	15:05	15.35	7.12	1.71	1,010	179	.001	.08	.20	34	.9
5	124–144	4/8/2004	12:05	13.37	7.14	1.86	1,102	207	<.001	.22	.37	35	.7
6	144–164	4/8/2004	17:00	11.66	7.01	.81	1,625	233	<.001	.16	.29	38	.5
7	168–188	4/9/2004	11:03	13.93	7.11	.66	1,209	212	.003	.12	.43	32	.3
8	260–300	4/12/2004	09:39	11.72	6.98	.10	1,568	266	.001	1.47	2.02	35	.2

Table 63. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2125 (RI-12D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., April 6-12, 2004.

[ft bls, feet below land surface; TCE, trichloroethylene; freon-11, trichloroflurομethane; µg/L, micrograms per liter; blank in column indicates compound was not detected; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	TCE (µg/L)	Toluene (µg/L)	Freon-11 (µg/L)	Acetone (µg/L)	Methylene chloride (µg/L)
1	above 65	4/6/2004	12:55		4J			
2	65–85	4/6/2004	16:15		1J		8J	
3	85–105	4/7/2004	09:00		1J			
4	105–125	4/7/2004	15:05		11	1J		
5	124–144	4/8/2004	12:05		13			
6	144–164	4/8/2004	17:00	2J	12			
7	168–188	4/9/2004	11:03	2J	14			
8	260–300	4/12/2004	09:39				4J	6J

MG-2126 (RI-13D)

Seven intervals (table 64) in the 279-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 20 ft. Geophysical logging indicated numerous probable water-bearing zones from about 43 to 222 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 64–68 ft bls as the most productive.

Results of the packer tests (table 64; fig. 62) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 52–72 and 116–136 ft bls were the most productive; these intervals (zones 2 and 4) had the largest transmissivity values (2,290 and 2,070 ft^2/d, respectively) of zones tested in the borehole. Water levels in the isolated intervals were up to 1.2 ft different than those in adjacent intervals (table 64; fig. 62). The lowest hydraulic heads were in the deepest intervals tested (zone 6, 144–164 ft bls and zone 7, 260–279 ft bls) and in the interval between 82–102 ft bls, indicating downward and upward downward gradients in the borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole through fractures near 43–47, 114, 123–131.5, and 146.5 ft bls, moved upward and downward, and exited the borehole through fractures at 96 and 222 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Overall, specific conductance of water from all intervals was somewhat higher than in water from most other boreholes tested. Water from the second shallowest interval (zone 2, 52–72 ft bls) had the highest specific conductance (1,188 µS/cm) (table 65). The elevated specific conductance indicates probable presence of dissolved salts, given the moderate concentrations of sulfate and alkalinity. Concentrations of dissolved oxygen were greater than 2.5 mg/L in water from all but one interval, zone 6 (190–210 ft bls), which had 0.45 mg/L. PCE, TCE, *cis*-1,2-DCE, toluene, and freon-11 were the main VOCs detected; toluene was measured at the highest concentration (410 µg/L) (table 65). Water from the shallowest interval tested (zone 1, above 52 ft bls) had the lowest TCE and the highest concentrations of toluene (table 66). Water from intervals between 82–102 and 116–136 ft bls (zones 3 and 4) had the highest TCE concentrations.

Table 64. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 8-10, 2004.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 52 ft bls) tested June 8, 2004										
above 52 (pumped)	25.98	25.72	329.80	0.26	45.01	19.29	2.1	22	0.109	[2]23.6
below 52	25.92	25.93	329.59	-.01	25.93	.00				
Zone 2 (52–72 ft bls) tested June 7, 2004										
above 52			355.52	.00		.00				
52–72 (pumped)	25.88	25.83	329.69	.05	26.23	.40	4.22		10.550	2,290
below 72	25.93	25.95	329.57	-.02	25.93	-.02				
Zone 3 (82–102 ft bls) tested June 8, 2004										
above 82	26.08	26.07	329.45	.01	26.08	.01				
82–102 (pumped)	26.09	26.67	328.85	-.58	29.40	2.73	2.8	65	1.026	223
below 102	26.08	26.00	329.52	.08	26.11	.11				
Zone 4 (116–136 ft bls) tested June 8, 2004										
above 116	26.08	26.07	329.45	.01	26.13	.06				
116–136 (pumped)	26.05	25.90	329.62	.15	26.33	.43	4.1	47	9.535	2,070
below 136	26.06	26.11	329.41	-.05	26.33	.22				
Zone 5 (136–156 ft bls) tested June 9, 2004										
above 136	26.07	25.96	329.56	.11	26.10	.14				
136–156 (pumped)	26.05	25.83	329.69	.22	26.67	.84	3.86	56	4.595	997
below 156	26.03	26.97	328.55	-.94	27.05	.08				
Zone 6 (190–210 ft bls) tested June 9, 2004										
above 190	25.99	25.88	329.64	.11	25.82	-.06				
190–210 (pumped)	26.01	27.06	328.46	-1.05	33.44	6.38	2.6	116	.408	88.4
below 210	25.99	26.88	328.64	-.89	28.08	1.20				
Zone 7 (210–230 ft bls) tested June 10, 2004										
above 210	25.95	25.89	329.63	.06	25.94	.05				
210–230 (pumped)	25.93	26.70	328.82	-.77	28.64	1.94	3.5	67	1.804	391
below 230	25.93	25.92	329.60	.01	26.04	.12				

[1]Land-surface altitude surveyed near well head was 357.9 feet above North American Vertical Datum of 1988 (NAVD 88).

[2]Specific capacity and transmissivity overestimated.

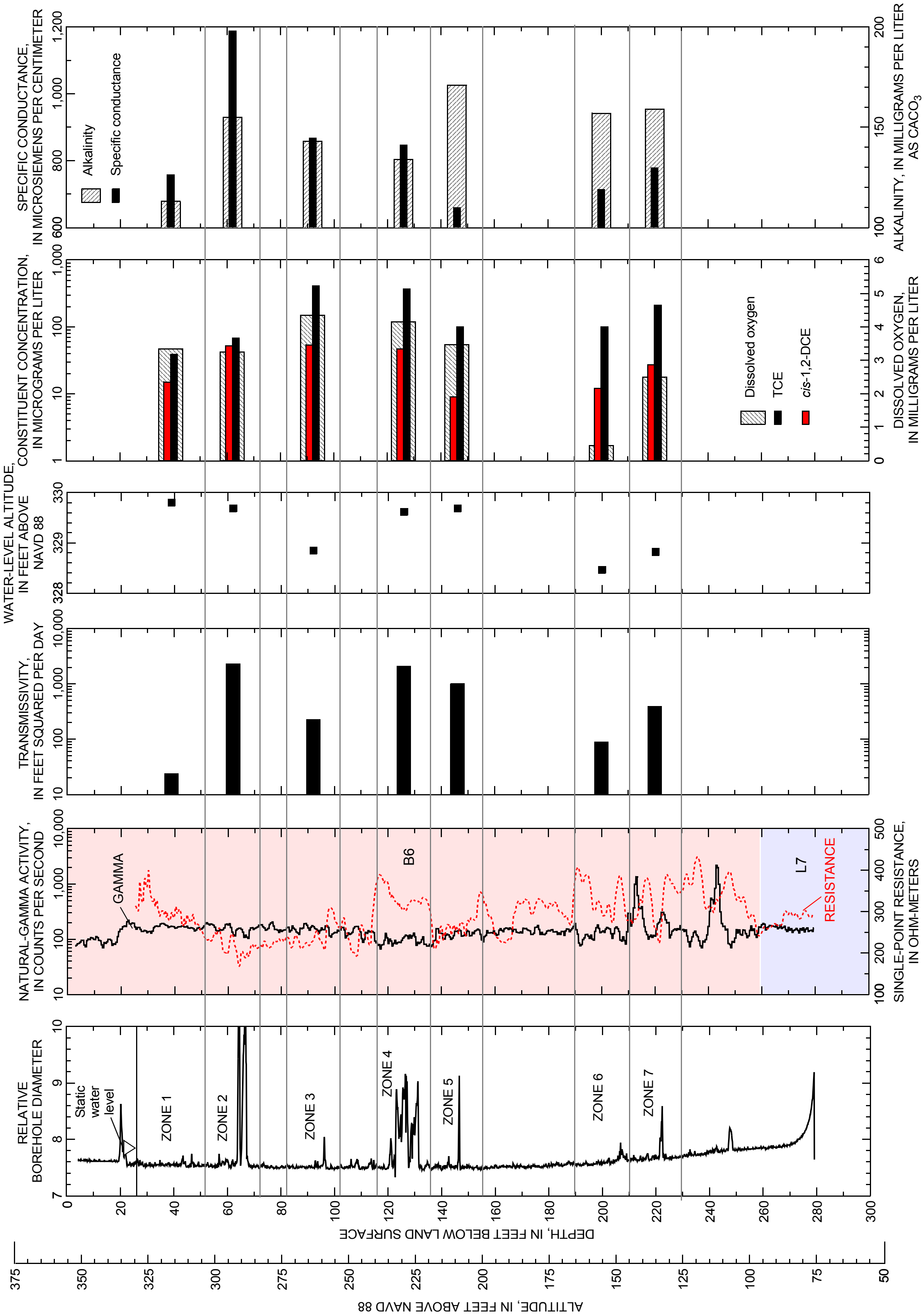


Figure 62. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 8-10, 2004.

Table 65. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG- 2126 (RI-13D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 8-10, 2004.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 52	6/8/2004	09:46	14.20	7.36	3.34	757	113	0.009	0.05	0.89	17	0.1
2	52–72	6/7/2004	17:16	13.31	7.10	3.25	1,188	155	<.001	.01	.10	23	.7
3	82–102	6/8/2004	12:15	14.25	7.34	4.35	867	143	.004	.01	.11	26	.6
4	116–136	6/8/2004	14:32	14.44	7.36	4.15	846	134	.000	.02	.20	25	1.2
5	136–156	6/9/2004	10:02	13.60	7.46	3.47	659	171	.005	.05	.11	26	.2
6	190–210	6/9/2004	14:20	14.50	7.52	.45	713	157	.002	.02	.11	28	.5
7	210–230	6/10/2004	10:30	13.53	7.36	2.49	778	159	.001	.03	.13	26	1.1

Table 66. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2126 (RI-13D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 8-12, 2004.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; PCE, tetrachloroethylene; freon-11, trichlorofluromethane; µg/L, micrograms per liter; blank in column indicates compound was not detected; E, estimated; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	Toluene (µg/L)	Freon-11 (µg/L)	Methylene chloride (µg/L)
1	above 52	6/8/2004	09:46	15	39		220	4J	
2	52–72	6/7/2004	17:16	52	68		2J	7J	
3	82–102	6/8/2004	12:15	30J	260	2J	2J	5J	14J
4	116–136	6/8/2004	14:32	25J	230			5J	6J
5	136–156	6/9/2004	10:02	9J	100			2J	
6	190–210	6/9/2004	14:20	12	100		2J	2J	
7	210–230	6/10/2004	10:30	27	150	1J	2J	3J	

MG-2129 (RI-14D)

Four intervals (table 67) in the 299-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 24 ft. Geophysical logging indicated several probable water-bearing zones from about 70, 90–94, 155, and 210 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 90–94 ft bls as the most productive.

Results of the packer tests (table 67; fig. 63) confirm some observations from the geophysical logging. The packer tests indicated the intervals above 85 and between 85–109 ft bls were the most productive; these intervals (zones 1 and 2) had the largest transmissivity values (352 and 399 ft^2/d, respectively) of zones tested in the borehole although an order of magnitude smaller than the largest transmissivity values of most other boreholes. Water levels in the isolated intervals were up to 0.9 ft different than those in adjacent intervals (table 67; fig. 63). The lowest hydraulic head was in the interval between 137–161 ft bls (zone 3), indicating downward and upward gradients in the borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow where water entered the borehole through fractures near 70 and 210 ft bls, moved downward and upward, respectively, and exited the borehole through the fractures at 90–94 and 155 ft bls.

The inorganic chemical constituents and properties showed few differences among water samples from the isolated intervals. Concentrations of dissolved oxygen were greater than 2 mg/L and decreased slightly with depth (table 68). No sample was collected from the interval between 161–299 ft bls (zone 4) because yield was too low. Water from the interval between 85–109 ft bls (zone 2) had the lowest specific conductance and concentration of alkalinity. PCE, toluene, and freon-113 at low concentrations were the only VOCs detected; PCE was measured at the highest concentration (10 µg/L) (table 69). PCE was only detected in water from the interval between 137–161 ft bls (zone 3).

Table 67. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2129 (RI-14D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 16-17, 2005.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
Zone 1 (above 85 ft bls) tested June16, 2005										
above 85 (pumped)	43.71	43.52	332.48	0.19	45.08	1.56	2.53	129	1.622	352
below 85	43.71	43.74	332.26	-.03	44.30	.56				
Zone 2 (85–109 ft bls) tested June16, 2005										
above 85	43.51	43.30	332.70	.21	43.77	.47				
85–109 (pumped)	43.51	43.50	332.50	.01	44.57	1.07	1.97	127	1.841	399
below 109	43.51	44.17	331.83	-.66	44.47	.30				
Zone 3 (137–161 ft bls) tested June17, 2005										
above 137	43.92	43.87	332.13	.05	43.95	.08				
137–161 (pumped)	43.93	44.42	331.58	-.49	96.05	51.63	1.45	266	.028	6.09
below 161	43.92	43.50	332.50	.42	43.78	.28				
Zone 4 (161–299 ft bls) tested June17, 2005										
above 161	43.94	43.92	332.08	.02	43.93	.01				
161–299 (pumped)	43.94	43.50	332.50	.44	67.55	24.05	.4	11	.017	3.61

[1]Land-surface altitude surveyed near well head was 357.9 feet above North American Vertical Datum of 1988 (NAVD 88).

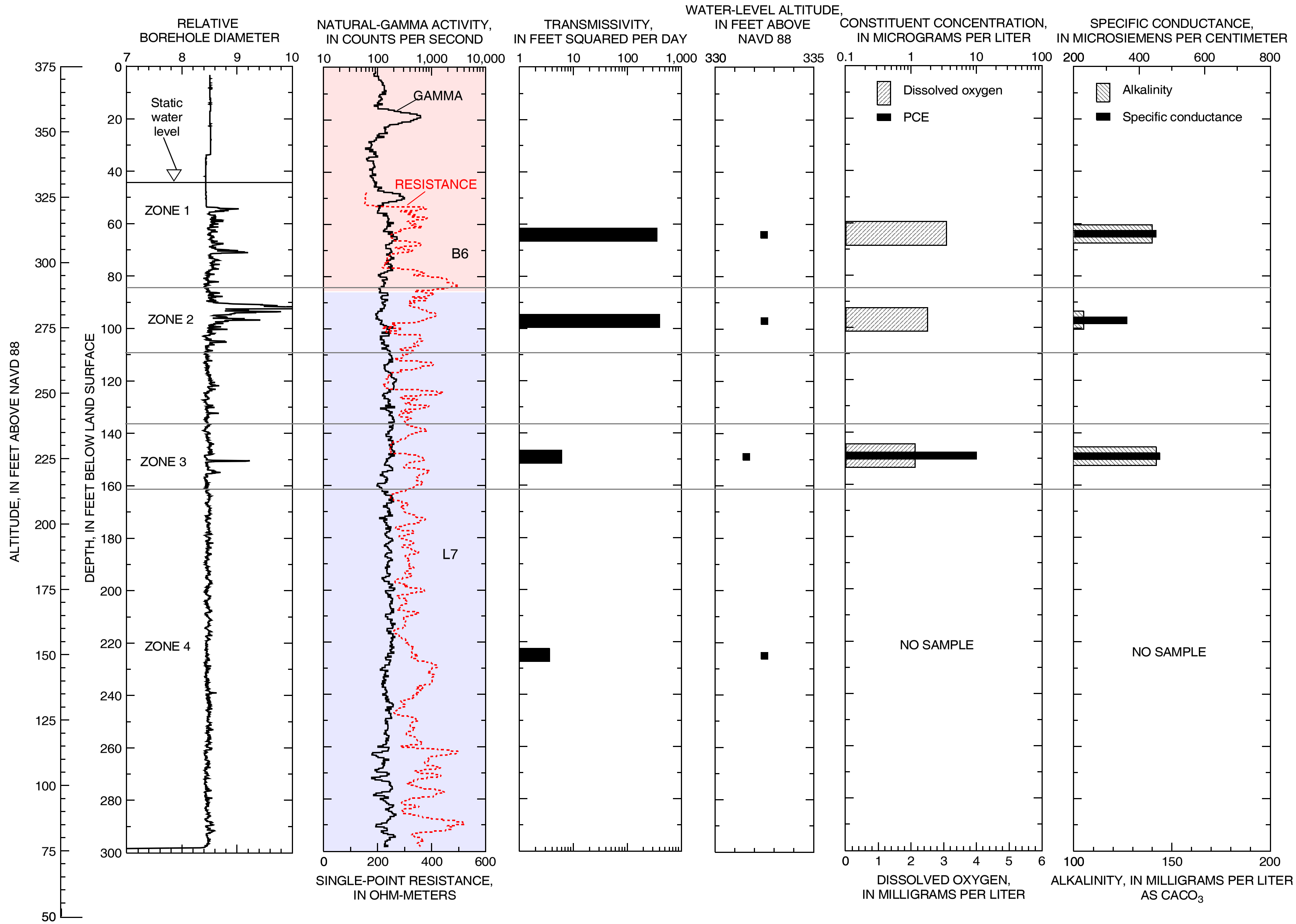


Figure 63. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2129 (RI-14D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 16-17, 2005.

Table 68. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2129 (RI-14D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 16-17, 2005.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 85	6/16/2005	17:30	16.83	7.22	3.09	451	140	0.003	0.07	0.14	39	1.4
2	85–109	6/16/2005	11:45	18.08	6.71	2.51	362	105	.009	.13	.29	31	1.5
3	137–161	6/17/2005	13:00	18.12	7.56	2.12	462	142	.002	.06	.16	32	1.0
4	161–299	6/17/2005	no sample										

Table 69. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2129 (RI-14D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 16-17, 2005.

[ft bls, feet below land surface; PCE, tetrachloroethylene; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; µg/L, micrograms per liter; blank in column indicates compound was not detected; J, analyte present but reported value may not be accurate or precise]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	PCE (µg/L)	Toluene (µg/L)	Freon-113 (µg/L)
1	above 85	6/16/2005	17:30		3J	2J
2	85–109	6/16/2005	11:45		4J	2J
3	137–161	6/17/2005	13:00	10	3J	
4	161–299	6/17/2005	no sample			

MG-2131 (RI-15DD)

Seven intervals (table 70) in the 299-ft deep well were selected for isolation on the basis of geophysical-logging results and borehole video. The spacing between the midpoints of the straddle packers was 22 ft. Geophysical logging indicated probable water-bearing zones from about 81 to 250 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse flowmeter identified the fracture zones near 81, 106, and 119 ft bls as the most productive.

Results of the packer tests (table 70; fig. 64) confirm some observations from the geophysical logging. The packer tests indicated the intervals between 72–94 and 94–116 ft bls were the most productive; these intervals (zones 2 and 3) had the largest transmissivity values (337 and 364 ft^2/d, respectively) of zones tested in the borehole although an order of magnitude smaller than the largest transmissivity values of most other boreholes. Water levels in the isolated intervals were up to 3.6 ft different than those in adjacent intervals (table 70; fig. 64). The lowest hydraulic head was in the interval between 234–256 ft bls (zone 6), indicating generally downward gradients in the borehole. The distribution of hydraulic heads (static water levels in isolated intervals) measured in the packer tests generally agrees with previously measured borehole flow, where under non-pumping conditions, water entered the borehole through fractures near 81 and 130 ft bls, moved downward, and exited the borehole through the fractures near 150 and 203 ft bls. Although flow was not detected below 220 ft bls during logging, the low hydraulic head measured in the test of zone 6 suggests that water might exit through fractures near 240 ft bls.

The inorganic chemical constituents and properties showed some differences among water samples from the isolated intervals. Concentrations of dissolved oxygen were about 2–3 mg/L in the upper 139 ft of the borehole but were less than 1 mg/L at depths greater than 193 ft bls (table 71). No sample was collected from the interval between 261–300 ft bls (zone 4) because yield was too low. Water from the interval between 94–116 ft bls (zone 3) had the lowest specific conductance. TCE, *cis*-1,2-DCE, toluene, freon-113, freon-11, and carbon tetrachloride were the only VOCs detected; TCE was measured at the highest concentrations (up to 640 μg/L) (table 72). The concentration of TCE was highest in the shallowest interval (zone 1, above 72 ft bls); concentrations of

Table 70. Depths, water levels, drawdown, pumping rate, pumping duration, specific capacity, and calculated transmissivity of aquifer intervals isolated by packers and tested for well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 9-13, 2005.

[ft bls, feet below land surface; ft avd, feet above vertical datum (North American Vertical Datum of 1988); ft, feet; gal/min, gallons per minute; min, minutes; (gal/min)/ft, gallons per minute per foot, ft^2/d, feet squared per day]

Depths of isolated interval (ft bls)	Open-hole depth to water (ft bls)	Post-inflation depth to water (ft bls)	Post-inflation water-level altitude[1] (ft avd)	Change in water level after inflation (ft)	Depth to water at end of pumping (ft bls)	Draw-down (ft)	Average pumping rate (gal/min)	Pumping duration (min)	Specific capacity [(gal/min)/ft]	Trans-missivity (ft^2/d)
			Zone 1 (above 72 ft bls) tested June 9, 2005							
above 72 (pumped)	40.23	39.75	329.25	0.48	60.44	20.69	0.6	102	0.029	[2]6.29
below 72	40.23	40.26	328.74	-.03	40.27	.01				
			Zone 2 (72–94 ft bls) tested June 9, 2005							
above 72	40.50	38.90	330.10	1.60	39.51	.61				
72–94 (pumped)	40.51	39.85	329.15	.66	41.42	1.57	2.44	82	1.554	337
below 94	40.49	40.67	328.33	-.18	40.83	.16				
			Zone 3 (94–116 ft bls) tested June10, 2005							
above 94	40.52	39.91	329.09	.61	40.08	.17				
94–116 (pumped)	40.53	40.67	328.33	-.14	42.31	1.64	2.75	93	1.677	364
below 116	40.52	40.80	328.20	-.28	41.68	.88				
			Zone 4 (117–139 ft bls) tested June10, 2005							
above 117	40.54	39.23	329.77	1.31	40.45	1.22				
117–139 (pumped)	40.54	39.23	329.77	1.31	41.18	1.95	2.13	117	1.092	237
below 139	40.53	41.84	327.16	-1.31	42.01	.17				
			Zone 7 (142–164 ft bls) tested June13, 2005							
above 142	40.37	39.84	329.16	.53	39.83	-.01				
142–164 (pumped)	40.37	40.84	328.16	-.47	58.18	17.34	.5	6	.029	6.26
below 164	40.37	41.83	327.17	-1.46	41.86	.03				
			Zone 5 (193–215 ft bls) tested June 13, 2005							
above 193	40.36	39.96	329.04	.40	39.22	-.74				
193–215 (pumped)	40.36	41.51	327.49	-1.15	44.65	3.14	2.06	125	.656	142
below 215	40.36	42.99	326.01	-2.63	43.49	.50				
			Zone 6 (234–256 ft bls) tested June 13, 2005[3]							
above 234	40.33	40.20	328.80	.13	40.21	.01				
234–256 (pumped)	40.32	43.93	325.07	-3.61	87.30	43.37	3.18	33	.073	15.9
below 256	40.31	41.48	327.52	-1.17	42.11	.63				

[1]Land-surface altitude surveyed near well head was about 369 feet above North American Vertical Datum of 1988 (NAVD 88) at thime of packer test.

[2]Specific capacity and transmissivity probably overestimated because drawdown did not stabilize during pumping.

[3]Second test of zone; during first test, interval was pumped at about 0.66 gal/min for 35 mintues with drawdown of 4.77 ft. resulting in calculated specific capacity of 0.138 (gal/min)/ft and transmissivity of 30 ft^2/d.

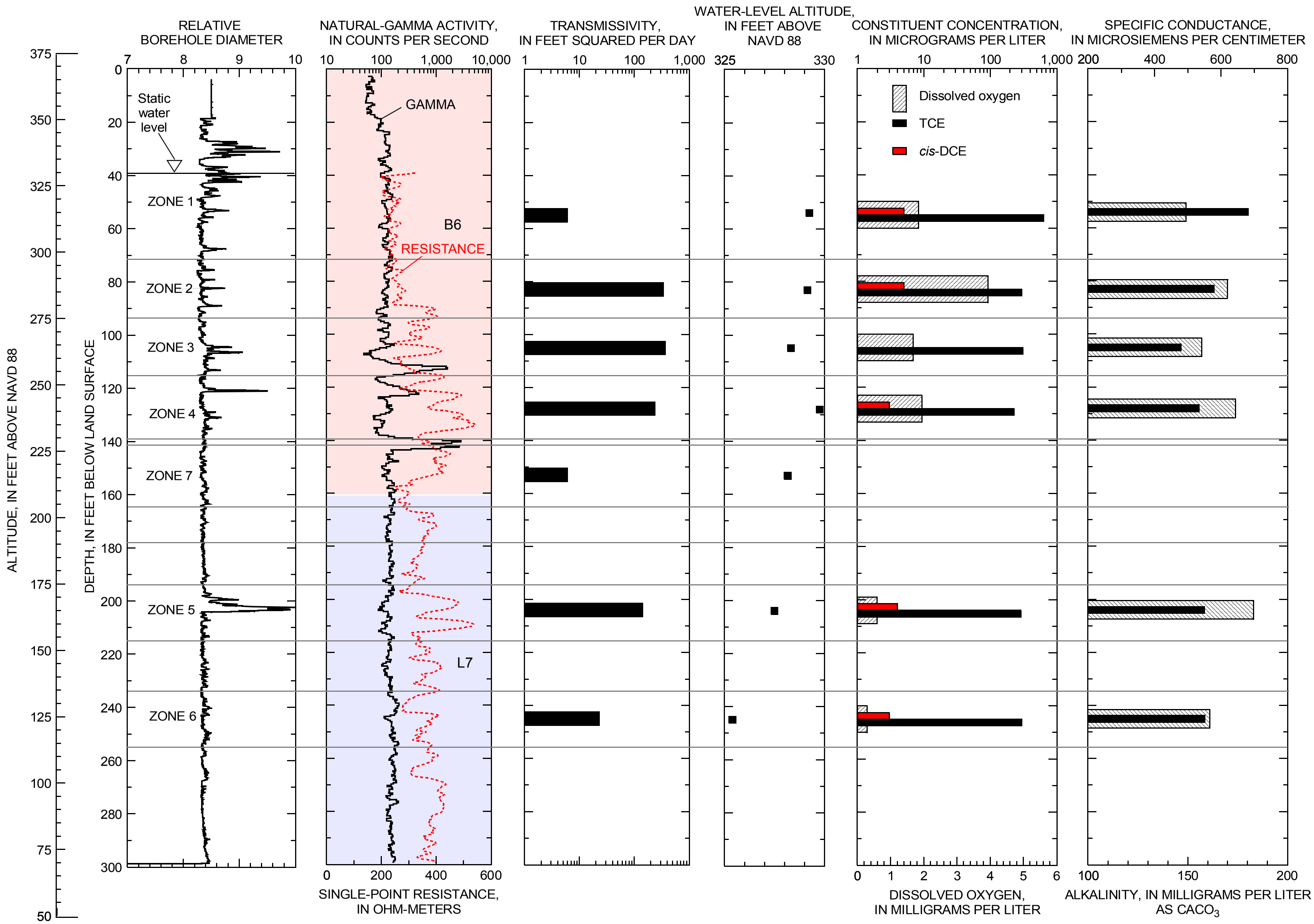


Figure 64. Borehole caliper log showing zones isolated by packers, natural-gamma and single-point-resistance logs with estimated extent of mapped geologic unit (see bed codes, fig. 5), and for each isolated interval, calculated transmissivity, measured static water-level altitude, and water-sample specific conductance and concentrations of selected volatile organic compounds, dissolved oxygen, and alkalinity in borehole MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 9-13, 2005.

Table 71. Inorganic water-quality constituents and physical properties for water samples collected from isolated intervals in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 9-13, 2005.

[ft bls, feet below land surface; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; <, less than]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Sulfide (mg/L)	Ferrous iron (mg/L)	Iron, total (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)
1	above 72	6/9/2005	10:25	18.28	7.49	1.84	682	149	0.015	0.03	0.88	35	1.1
2	72–94	6/9/2005	14:25	18.42	7.55	3.93	579	170	.007	.05	.12	37	1.3
3	94–116	6/10/2005	11:05	17.56	7.64	1.92	479	157	.013	.02	.08	42	.9
4	117–139	6/10/2005	16:00	17.90	7.57	1.94	534	174	.006	.02	.11	41	.8
7	142–164	6/13/2005	no sample										
5	193–215	6/13/2005	12:00	18.59	7.57	.59	550	183	.007	.03	.17	45	1.1
6	234–256	6/13/2005	17:30	16.64	7.66	.29	551	161	.005	<.01	.21	43	1.0

Table 72. Concentrations of detected volatile organic compounds in water samples collected from isolated intervals in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., June 9-13, 2005.

[ft bls, feet below land surface; *cis*-1,2-DCE, *cis*-1,2-dichloroethylene; TCE, trichloroethylene; freon-113, 1,1,2-trichloro-1,2,2-trifluoroethane; freon-11, trichlorofluromethane; carbon tet., carbon tetrachloride; µg/L, micrograms per liter; J, analyte present but reported value may not be accurate or precise; E, estimated; blank in column indicates compound was not detected]

Zone	Depth of isolated interval (ft bls)	Date of sample	Time of sample	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Toluene (µg/L)	Freon-113 (µg/L)	Freon-11 (µg/L)	Carbon tet. (µg/L)
1	above 72	6/9/2005	10:25	5J	[1]640E	130	9J	2J	2J
2	72–94	6/9/2005	14:25	5J	[2]300E	4J	7J	2J	2J
3	94–116	6/10/2005	11:05		310		6J		
4	117–139	6/10/2005	16:00	3J	230	6J	3J		
5	193–215	6/13/2005	12:00	4J	290	5J	6J	3J	
6	234–256	6/13/2005	17:30	3J	300	6J	6J	3J	

[1]520 µg/L by replicate analysis of diluted sample.

[2]270 µg/L by replicate analysis of diluted sample.

TCE were similar (about 300 µg/L) in water from the deeper intervals.

Comparison of Aquifer-Interval-Isolation Tests

Aquifer-interval-isolation tests provided information about relative productivity of water-bearing zones and distribution of hydraulic heads that generally confirmed preliminary estimates of productivity and vertical gradients determined from geophysical logging, with some exceptions. The aquifer-interval-isolation tests in some cases identified water-bearing zones not explicitly determined from geophysical logging. Both types of investigations in the 300-ft wells yielded results that indicate water-bearing zones may occur from about 18 (bottom of casing) to nearly 300 ft bls (bottom of well).

Transmissivities of tested isolated water-bearing zones ranged over three orders of magnitude for all 17 wells tested (from 2.8 to 2,300 ft^2/d) and commonly ranged over two or more orders of magnitude for zones in a single well (table 21). The single-well total transmissivity ranged from 515 to 6,080 ft; the median was about 1,900 ft^2/d. Wells with the highest total transmissivity (greater than 3,500 ft^2/d) included MG-2126 (RI-13D), MG-2097 (RI-8D), and MG-2100 (RI-9D). Wells with the lowest total transmissivity (less than 800 ft^2/d) included MG-2129 (RI-14D), MG-2080 (RI-1D), MG-2122 (RI-11D), and MG-2125 (RI-12).

Hydraulic head differences between isolated zones were greatest (more than 12 ft) in wells MG-2081 (RI-2D), MG-2093 (RI-6D), and MG-2100 (RI-9D), all of which probably are affected by nearby pumping. Heads in isolated zones indicated a downward gradient in MG-2081 (RI-2D) and upward gradients to water-receiving zones at about 80–100 ft bls in wells MG-2093 (RI-6D) and MG-2100 (RI-9D). In the 17 wells tested, the lowest hydraulic head of about 293 ft above NAVD 88 was measured in the deepest zone of MG-2081 (RI-2D) and an intermediate zone (80–106 ft bls) of MG-2100 (RI-9D). The highest hydraulic head measured was about 351 ft above NAVD 88 in a deep zone of MG-2093 (RI-6D). In other wells, hydraulic head differences between isolated zones were smaller, and heads ranged from about 315 to 340 ft above NAVD 88.

Inorganic water-quality differences in samples from isolated zones indicated that ground-water flow follows discrete paths in the aquifer. Water-quality differences determined from interval-isolation (packer) tests of open-hole wells should be considered estimates only because during the period prior to testing, water from producing intervals flowed to receiving intervals, potentially affecting water quality in the receiving-water zone. Trends with depth were apparent for some chemical characteristics. In most samples from isolated intervals of a given well, pH appeared to increase with depth. In many wells, specific conductance and the concentrations of dissolved oxygen generally decreased with depth of isolated interval.

Overall, pH in water from isolated intervals was near neutral and ranged from about 6.3 to 8.1; most samples had neutral pH from about 7.0 to 7.6. Alkalinity ranged from 25 to 354 mg/L as $CaCO_3$; alkalinity in most intervals ranged from about 120 to 200 mg/L as $CaCO_3$. The concentrations of dissolved oxygen ranged from 0.1 to 9.0 mg/L and were less than 1 mg/L in most of the deeper intervals isolated, indicating possible reducing conditions that may increase potential for VOC degradation. Ferrous iron, indicative of reducing conditions, was present in concentrations greater than 1.0 mg/L in water from two wells [MG-1920 (Ford MW-1) and MG-2125 (RI-12D)].

Specific conductance ranged from 373 to 2,742 µS/cm in samples from all intervals and was especially elevated (greater than 900 µS/cm) in water from intervals in several wells on the western part of the part of the study area, including wells MG-2090 (RI-5D), MG-2125 (RI-12D), and MG-2126 (RI-13D). The source of the elevated specific conductance probably is dissolved salts because concentrations of sulfate and alkalinity in water from two of these wells were similar to that in water from other wells tested. Water from well MG-2125 had the highest specific conductance, however, and the highest concentration of alkalinity of any tested well. Dissolved salts may be conservative and useful as a tracer.

Trichloroethylene was the most frequently detected chlorinated VOC; the maximum concentration was 640 µg/L in samples from 13 of the 17 wells tested. Other halogenated VOCs detected in half or less of the 18 wells tested include *cis*-1,2-dichloroethylene, tetrachloroethylene, freon-113, and freon-11 at maximum concentrations of 120, 37, 71, and 55 µg/L, respectively. VOCs detected in water samples from three or fewer wells include carbon tetrachloride, 1,1-dichloroethylene, 1,1-dichloroethane, 1,1,1-trichloroethane, and xylenes at maximum concentrations of 33, 33, 4, 10, and 4 µg/L, respectively. Toluene was detected in samples from at least 1 interval in all 17 wells tested at concentrations ranging from 3 to 280 µg/L but may be present largely because of possible sampling-equipment contamination. Toluene was detected in samples from zones isolated by packers in some wells during phase 1 (December 2000 through September 2002) but was not detected in subsequent samples from those wells collected without packers (CDM, written commun., 2005). The absence of detected toluene in samples collected without packers suggests that toluene concentrations above 1 µg/L may be associated with packer-equipment contamination, except at the Spra-Fin property where 240 µg/L toluene was measured in a sample collected without packers in February 2001. Acetone and(or) methylene chloride (dichloromethane) were reported as detected in low concentrations ranging from 1 to 14 µg/L in a few water samples from four wells; these compounds are common laboratory contaminants so it is not known if they were actually present in the ground water in the study area.

Concentrations of most VOC contaminants in most wells with predominantly upward vertical gradients were greatest in ground-water samples from the relatively shallow isolated intervals. Concentrations of VOCs in wells with predominantly downward gradients showed less variability with depth, which partly may be a result of borehole flow transporting contamination from shallower to deeper intervals while the hole was open. Consequently, concentrations of VOCs in samples collected during aquifer-isolation tests of the open boreholes should be evaluated with caution.

Multiple-Well Test

In late November and early December 2004, water levels were monitored in 14 wells in the vicinity of MG-202 (L-22) (fig. 65) to record response to the shutdown and restart of pumping in well MG-202. Water-level data were also available during this period in two background wells (MG-68 and MG-917, fig. 65) not thought to be affected by pumping of well MG-202. Well MG-202 was shutdown after pumping at a rate of about 75 gal/min on November 30 and restarted at the same rate on December 3, 2004. Wells selected for water-level monitoring during this period included 4 open holes and 10 monitor wells that had been reconstructed to be open to 20-ft intervals (table 73).

Water levels from November 29 through December 10, 2004, for pumping well MG-202, background wells MG-917 and MG-68, and 14 observation wells are shown in figures 66-69. Soon after the shutdown on November 30, a storm passed through the area resulting in rainfall and changes in barometric pressure that affected water levels regionally, with a maximum rise in background water levels of about 0.8 ft on December 1, 2004 (fig. 67). Little to no rainfall and smaller pressure changes occurred during the first day after the restart of pumping on December 3, 2004. Because the storms effect on water levels was difficult to remove from response to the shutdown, only the early-time (about 1 day or first 1,000 minutes) observation-well responses to restart of pumping production well MG-202 were considered for analysis. Water levels in 8 of 14 observation wells [(MG-72, MG-1897, MG-2093 (RI-6D), MG-2094 (RI-6S), MG-2122 (RI-11S), MG-2082 (RI-2I), MG-2081 (RI-2D), and MG-2101 (RI-9I)] clearly responded to pumping of well MG-202; water levels in the other 6 wells responded slightly or not at all [MG-2123 (RI-11I), MG-2122 (RI-11D), MG-1145 (T-14), MG-1146 (T-4), MG-2087 (RI-4D), and MG-2084 (RI-3D)] (figs. 68 and 69). Three wells [MG-1146 (T-4), MG-2087 (RI-4D), and MG-2084 (RI-3D)] along strike to each other on the east side of Wissahickon Creek downdip of MG-202 apparently responded to one or more separate pumping stresses (fig. 69,

Table 73. Depth of open intervals in wells selected for water-level monitoring during aquifer test of well MG-202 (L-22), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., November-December 2004.

[ft bls, feet below land surface; NAVD 88, North American Vertical Datum of 1988; ft, feet; ft^2/d, feet squared per day; --, not estimated because of no apparent or very muted, delayed response to pumping well MG-202]

U.S. Geological Survey local well number	Well name	Altitude of land surface (ft above NAVD 88)	Depth of open interval (ft bls)	Altitude of top of open interval (ft above NAVD88)	Altitude of bottom of open interval (ft above NAVD88)	Radial distance from pumped well MG-202 (ft)	Transmissivity estimated[1] from water-level response (ft^2/d)	Storage coefficient
Pumped well								
MG-202	L-22	352	40–623	312	-271	0.5	69	0.52
Observation wells—along approximate strike								
MG-72	L-13	355.1	41.5–298	313.6	57.1	1,672	834	.00011
MG-1897	Clearline 3	334.2	44–288	290.2	46.2	1,148	1,131	.00045
MG-2082	RI-2I	329.1	176–186	153.1	143.1	2,287	739	.00007
MG-2081	RI-2D	329.3	276296	53.3	33.3	2,281	712	.00010
Observation wells—downdip								
MG-1145	T-14	330.6	1983	311.6	247.6	2,659	--	--
MG-1146	T-4	343.8	18.584.5	325.3	259.3	2,338	--	--
MG-2084	RI-3D	371.5	182202	189.5	169.5	1,387	--	--
MG-2087	RI-4D	348.8	192212	156.8	136.8	2,315	--	--
Observation wells—updip								
MG-2094	RI-6S	343.9	4060	323.9	303.9	450	2,226	.0071
MG-2093	RI-6D	344.2	169189	175.2	155.2	454	891	.0026
MG-2101	RI-9I	335.5	166186	169.5	149.5	4,261	889	.00004
MG-2124	RI-11S	354.5	4060	314.5	294.5	1,660	1,139	.00058
MG-2123	RI-11I	355.0	80100	275	255	1,657	--	--
MG-2122	RI-11D	355.6	175195	180.6	160.6	1,654	--	--

[1]Transmissivity estimated using Theis solution for aquifer-test analysis of drawdownas a function of time.

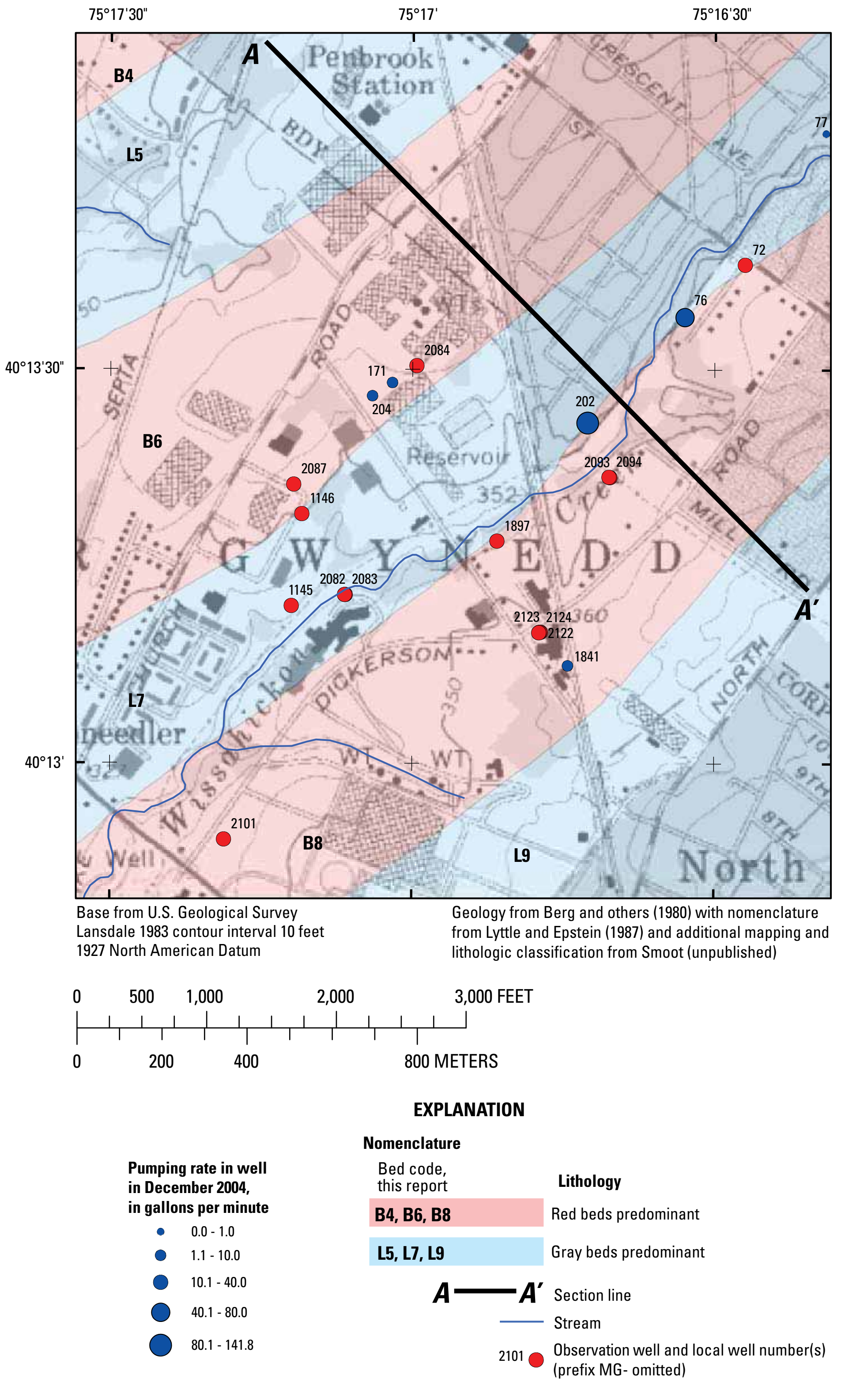


Figure 65. Location of production well MG-202, pumping wells MG-76, MG-171, and MG-204, and 14 observation wells monitored during shutdown and after restart of pumping production well MG-202 in the vicinity North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., late November to early December 2004.

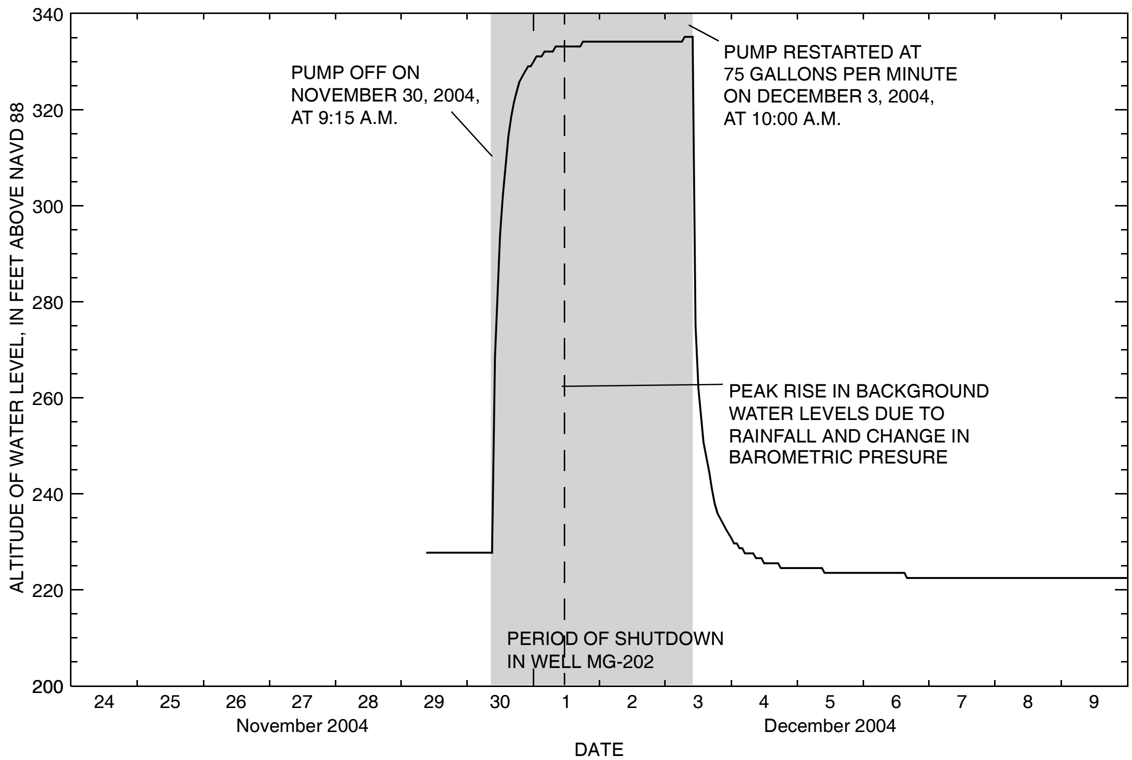


Figure 66. Hourly water-level altitude in production well MG-202 while pumping, during shutdown, and after restart of pumping at about 75 gallons per minute in the vicinity North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa. Pumping was stopped in well MG-202 on November 30, 2004, at 9:15 a.m. and restarted on December 3, 2004, at about 10:00 a.m. Eastern Standard Time.

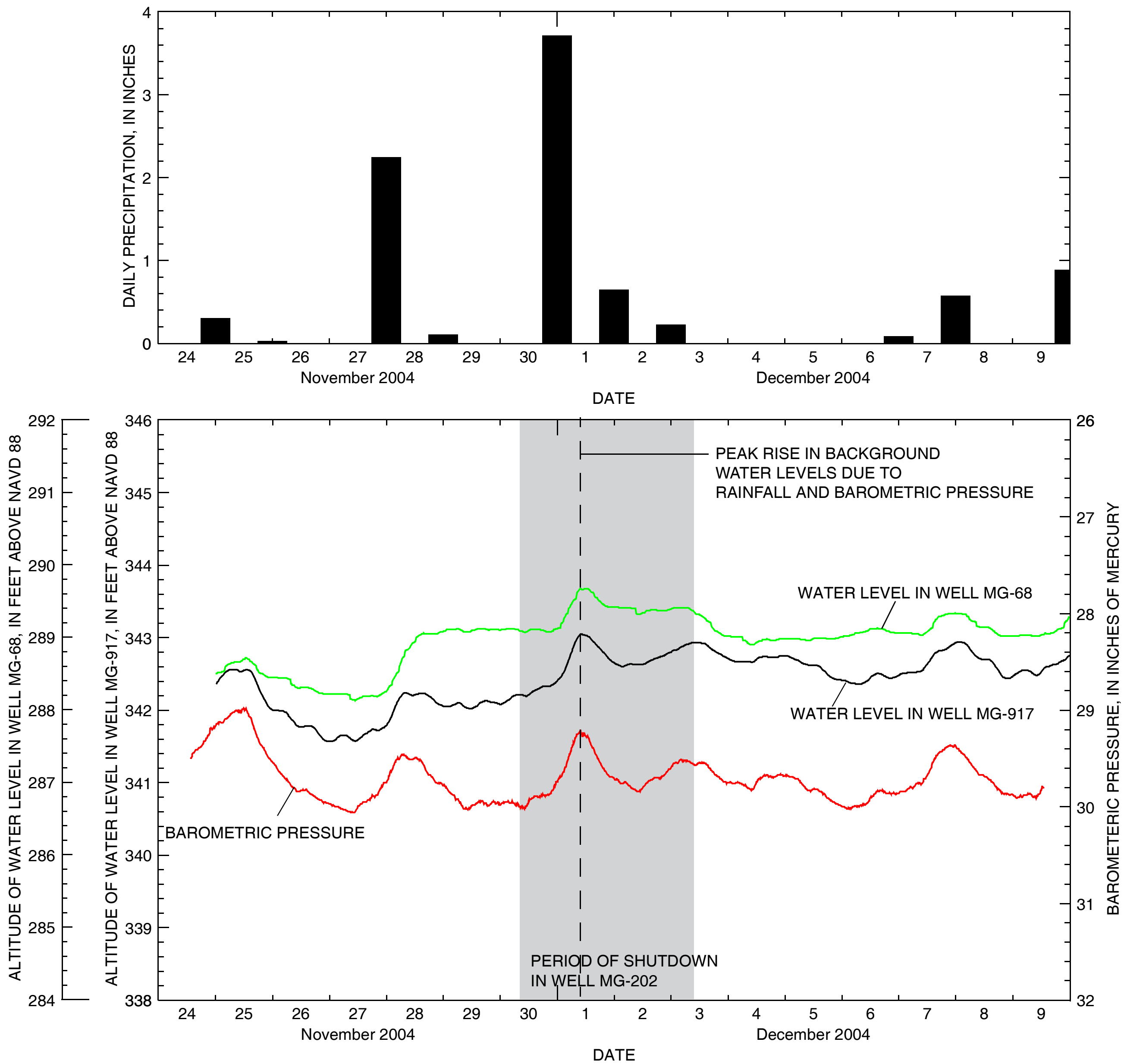


Figure 67. Daily precipitation recorded at the Graterford, Pa., National Oceanic and Atmospheric Administration observation station, water-level altitude in observation wells MG-68 and MG-917, and barometric pressure recorded by the U.S. Geological Survey in Lansdale, Pa., near North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., November 24 through December 9, 2004.

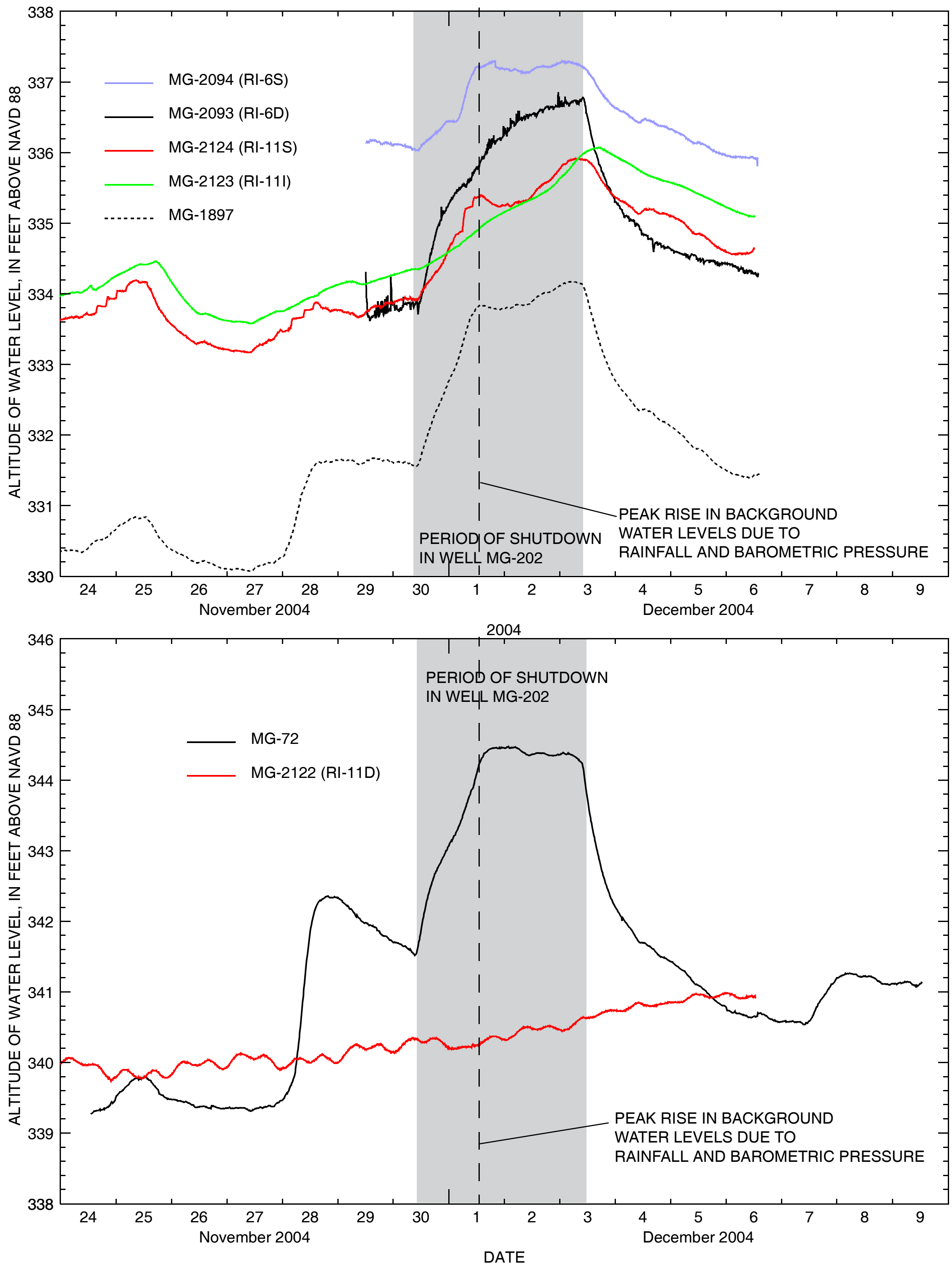


Figure 68. Water-level altitude in observation wells (top) MG-2094 (RI-6S), MG-2093 (RI-6D), MG-2124 (RI-11S), MG-2123 (RI-11I), and MG-1897 and (bottom) MG-72 and MG-2122 (RI-11D) during period when pumping in production well MG-202 was shutdown and restarted, North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., November 24 through December 9, 2004. Water levels responded most strongly to changes in pumping of MG-202 in wells MG-72, MG-1897, and MG-2093 (RI-6D), less strongly in wells MG-2094 (RI-6S), MG-2122 (RI-11S), weakly in MG-2123 (RI-11I) and not all in MG-2122 (RI-11D).

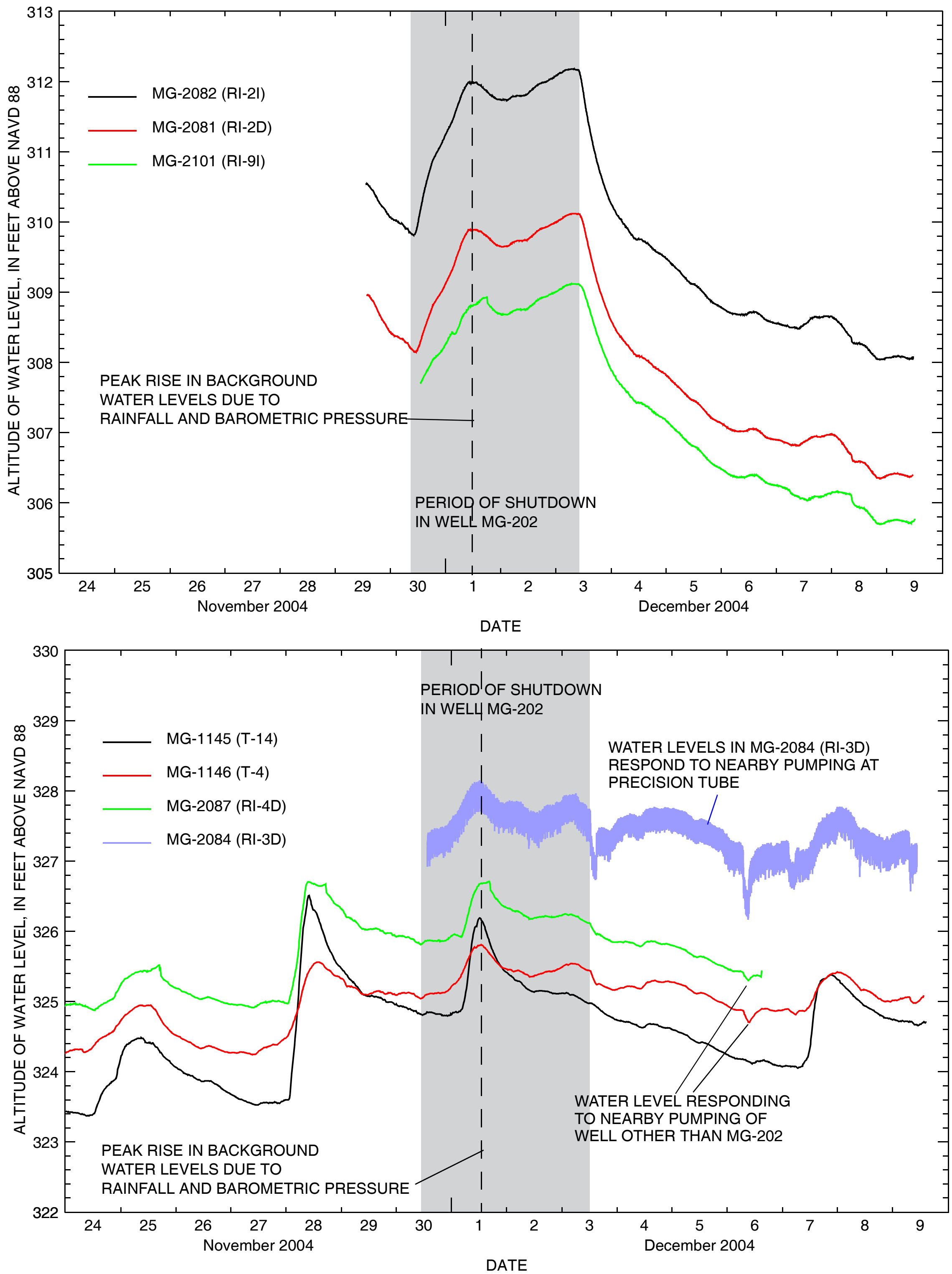


Figure 69. Water-level altitude in observation wells (top) MG-2082 (RI-2I), MG-2081 (RI-2D), and MG-2101 (RI-9I), and (bottom) MG-1145 (T-14), MG-1146 (T-4), MG-2087 (RI-4D), and MG-2084 (RI-3D) during period when pumping in production well MG-202 was shutdown and restarted, North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., November 24 through December 9, 2004. Water levels responded most strongly to changes in pumping of MG-202 in wells MG-2082 (RI-2I), MG-2081 (RI-2D), and MG-2101 (RI-9I), and not at all or very weakly in wells MG-1145 (T-14), MG-1146 (T-4), MG-2087 (RI-4D), and MG-2084 (RI-3D).

bottom), which includes pumping at the Precision Tube facility.

The spatial distribution of water-level responses to the shutdown and restart of pumping of well MG-202 appears related to the dip of the beds, where water-level responses are greatest in wells that intersect the bed with pumped zones. As shown in a cross-section schematic (fig. 70), where wells are projected onto the dip section, wells open to geologic unit with bed code B8 (fig. 5) responded whereas wells that are not open to that unit are not. Most water-bearing zones in well MG-202 are within unit B8 (fig. 70). The location of an existing production well MG-175 at Spra-Fin property is also shown for reference on figure 70. The well MG-175 was monitored and showed no responses to a previous shutdown and pumping test of MG-202 in 2002 (Senior and others, 2005).

The aquifer characteristics transmissivity (T) and storage coefficient (S) were estimated from analysis of drawdown data using the Cooper-Jacob straight-line method (Cooper and Jacob, 1946) for the pumped well MG-202 (fig. 71) and Theis curve-fitting method (Theis, 1935) for the observation wells (figs. 72-75). Both methods assume a confined isotropic aquifer that may not be the case for the heterogeneous, dipping-bed, fractured-rock aquifer, and therefore, estimates of T and S determined from analyses of the drawdowns are approximate at best. In heterogeneous systems, the highest drawdown generally is observed in zones of highest T (Goode and Senior, 1998), which may result in an inverse relation to T estimated from drawdown using the Theis method. Results of the analyses (table 73; figs. 71-75) show estimates of aquifer T are lowest for the pumped-well data (about 69 ft^2/d) and are an order of magnitude higher for the observation-well data (ranging from about 712 to 2,226 ft^2/d with a median of about 890 ft^2/d). Estimates of S from analyses of the observation-well data range over two orders of magnitude (from 0.00007 to 0.007) and are more reliable than estimates of S from analysis of the pumped-well data.

The estimates of T from the 2004 pumping test of MG-202 are similar in magnitude to the range determined using similar methods for observation-well responses to a shutdown test of production well MG-202 during phase 1 of the North Penn Area 7 investigations (800 to 1,600 ft^2/d; Senior and other, 2005), for aquifer tests done previously nearby at Merck (about 150 to 1,700 ft^2/d; Goode and Senior, 1998), and for pumping tests run by Martin (1981) in wells MG-202 and MG-1897 as described by CH2M Hill (1992). From the 1981 tests of MG-202 and MG-1897, T was estimated as 3,130 ft^2/d and 2,530 ft^2/d, respectively, and S was estimated as 0.00017 and 0.0003, respectively (CH2M Hill, 1992).

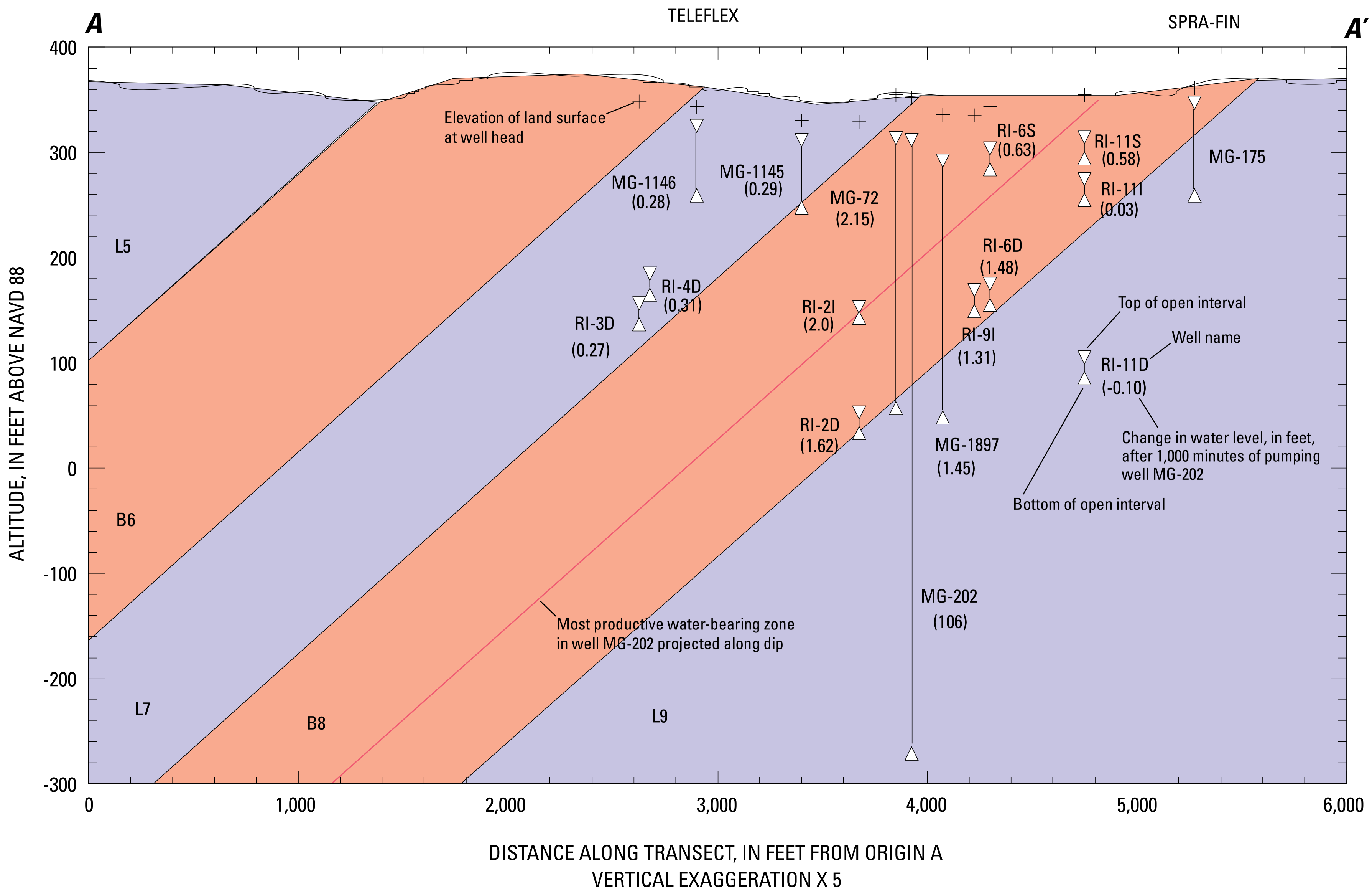


Figure 70. Cross section showing locatoin of production well MG-202, 14 observation wells monitored during shutdown and after restart of pumping production well MG-202 late November to early December 2004, well MG-175 at the Spra-Fin property, and mapped geologic unts (fig. 5) in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa. Well open interval depicted with measured change in water levels 1,000 mintues after restart of pumping in well MG-202 on December 3, 2004.

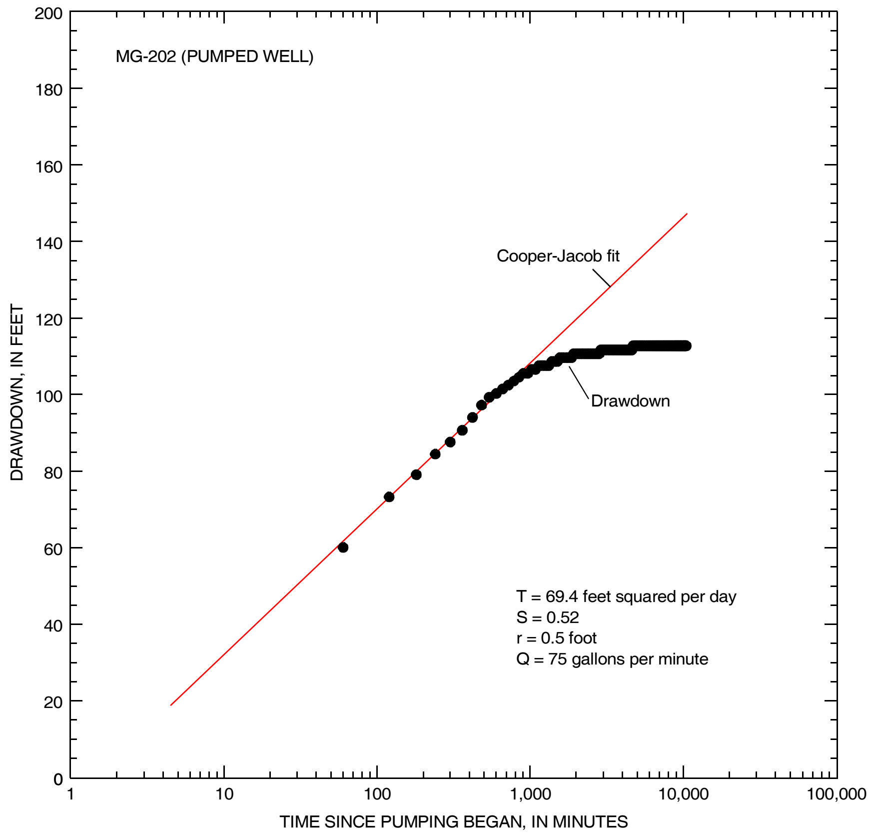


Figure 71. Drawdown in production well MG-202 in response to the start of pumping well MG-202 in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., on December 3, 2004, at a rate of 75 gallons per minute. Observed data are shown with Cooper-Jacob straight line fitted for the first 1,000 minutes of data and resulting estimates of transmissivity (T) and storage coefficient (S) for the production well with a radius (r).

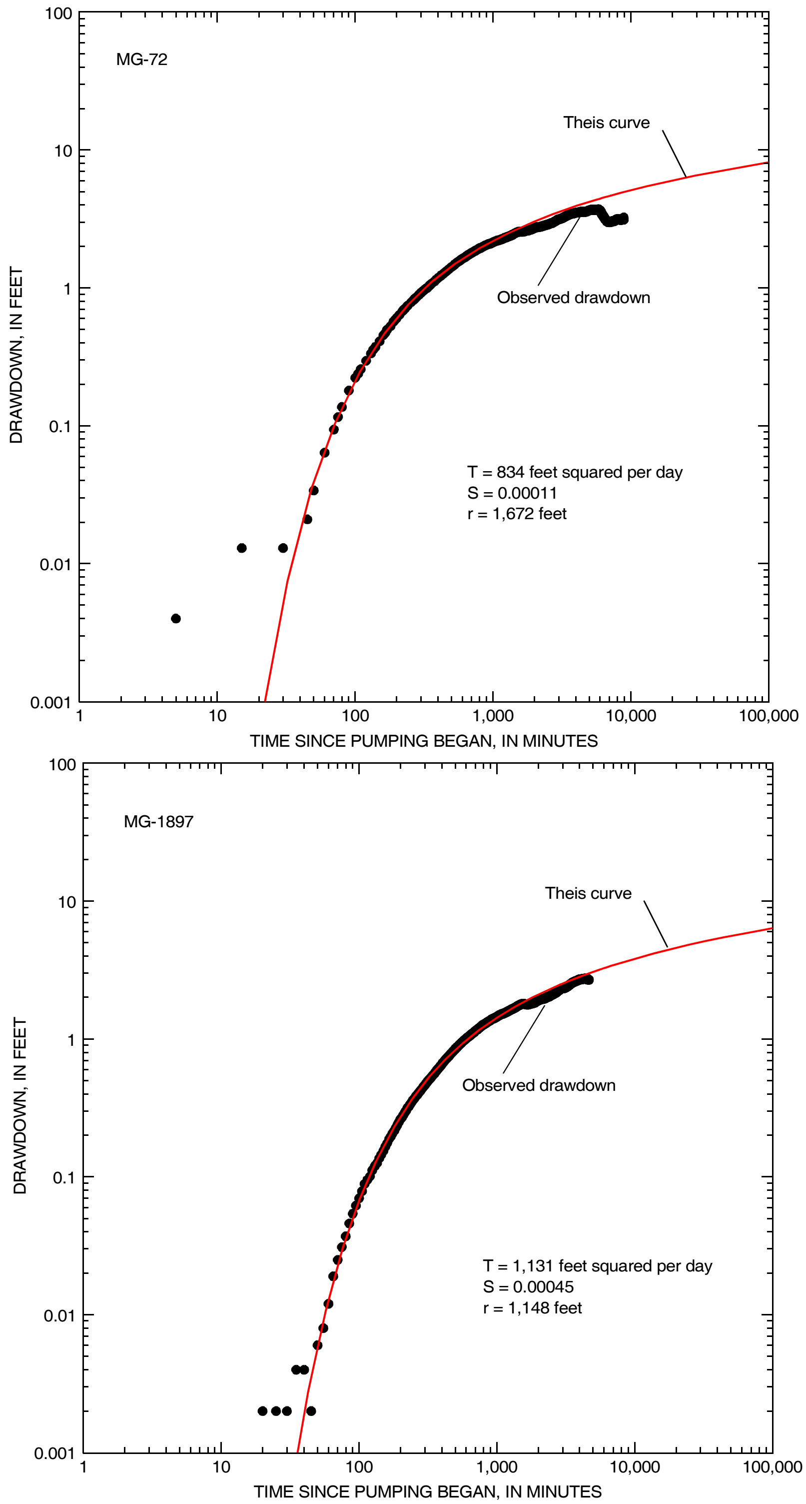


Figure 72. Drawdown in observation wells MG-72 and MG-1897 in response to the start of pumping of production well MG-202 in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., on December 3, 2004, at a rate of 75 gallons per minute. Observed data are shown with Theis curves fitted for the first 1,000 minutes of data and resulting estimates of transmissivity (T) and storage coefficient (S) for observation wells at radial distances (r) from the pumping well.

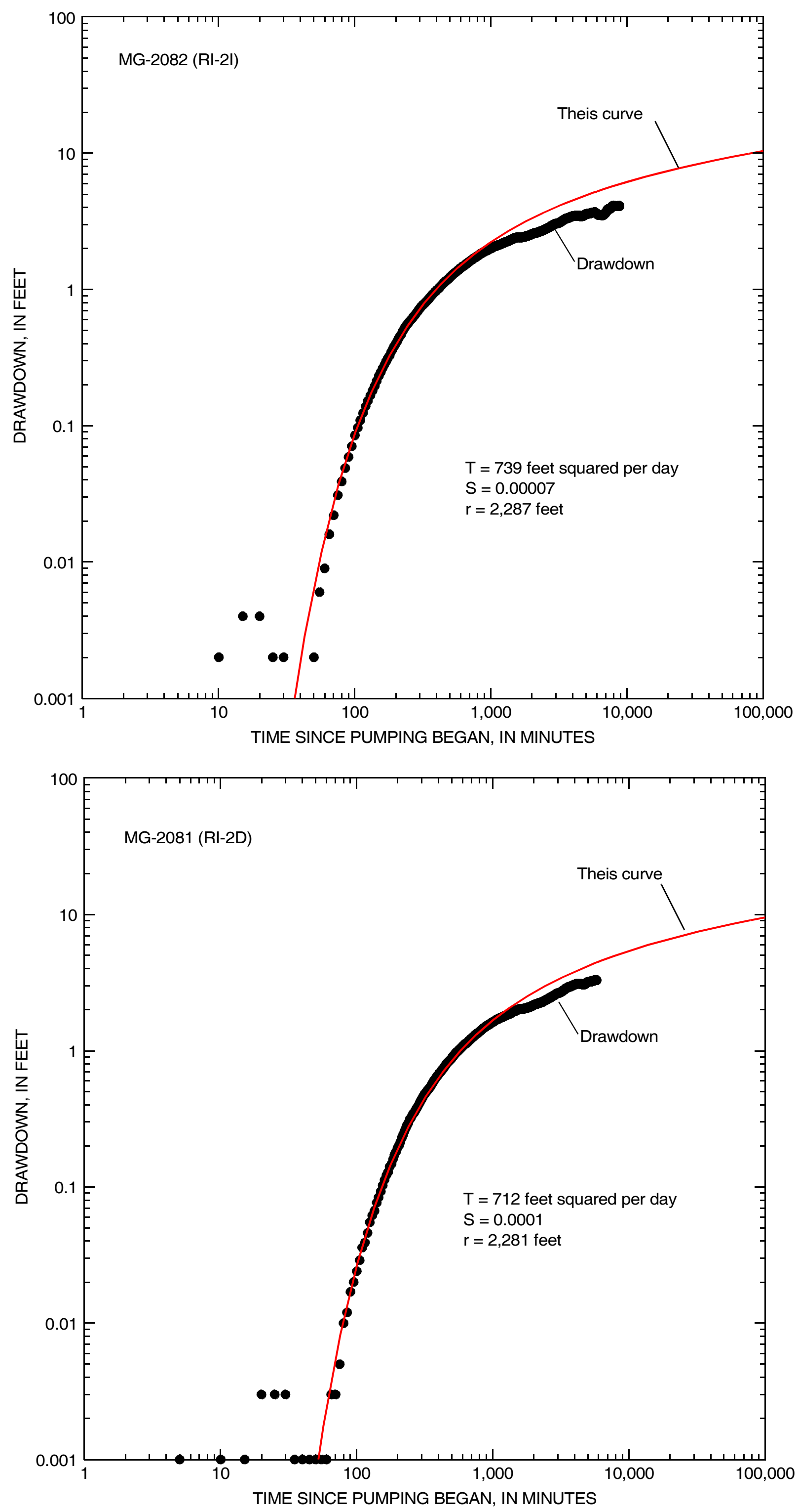


Figure 73. Drawdown in observation wells MG-2082 (RI-2I) and MG-2081 (RI-2D) in response to the start of pumping of production well MG-202 in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., on December 3, 2004, at a rate of 75 gallons per minute. Observed data are shown with Theis curves fitted for the first 1,000 minutes of data and resulting estimates of transmissivity (T) and storage coefficient (S) for observation wells at radial distances (r) from the pumping well.

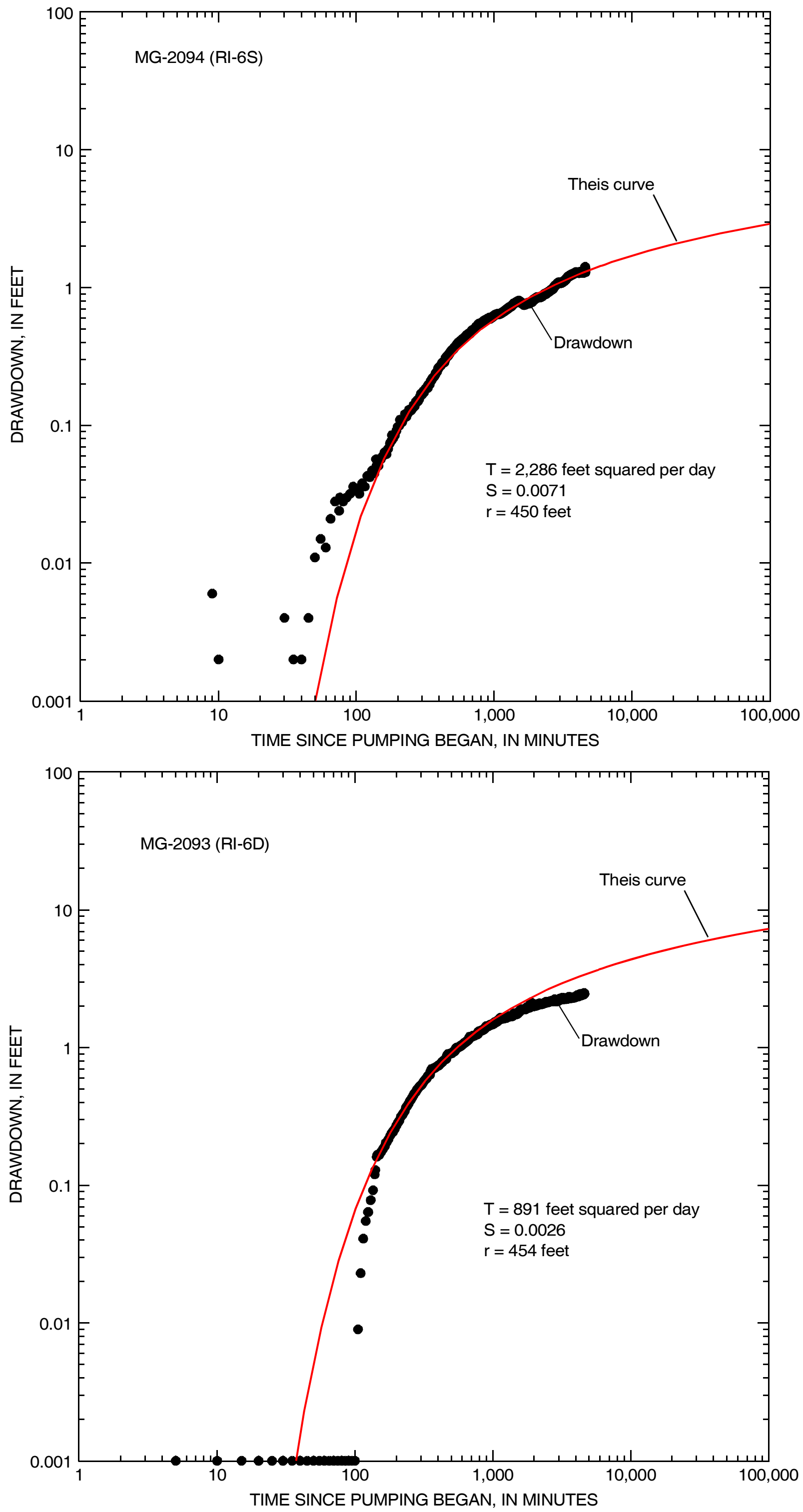
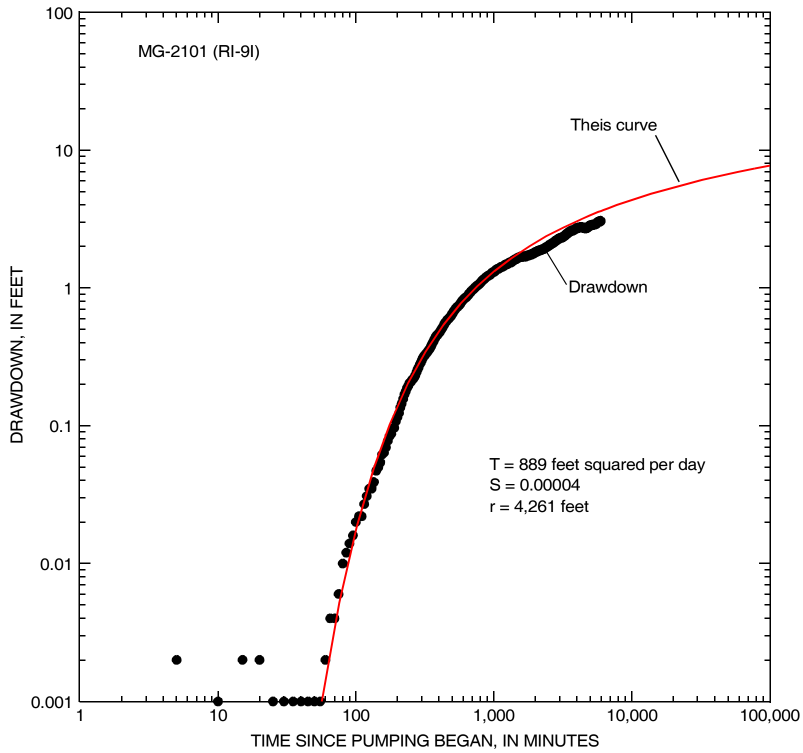


Figure 74. Drawdown in observation wells MG-2094 (RI-6S) and MG-2093 (RI-6D) in response to the start of pumping of production well MG-202 in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., on December 3, 2004, at a rate of 75 gallons per minute. Observed data are shown with Theis curves fitted for the first 1,000 minutes of data and resulting estimates of transmissivity (T) and storage coefficient (S) for observation wells at radial distances (r) from the pumping well.



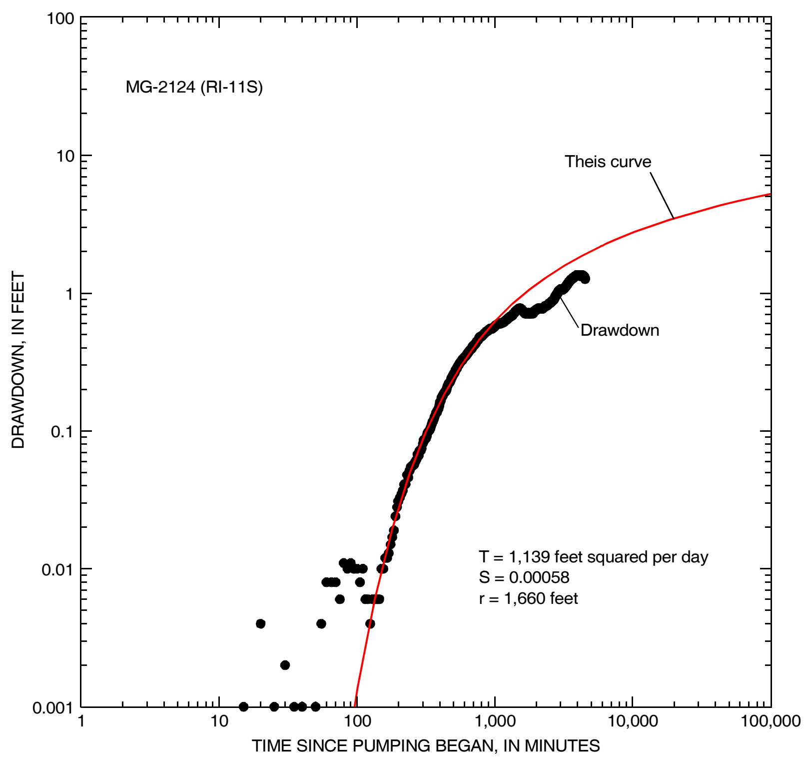


Figure 75. Drawdown in observation wells MG-2101 (RI-9I) and MG-2124 (RI-11S) in response to the start of pumping of production well MG-202 in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., on December 3, 2004, at a rate of 75 gallons per minute. Observed data are shown with Theis curves fitted for the first 1,000 minutes of data and resulting estimates of transmissivity (T) and storage coefficient (S) for observation wells at radial distances (r) from the pumping well.

Streamflow

Streamflow consists of runoff related to storms and base flow supplied by ground-water discharge. Streams will gain water from ground-water discharge when the potentiometric head in the aquifer near the stream is greater than the altitude of the stream. Conversely, streams will lose water to the aquifer when the potentiometric head in the aquifer near the stream is less than the altitude of the stream. Some streams in the region may be supplied in part from ground water discharged from a shallow perched aquifer. The Wissahickon Creek flows intermittently and is dry much of the year during periods of low precipitation.

Streamflow under base-flow conditions was measured quarterly at two sites on Wissahickon Creek from October 2002 through September 2005; additional measurements were made at a third site from June 2003 through September 2005 (table 74; fig. 76). There was no flow (dry) in the stream at station 01473809 near Sumneytown Pike for about half of the quarterly measurements. Streamflow losses between measurement stations were calculated for about two thirds of the period. Streamflow gains were calculated for June 11, 2003, March 4, 2004, December 21, 2004, and March 22, 2005, measurements between stations 01473808 and 01473809. In June 2003, the streamflow between stations 01473808 and 01473809 changed from a gain on June 11 to a loss on June 30, which probably was related to streamflow recession after rainfall. The June 11, 2003, measurement was made about 3 days after a storm, whereas the June 30, 2003, measurement was made about 9 days after a storm.

Continuous records of streamflow are not available for Wissahickon Creek at North Penn Area 7 but are maintained at a site about 8 mi downstream, streamflow-measurement station 01473900, Wissahickon Creek at Fort Washington, Pa. (fig. 3). Using continuous data at station 01473900 to infer streamflow upstream at North Penn Area 7 may be problematic because of several factors including (1) drainage area is larger at Fort Washington; (2) the stream is supplemented by discharges above Fort Washington; and (3) ground-water withdrawals in the drainage area are relatively larger in North Penn Area 7 than at Fort Washington. The drainage area is 40.8 mi^2 at Fort Washington, and there are several sewage discharges, including water imported from other basins, entering the stream below North Penn Area 7 but above Fort Washington. However, the hydrograph at station 01473900 generally reflects seasonal changes in runoff and base-flow components of flow that may provide information about upper limits of base flow in the Wissahickon Creek at North Penn Area 7. Base flow at streamflow-measurement station 01473900 represents about 40 to 50 percent of total streamflow, as determined by local-minimum hydrograph separation methods (Sloto and Crouse, 1996). The percentage of streamflow as base flow probably is smaller in Wissahickon Creek at North Penn Area 7 than at station 01473900 because of factors listed above.

Table 74. Base flow measured at three streamflow-measurement stations on Wissahickon Creek, North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., December 2002-September 2005. Location of streamflow-measurement stations shown on figure .

[ft^3/s, cubic feet per second; --, no data]

Date	Streamflow (ft^3/s)				
	01473807	01473808	Gain[1] from 01473807 to 01473808[2]	01473809	Gain[1] from 01473808 to 01473809
12/3/2002	--	0.080	--	0.01	-0.070
6/11/2003	--	1.400	--	1.41	.010
6/30/2003	0.56	.590	0.013	.44	-.150
7/3/2003	--	.230	--	.1047	-.125
9/9/2003	--	.045	--	0	-.045
3/4/2004	--	2.530	--	3.8	1.270
6/9/2004	--	.045	--	0	-.045
6/28/2004	.007	.010	-.014	0	-.010
8/30/2004	0	.002	-.015	0	-.002
12/21/2004	.57	.680	.093	.99	.310
3/22/2005	1.06	1.090	.013	1.3	.210
5/31/2005	0	.007	-.010	0	-.007
9/8/2005	0	.000	-.017	0	0

[1]Negative value indicates stream loss.

[2]Calculated by subtracting Precision Tube discharge of 0.017 ft^3/s from streamflow at 01473808. Precision Tube discharges below station 01473807 but above station 01483808.

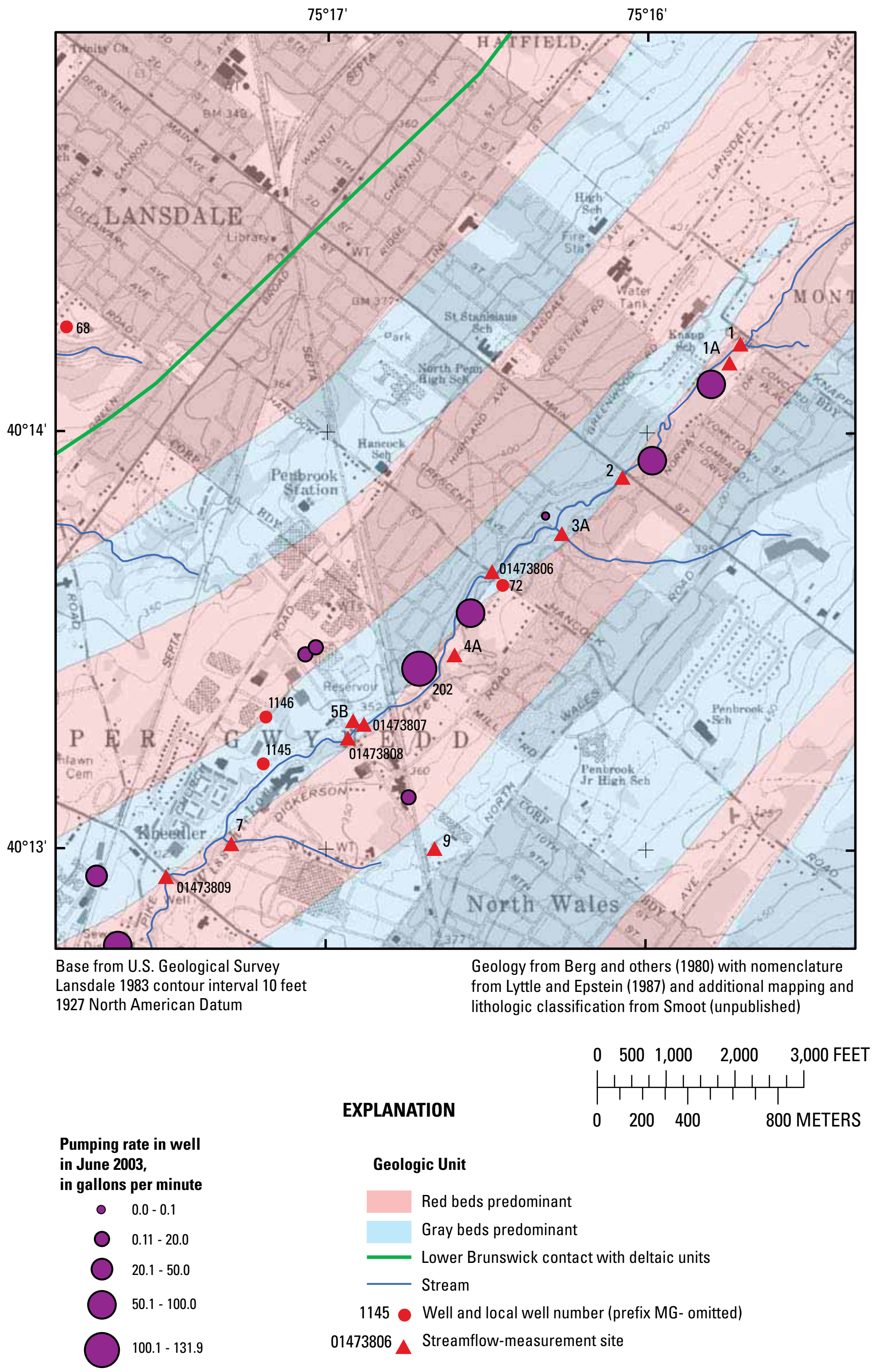


Figure 76. Location of pumping wells and streamflow-measurement stations and seepage sites for June 2003 investigation on Wissahickon Creek and selected observation wells in the vicinity of North penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., October 2002–September 2005.

Seepage Study

Streamflow under base-flow conditions was measured on June 30, 2003, at mainstem and tributary sites on Wissahickon Creek in the drainage area upstream of Sumneytown Pike (fig. 76). Results of this seepage investigation indicate reaches of stream gain and loss (table 75). Numerous production wells were pumping along Wissahickon Creek in June 2003 (fig. 76), and stream losses were measured in reaches where production wells were pumping (from site 1 to site 2; from site 4 to site 5A; and lastly from site 6 to site 8, probably because of the large amount of pumping nearby at the Merck facility southwest of site 8).

Ground-Water Levels

Water levels measured in wells in an unconfined aquifer indicate the level of the water table. In confined aquifers, water levels measured in wells indicate the level of a potentiometric surface. In the bedrock aquifers underlying North Penn Area 7 and vicinity, water-bearing fractures in wells constructed as open holes typically have different potentiometric heads, and therefore, water levels measured in wells constructed as open holes that intersect one or more water-bearing fractures represent composite heads. Water levels typically are measured as the depth to water from land surface and may be expressed as the altitude of the water level above a vertical datum (NVGD 29 or NAVD 88). The altitude of the water table or potentiometric surface indicates potential energy (head). In pumped or recently pumped wells, observed water levels may be depressed by drawdown (including well loss) or slow recovery and do not necessarily reflect nearby water levels in the aquifer.

Fluctuations

Seasonal processes, precipitation events, and changes in pumping cause water-level fluctuations. Water levels rise in response to recharge to the ground-water system from precipi-

Table 75. Base flow measured at mainstem and tributary sites on Wissahickon Creek in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 30, 2003.

Site nubmer	U.S. Geological Survey station number	Type of site	Site description	Time	Method	Streamflow, in cubic feet per second: Measured flow	Calculated flow (Mainstem plus tributary)	Gain or loss in mainstem flow[1]
June 30, 2003								
1		mainstem	at Knapp Rd.	14:30	flume	0.301		
1A		tributary	at Salem and Brook Dr	14:30	flume	.040		
2		mainstem	at Main St.	16:00	flume	.312	0.341	-0.029
3		tributary	at Ivy Ln.	17:30	flume	.057		
4	01473806	mainstem	at Hancock St.	12:25	meter	.560	.369	.191
4A		tributary	near well L-22	12:45	flume	.030		
5A	01473807	mainstem	200 ft above bridge at Wissahickon Ave	14:10		.440	.590	-.150
5B		discharge	Precision Tube	mean	reported[2]	.017		
6	01473808	mainstem	at Wissahickon Ave	12:45		.590	.457	.133
9		tributary	at North Wales Rd. above pond	11:00	flume	.063		
7		tributary	at Dickerson Rd below pond	11:30	flume	.076		
8	01473809	mainstem	at Sumneytown Pike	15:12		.440	.666	-.226
July 3, 2003								
5		mainstem	above Wissahickon Ave			.180		
5B		discharge	Precision Tube	mean	reported	.017		
6	01473808	mainstem	at Wissahickon Ave	17:12		.230	.197	.033
8	01473809	mainstem	at Sumneytown Pike			.1047	.230	-.125

[1]Calculated difference in flow between mainstem site (plus tributaries) and nearest upstream mainstem site.

[2]Reported as of February 2001.

tation and decline in response to discharge from the ground-water system to ground-water evapotranspiration, streams, and pumping. In southeastern Pennsylvania, where precipitation is distributed nearly evenly year-round, water levels generally rise during the late fall, winter, and early spring when soil-moisture and ground-water evapotranspiration are at a minimum and recharge is at a maximum. The depth to water is least in the late winter and early spring when water levels rise because rates of recharge are greater than rates of discharge. Water levels generally decline during the late spring, summer, and early fall when soil-moisture and ground-water evapotranspiration are at a maximum and recharge is at a minimum. The magnitude of seasonal fluctuations or shorter-term changes in water levels in response to recharge is related to aquifer porosity and storage. Following recharge, the rise in water levels may be greater and sustained longer in aquifers with low permeability and (or) storage than in aquifers with high permeability and (or) storage.

Water levels were measured continuously from December 2000 through December 2006 in three wells (MG-68, MG-72, and MG-1146) and from July 2002 through December in one well (MG-1145) in and near North Penn Area 7 (figs. 3 and 64). Water-level data for the period December 2000 through September 2002 were reported in Senior and others (2005). Additionally, water- levels are measured continuously in an unused production well for the purposes of drought monitoring by USGS for the Pennsylvania Department of Environmental Protection in well MG-917, about 4 mi north of North Penn Area 7, and in a nearby unused production well MG-68 in Lansdale to provide background water levels for this and other nearby investigations (fig. 3). The wells are constructed as open holes, range in depth from about 85 to 460 ft, are cased from 9 to 41.5 ft bls, and have multiple water- bearing zones (table 76).

Fluctuations in the depth to water (fig. 77) were greater for the three wells (MG-72, MG-1145, and MG-1146) near Wissahickon Creek than in observation wells MG-68 and MG-917. One factor that may affect water-level fluctuations is pumping. Factors other than pumping that also may affect long-term fluctuations in water levels are spatial variability in recharge rates or storage characteristics of the aquifer. Water levels in wells MG-68 and MG-917 probably are not affected to a large degree by local pumping and approximate background conditions in the area. However, water levels in well MG-72 are affected by pumping in nearby production wells (MG-76 and MG-202) along Wissahickon Creek., as noted by water-level responses in aquifer tests (Senior and others, 2005; this report). Daily-mean water-level fluctuations in wells MG-1145, MG-1146, and MG-72 are similar in the period from October 2003 through November 2006 (fig. 77), despite differences in well depths, distances from the stream, and proximity and response to pumping production wells, suggesting these wells have similar aquifer-storage properties and responses to regional pumping stresses. The water-level response to recharge from precipitation is more muted in well MG-1146 than in wells MG-1145 and MG-72, probably because wells MG-72and MG-1145 are closer to the stream channel than MG-1146 and have shallow fractures affected by streamflow.

In wells not affected by nearby pumping, rising water levels indicate periods of recharge. Recharge is indicated by rising water levels in all three wells monitored during winter and spring of each year. In southeastern Pennsylvania, autumn of 2001 through winter of 2002, summer of 2002, and summer of 2005 were drought periods, and water levels declined sharply during these periods. Annual precipitation as measured at nearby meteorological stations (table 77; fig. 2) was above average in years 2000, 2004, and 2006, near average in year 2005, and below average in years 2001 and 2002 (National Oceanic and Atmospheric Administration 2000; 2001; 2007).

Relation to Streamflow

Ground-water levels near Wissahickon Creek in the vicinity of North Penn Area 7 were lower than the altitude of stream channels for much of the period December 2002 through September 2005 as they were in the previously monitored period of December 2000 through September 2002 (Senior and others, 2005). The altitude of the stream-channel

Table 76. Well depth, casing length, well diameter, depth of water-bearing zones, and proximity to a stream for wells with continuous water-level monitoring in the vicinity of North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[USGS, U.S. Geological Survey; ft bls, feet below land surface; ft, feet; in., inches; >, greater than]

USGS local well number	Well depth (ft bls)	Casing length (ft)	Well diameter (in.)	Depth of water-bearing zones[1] (ft bls)	Within 200 ft of stream
MG-68	500	9	[2]14	110, 171, 323, 371, >426	yes
MG-72	298	41.5	10	[3]71, 86, 250	yes
MG-1146	84.5	18.5	6	58, 84	no
MG-1145				33, 60, 73, 79-83	yes

[1]Greatest depth reported for water-bearing zone as Inferred from geophysical logs; zones typically less than 10 ft in thickness.

[2]Borehole diameter decreases to 10 in. at 50 ft bls and to 8 in. at 250 ft bls.

[3]Water level at the time of geophysical logging was 65.63 ft bls (Conger, 1999) and water- bearing fractures shallower than that depth could not be identified.

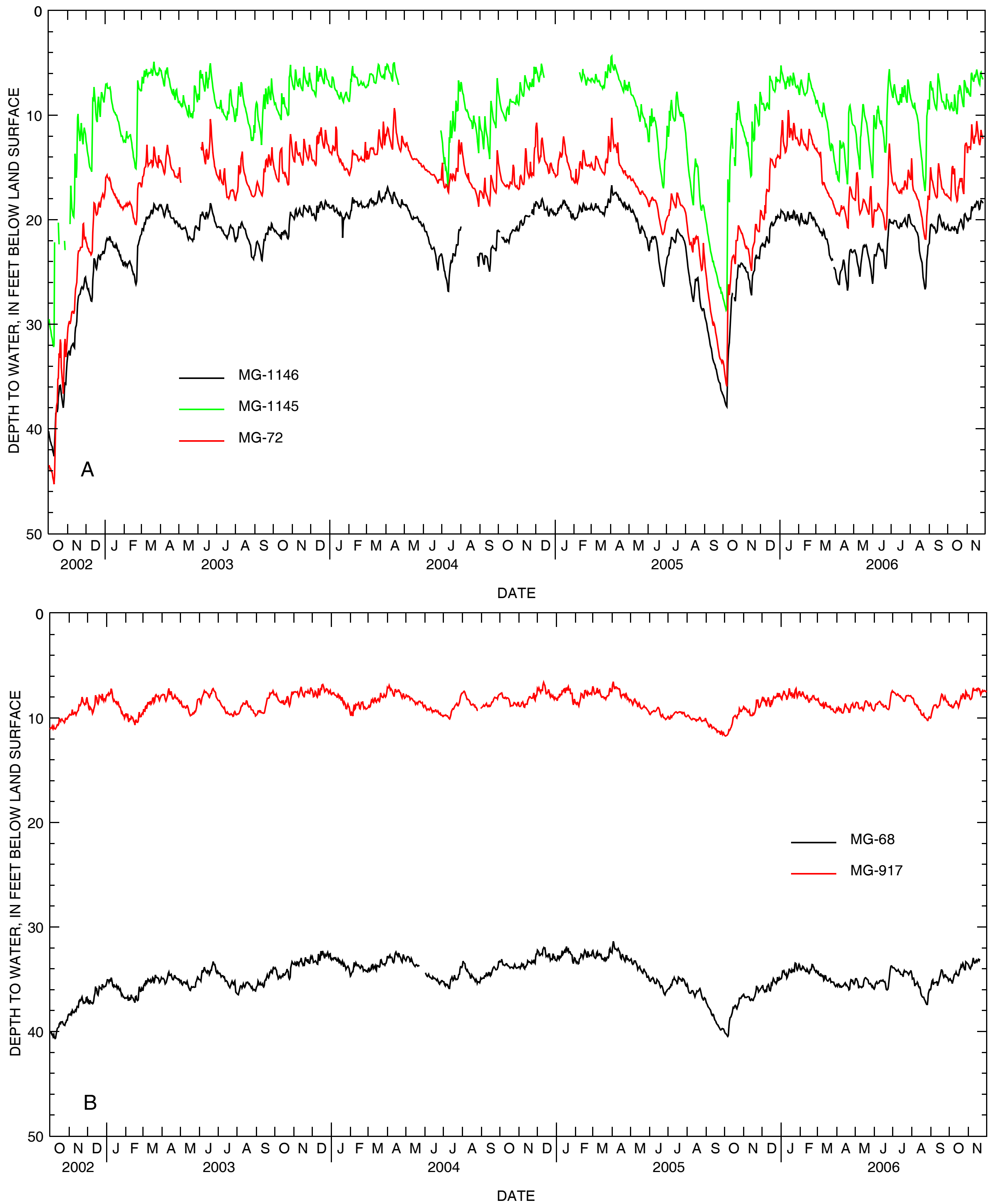


Figure 77. Daily mean depth to water in (A) wells MG-72, MG-1145, and MG-1146 in North Penn Area 7, near Wissahickon Creek, and possibly affected by local pumping and (B) wells MG-68 and MG-917 near North Penn Area 7 that are not affected by local pumping, Montgomery County, Pa., October 2002 through November 2006

Table 77. Annual precipitation in inches for 2000-2006 and 30-year normal precipitation at five meteorological stations near North Penn Area 7 in Bucks and Montgomery Counties, southeastern, Pa. Location of meteorological stations are shown on figure 2.

[M, 1-9 days of missing data in monthly records used to compute annual total; --, no data]

Station	County	Annual precipitation, in inches							
		2000	2001	2002	2003	2004	2005	2006	1971-2000 normal
Bucksville	Bucks	46.56 M	43.22 M	--	63.47M	56.09M	49.34M	54.91M	49.75
Sellersville	Bucks	46.40 M	39.76	45.72	65.99M	55.51M	51.82M	60.50	--[1]
Conshohocken	Montgomery	51.09 M	36.05	--	53.84M	--	--	56.66M	48.79
Graterford 1 E	Montgomery	44.55 M	--	43.55M	--	52.34M	43.17M	55.97	44.35
Neshaminy Falls	Bucks	50.78 M	40.25 M	--	--	54.14M	50.49M	55.87M	50.24

[1]No data for 30-year normal because period of record started in 1995.

bottom is about 328 ft above NAVD 88 at streamflow-measurement station 01473808 Wissahickon Creek at North Wales, Pa., and 312 ft above NAVD 88 at streamflow-measurement station 01473809 Wissahickon Creek at Kneedler, Pa., which is about 0.6 mi. downstream (fig. 76).

These ground-water-level conditions indicate that Wissahickon Creek is a losing stream during periods when levels are lower than stream-channel bottoms. Stream losses to ground water are indicated by the smaller amount of discharge measured at the downstream station compared to the upstream station. For the reaches from station 01473807 to station 01473808 and from station 01473808 to station 01473809, stream losses were indicated by all measurements made except those made in June 2003, March 2004, December 2004, and March 2005 (table 74). During those periods, ground-water levels in wells MG-1145 and MG-1146 were near or above the nearby stream-channel bottom (fig. 78). The losing conditions probably are largely the result of nearby pumping. Simulation of ground-water flow in the area (Senior and Goode, 1999) indicated that ground-water discharges to Wissahickon Creek under conditions of no pumping.

Although the reach of the Wissahickon Creek that bisects North Penn Area 7 loses water to the ground-water system, changes in ground-water levels in North Penn Area 7 generally correspond to changes in base flow farther downstream, indicating gaining reaches elsewhere. Relations between ground-water levels and base flow at a continuous-record streamflow-measurement station, 01473900 Wissahickon Creek at Fort Washington, Pa., about 8 mi downstream from North Penn Area 7 (fig. 3), are shown in figure 79, where base flow was determined by streamflow separation using the local-minimum method (Sloto and Crouse, 1996), a technique that provides the most conservative base-flow values. Streamflow at the station 01473900 is affected by withdrawals and discharges upstream, and therefore, the streamflow record includes these influences in addition to natural conditions. During the period from December 2000 through December 2006, ground-water levels and base flow were lowest in the autumns of 2001, 2002, and 2005 and highest in winters and springs of 2001, 2003, 2004, 2005, and 2006.

Based on altitudes of ground-water levels nearby, most measured flow in the reach of Wissahickon Creek near wells MG-72 and MG-1146 probably is derived from surface runoff, discharge from saturated soils and perhaps a shallow perched aquifer in the saprolite, and upstream contributions from the ground-water system rather than local discharge from the bedrock aquifer.

Vertical Gradients

On a local or borehole scale, ground-water flow directions may appear to deviate from regional flow directions. These local- scale deviations may be caused by vertical gradients, nearby pumping, or natural flow through a complex network of fractures in the dipping-bed hydrogeologic system. Where differences in potentiometric head between zones of water-bearing fractures in a well are present, water in the borehole flows vertically from zones of higher head to zones of lower head. The well can act as a short circuit between these different zones, which under natural conditions are separated by layers of unfractured or low-permeability bedrock. An example of vertical borehole flow between producing and thieving fractures is shown in figure for a well (MG-2093, RI-6D) exhibiting both upward flow and downward flow.

In the North Penn 7 area, vertical gradients in 16 deep wells (250 to 477 ft in depth) were inferred from borehole flow measured using a heatpulse flowmeter under non-pumping conditions and from static water levels measured in intervals isolated by packers from 2002 through 2005.

Previously, borehole-flow measurements made in 15 existing observation, industrial, commercial, and public supply wells ranging in depth from 51 to 623 ft indicated upward borehole flow only in three wells, downward flow only in three wells, both upward and downward flow in two wells, and no detectable flow in seven wells (Senior and others, 2005). All three of the wells with upward flow (and upward vertical gradients) were on the east side of Wissahickon Creek. The wells with downward flow (downward vertical gradients) and mixed upward and downward flow were on the west side

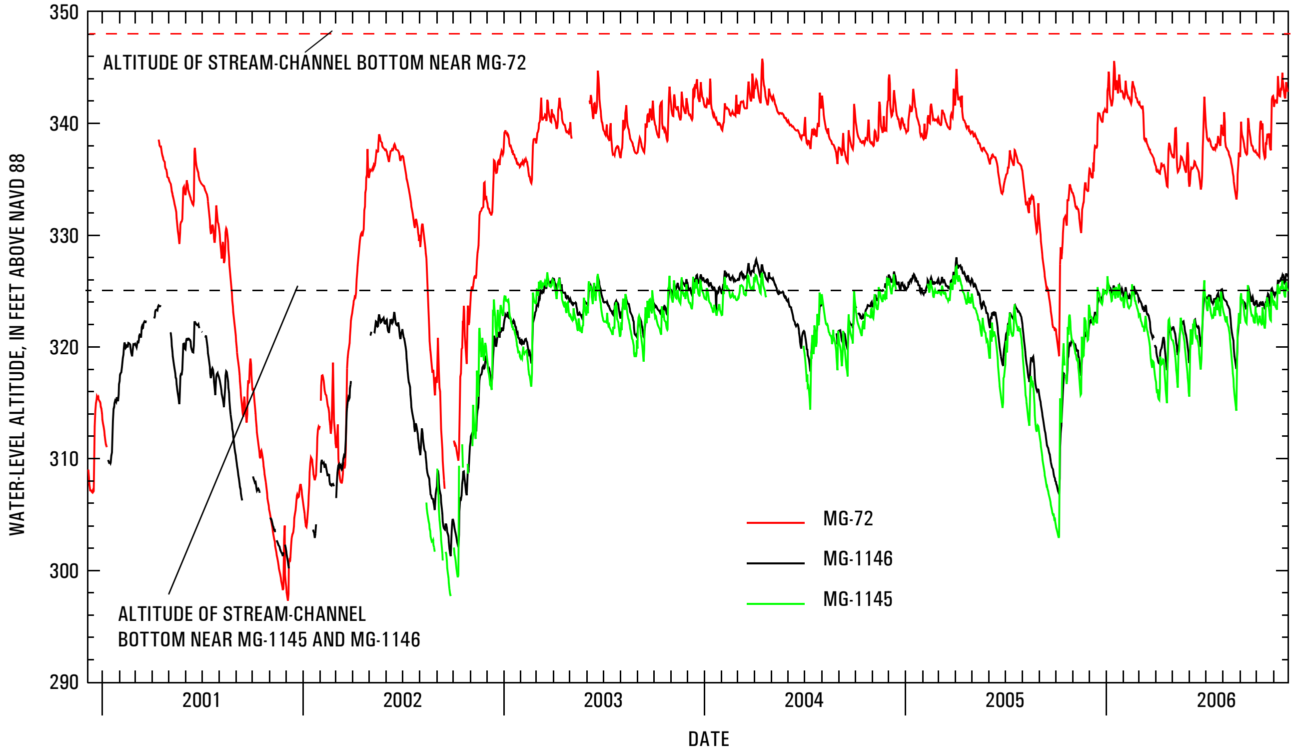


Figure 78. Hydrographs showing altitudes of water levels in wells MG-72, MG-1145, and MG-1146 and estimated altitudes of nearly stream-channel bottoms in Wissahickon Creek, North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., December 2000-November 2006.

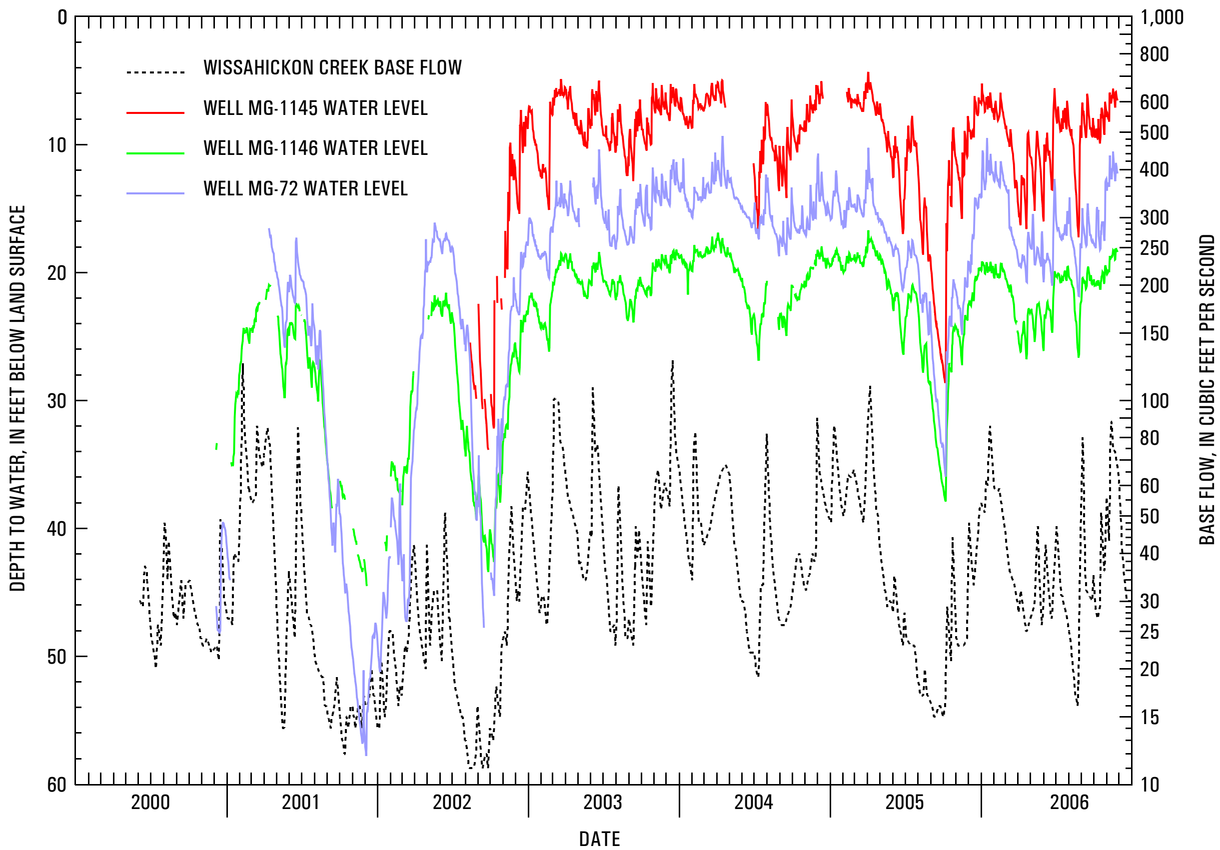


Figure 79. Daily mean depth to water in wells MG-72, MG-1145, and MG-1146 in North Penn Area 7, near Wissahickon Creek, and base flow at streamflow-measrement station 01473900 Wissahickon Creek at Fort Washington, Pal, June 2000 through December 2006.

of Wissahickon Creek. Flow was not detected in 6 of the 11 shallow wells (less than 85 ft deep). In wells near the Wissahickon Creek, a potential discharge area where upward vertical gradients might be expected, the presence of downward vertical flow and downward gradients may be partly caused by nearby pumping. Wells with downward vertical gradients that may be affected by pumping include MG-202, MG-1144, and MG-1145.

Water-level measurements in well clusters consisting of two to three wells constructed to be open at different depth intervals also provide information about vertical gradients. In December 2004, June 2005, and September 2005, the USGS collected water-level measurements (table 78 and, at the back of the report, table 80) in the monitor well clusters installed by USEPA for the North Penn Area 7 RI/FS. Downward, or predominantly downward, gradients (denoted by negative values in the difference in water-level altitude columns, table 78) were indicated in well clusters named RI-2, RI-3, RI-4, RI-5, RI-6, RI-10, and RI-15. Except for clusters RI-2 and RI-6, well clusters with downward gradients are west of Wissahickon Creek. RI-2 and RI-6 clusters are near the east bank of the creek and are probably affected by nearby pumping. Upward, or predominantly upward, gradients (denoted by positive values in the difference in water-level altitude columns, table 78) were indicated in the clusters named RI-7, RI-8, RI-9, and RI-11, all east of Wissahickon Creek. The direction of gradients in some well clusters changed through time, which may be related to transient pumping. The gradient from the deep well to intermediate well in the cluster named RI-4D was up in December 2004 but down in the June and September 2005 measurements. Long-term monitoring shows wells near the RI-4 cluster appear to respond to periodic pumping. Also, the gradient from shallow and intermediate wells in the RI-7 cluster was down in December 2004 but was up in the June and September 2005 measurements. A small production well (MG-1841) near the RI-7 cluster may affect gradients.

Regional Potentiometric Surface

Water levels in about a 16-mi^2 area including and surrounding North Penn Area 7 were measured during a short, 3-day period in December 4-6, 2000, to provide information for estimating the regional potentiometric surface at that time. On the basis of records of long-term monitoring

Table 78. Depth to water, water-level altitudes, and difference in water-level altitudes in well nests in and near North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., December 2004, June 2005, and September 2005.

[USGS, U.S. Geological Survey; ft, feet; NAVD 88, North American Vertical Datum 1988; ft bmp, feet below measuring point (typically top of inner casing); D-I, deep-well minus intermediate-well water level; D-S, deep-well minus shallow-well water level; I-S, intermediate-well minus shallow-well water level; --, no data]

USGS local well number MG-	Well name in cluster	Altitude of measuring point, in ft above NAVD 88	Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft			Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft			Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft		
						D-I	D-S	I-S				D-I	D-S	I-S				D-I	D-S	I-S
2081	RI-2D	331.48	12/09/04	25.45	306.03	-1.99	-17.23	-15.24	06/06/05	56.78	274.70	-4.44	-42.78	-38.34	09/08/05	69.70	261.78	-5.64	-44.25	-38.61
2082	RI-2I	330.72	12/09/04	22.70	308.02				06/06/05	51.58	279.14				09/08/05	63.30	267.42			
2083	RI-2S	330.44	12/09/04	7.18	323.26				06/06/05	12.96	317.48				09/08/05	24.41	306.03			
2080	RI-1D	374.54	--	--					--	--					09/08/05	48.16	326.38			
2084	RI-3D	372.53	12/09/04	45.30	327.23	-.92	-.41	.51	06/06/05	47.95	324.58	-1.34	-1.09	.25	09/08/05	57.06	315.47	-1.86	-2.24	-.38
2085	RI-3I	372.53	12/09/04	44.38	328.15				06/06/05	46.61	325.92				09/08/05	55.20	317.33			
2086	RI-3S	372.36	12/09/04	44.72	327.64				06/06/05	46.69	325.67				09/08/05	54.65	317.71			
2087	RI-4D	348.35	12/06/04	22.92	325.43	.43	-.3	-.73	06/06/05	26.40	321.95	-.08	-1.17	-1.09	09/08/05	37.90	310.92	-1.33	-3.56	-2.23
2088	RI-4I	348.35	12/06/04	23.35	325.00				06/06/05	26.32	322.03				09/08/05	36.35	312.25			
2089	RI-4S	348.18	12/06/04	22.45	325.73				06/06/05	25.06	323.12				09/08/05	34.02	314.48			
2090	RI-5D	352.83	12/08/04	25.16	327.67	-4.4	-5.1	-.7	06/08/05	24.06	328.77	-2.83	-3.79	-.96	09/08/05	34.21	319.51	-5.6	-6.55	-.95
2091	RI-5I	353.73	12/08/04	21.66	332.07				06/08/05	22.13	331.60				09/08/05	28.89	325.11			
2092	RI-5S	353.51	12/08/04	20.74	332.77				06/08/05	20.95	332.56				09/08/05	27.95	326.06			
2093	RI-6D	343.88	12/06/04	8.98	334.90		-.98		06/06/05	14.37	329.83		-3.05		09/08/05	22.81	321.39		-1.51	
2094	RI-6S	343.42	12/06/04	7.54	335.88				06/06/05	11.05	332.88				09/08/05	21.03	322.90			
2095	RI-7D	361.64	12/08/04	19.94	341.70	4.01	-.2	-4.21	06/06/05	23.34	338.30	4.03	4.63	.6	09/08/05	29.46	332.18	4.07	4.47	.4
175	RI-7I	361.42	12/08/04	23.73	337.69				06/06/05	27.15	334.27				09/08/05	33.31	328.11			
2096	RI-7S	361.58	12/08/04	19.68	341.90				06/06/05	27.91	333.67				09/08/05	33.87	327.71			
2097	RI-8D	346.69	12/08/04	5.33	341.36	5.97	6.09	.12	06/06/05	9.26	337.43	5.52	5.52	0	09/08/05	14.99	331.70	5.21	5.09	-.12
2098	RI-8I	347.26	12/08/04	11.87	335.39				06/06/05	15.35	331.91				09/08/05	20.77	326.49			
2099	RI-8S	347.31	12/08/04	12.04	335.27				06/06/05	15.40	331.91				09/08/05	20.70	326.61			
2100	RI-9D	335.23	--	--	--				06/06/05	32.75	302.48	28.58	34.38	5.8	09/08/05	41.24	293.99	33.43	41.28	7.85
2101	RI-9I	335.62	12/09/04	29.51	306.11			2.11	06/06/05	61.72	273.90				09/08/05	75.06	260.56			
2102	RI-9S	335.90	12/09/04	31.90	304.00				06/06/05	67.80	268.10				09/08/05	83.19	252.71			
2119	RI-10D	365.56	12/08/04	41.25	324.31	-2.41	-2.64	-.23	06/06/05	43.39	322.17	-3.56	-3.93	-.37	09/08/05	51.47	314.09	-4.7	-5.18	-.48
2120	RI-10I	365.95	12/08/04	39.23	326.72				06/06/05	40.22	325.73				09/08/05	47.16	318.79			
2121	RI-10S	366.11	12/08/04	39.16	326.95				06/06/05	40.01	326.10				09/08/05	46.84	319.27			
2122	RI-11D	355.19	12/06/04	13.93	341.26	6.26	6.62	.36	06/06/05	17.61	338.12	6.27	7.94	1.67	09/08/05	23.60	332.13	5.78	8.53	2.75
2123	RI-11I	354.61	12/06/04	19.61	335.00				06/06/05	23.21	331.85				09/08/05	28.71	326.35			
2124	RI-11S	354.26	12/06/04	19.62	334.64				06/06/05	24.44	330.18				09/08/05	31.02	323.60			
2125	RI-12D	358.58	12/08/04	46.20	312.38				06/06/05	46.85	311.73				09/08/05	54.11	305.27			
2126	RI-13D	356.00	12/08/04	28.00	328.00	-2.73	-2.53	.2	06/06/05	27.95	328.05	-2.6	-2.26	.34	09/08/05	34.96	321.04	-3.06	-2.68	.38
2127	RI-13I	357.10	12/08/04	26.37	330.73				06/06/05	26.45	330.65				09/08/05	33.00	324.10			

Table 78. Depth to water, water-level altitudes, and difference in water-level altitudes in well nests in and near North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., December 2004, June 2005, and September 2005.—Continued

[USGS, U.S. Geological Survey; ft, feet; NAVD 88, North American Vertical Datum 1988; ft bmp, feet below measuring point (typically top of inner casing); D-I, deep-well minus intermediate-well water level; D-S, deep-well minus shallow-well water level; I-S, intermediate-well minus shallow-well water level; --, no data]

USGS local well number MG-	Well name in cluster	Altitude of measuring point, in ft above NAVD 88	Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft			Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft			Date of measurement	Depth to water, in ft bmp	Altitude of water level, in ft above NAVD 88	Difference in water-level altitudes, in ft		
						D-I	D-S	I-S				D-I	D-S	I-S				D-I	D-S	I-S
2128	RI-13S	357.20	12/08/04	26.67	330.53				06/06/05	26.89	330.31				09/08/05	33.48	323.72			
2129	RI-14I	379.44	--	--	--				--	--	--				09/08/05	58.30	321.14	--	--	-2.33
2130	RI-14S	379.19	--	--	--				--	--	--				09/16/05	55.72	323.47			
2131	RI-15DD	383.20							--	--	--				09/08/05	67.16	316.04	-2.38	-6.44	-4.06
2132	RI-15D	384.00	--	--	--				--	--	--				09/08/05	65.58	318.42	-4.06	-4.44	-.38
2133	RI-15I	380.90	--	--	--				--	--	--				09/08/05	58.42	322.48			
2134	RI-15S	381.40	--	--	--				--	--	--				09/08/05	58.54	322.86			
1602	Rogers 2I	375.78							06/06/05	53.79	321.99									
1603	Rogers 2S	375.62							06/06/05	67.77	307.85									
1600	Rogers 3I	365.49							06/06/05	41.64	323.85									
1601	Rogers 3S	365.22							06/06/05	56.38	308.84									

wells (BK-929 and BK-1020) in similar geologic settings in southeastern Pennsylvania, ground- water levels on December 5, 2000, were within 0.8 ft of long-term averages for early December and about 2 ft lower than the long- term average annual water level (Senior and others, 2005). In the region, lowest annual water levels typically occur in September or October, highest annual water levels occur in April or May, and average annual water levels occur in January and July.

A map of water levels measured December 4-6, 2000 (Senior and Ruddy, 2003), shows the altitudes of water levels are highest on the ridges underlain by the Lockatong Formation that straddle the Wissahickon Creek and lowest in the cone of depression caused by pumping at Merck and Towamencin Creek to the southwest. The contoured map represents only changes in water-level altitudes in the horizontal direction. Although the contoured water levels in the semi-confined aquifer beneath North Penn Area 7 do not represent the water table, the surface is nevertheless similar to topography. The contoured water-level altitudes differ from topography in the areas affected by relatively large amounts of pumping. Ground-water divides between the Wissahickon Creek Basin and the adjacent basins appear to be coincident with the topographic divides on the ridges underlain by the Lockatong Formation. However, in the area affected by industrial pumping at Merck, the ground-water divides occur at the edges of the cone of depression. The map of water levels measured in December 2000 confirms the general configuration of potentiometric surface depicted in the overlapping area of a map based on water levels measured in August 1996 (Senior and others, 1998).

Because ground water flows from higher to lower head, the general direction of ground-water flow can be estimated from a map of the water table or potentiometric surface. If no vertical head differences exist, then flow is planar (two-dimensional). In isotropic aquifers, the direction of flow is perpendicular to hydraulic gradient but in anisotropic aquifers, the direction of flow is not exactly perpendicular to the hydraulic gradient. The map of water levels in December 2000 indicates that ground water flows from the ridges underlain by the Lockatong Formation north of North Penn Area 7 in directions similar to the topographic gradient toward the Wissahickon Creek and in a general southwest direction.

During phase 2 of data collection at North Penn Area 7, water levels were measured periodically in a set of wells in an area smaller than the regional extent of the year 2000 synoptic. Synoptic measurements in the phase-2 period included water levels in monitor wells in and near North Penn Area 7 and selected other wells in December 2004, June 2005, and September 2005 (tables and at the back of the report). Water-level measurements for wells on the Merck property were provided by Merck (Rob Cavett, written commun.). The general configuration of the regional potentiometric surface is similar in all rounds of water-level measurements.

Summary and Conclusions

Ground water in the vicinity of several industrial facilities in Upper Gwynedd Township and Lansdale Borough, Montgomery County, Pa., is contaminated with several volatile organic compounds (VOCs). The 2-square-mile area was placed on the National Priorities List as the North Penn Area 7 Superfund Site by the U.S. Environmental Protection Agency (USEPA) in 1989 and included at least five possible contaminant-source locations. The U.S. Geological Survey (USGS) conducted geophysical logging, aquifer testing, water-level monitoring, and streamflow measurements in the vicinity of North Penn Area 7 from October 2002 through December 2006. This followed work that began in 2000 to assist the USEPA in developing an understanding of the hydrogeologic framework in the area as part of the USEPA Remedial Investigation.

The study area is underlain by Triassic and Jurassic-age sandstones, siltstones, and shales of the Lockatong Formation and the Brunswick Group. Regionally, these rocks strike northeast and dip to the northwest. Unpublished lithologic mapping (Smoot, written commun., 2006), indicates that deltaic sediments interfinger with sediments in the vicinity of the study area and may disrupt lateral continuity of beds. The sequence of rocks forms fractured-rock aquifers that act as a set of confined to semi-confined layered aquifers of differing permeabilities. The aquifers are recharged by precipitation and discharge to streams and wells. The Wissahickon Creek headwaters are less than 1 mi northeast of the study area, and this stream flows approximately parallel to strike southwest to bisect North Penn Area 7. Ground water is pumped in the vicinity of North Penn Area 7 for industrial use and public supply.

The USGS collected geophysical logs in 42 wells that ranged in depth from 40 to 477 ft and included 3 existing wells and 39 new monitor wells. Logs were collected in deep (about 300 ft) monitor wells drilled first at 15 locations to provide a basis for aquifer-interval-isolation tests and subsequent selection of depths for 24 shallow and intermediate-depth monitor wells to form clusters. Geophysical logging identified water-bearing zones associated with high-angle fractures and bedding-plane openings throughout the depth of the boreholes. Heatpulse-flowmeter measurements under non-pumping, ambient conditions in 16 wells greater than 200 ft in depth indicated borehole flow, where detected, was upward only in 2 wells and downward only in 5 wells. In nine wells, both upward and downward flow were measured. Geologic structure and pumping in the area affect the spatial distribution of vertical gradients. Heatpulse-flowmeter measurements under pumping conditions were used to identify the most productive water-bearing intervals in wells. Correlation of natural-gamma-ray logs was only possible in the western part of the study area and indicated that bedding probably strikes about 45 to 65 degrees northeast and dips about 9 to 10 degrees northwest. This orientation of beds was assumed to be similar throughout the study area. Borehole deviation logs showed that most holes were drilled with an approximately linear deviation to the southeast, which is consistent with bedding that dips to the northwest.

Aquifer-interval-isolation testing was done in 17 of the 42 wells, for a total of 122 zones tested in 2 existing and 15 deep monitor wells. Intervals were selected on the basis of geophysical logs. Aquifer intervals isolated by inflatable packers in 17 wells were pumped to test productivity and to collect samples to determine chemical quality of water produced from the isolated intervals. Interval-isolation testing confirmed the presence of vertical hydraulic gradients indicated by heatpulse-flowmeter measurements. The specific capacities of the 122 isolated intervals ranged over three or more orders of magnitude, from 0.01 to10.6 gallons per minute per foot, corresponding to calculated transmissivities of 1.2 to 2,290 feet squared per day. Intervals adjacent to isolated pumped intervals commonly showed little response to pumping of the isolated zone. The presence of vertical hydraulic gradients and lack of adjacent-interval response to pumping in isolated intervals indicate a limited degree of vertical hydraulic connection between the aquifer sections tested.

Water-quality differences were apparent in water from isolated intervals of a given well, indicating that ground water follows discrete paths in the aquifer. Measured field water quality included pH, specific conductance, temperature, alkalinity, and concentrations of dissolved oxygen and selected inorganic constituents. In most wells, pH increased with depth of interval, and concentrations of dissolved oxygen and specific conductance decreased with depth of interval. Concentrations of dissolved oxygen were less than 1 mg/L in most deeper intervals. Specific conductance was especially elevated (greater than 900 µS/cm) in water from wells in the western part of the study area. This was probably because of dissolved salts. Trichloroethylene was the most frequently detected chlorinated VOC, with a maximum concentration of 640 µg/L in samples from 13 of 17 wells tested. Other halogenated VOCs detected in half or less of the 18 wells tested include cis-1,2-dichloroethylene, tetrachloroethylene, freon-113, and freon-11 at maximum concentrations of 120, 37, 71, and 55 µg/L, respectively. VOCs detected in water samples from three or fewer wells include carbon tetrachloride, 1,1-dichloroethylene, 1,1-dichloroethane, 1,1,1-trichloroethane, and xylenes at maximum concentrations of 33, 33, 4, 10, and 4 µg/L, respectively. Toluene was detected in samples from at least 1 interval in all 17 wells tested at concentrations ranging from 3 to 280 µg/L but may have been present because of possible sampling-equipment contamination. Acetone and(or) methylene chloride were detected at low concentrations ranging from 1 to 14 µg/L in a few samples from four wells but these concentrations might indicate laboratory contamination. Concentrations of most VOC contaminants in most wells with predominantly upward vertical gradients were greatest in well-water samples from the relatively shallow isolated intervals.

A multiple-well aquifer test was conducted by monitoring the response of 14 wells to pumping and shutdown of a 600-ft deep production well in November-December 2004. Results of the aquifer test with multiple observation wells showed that water levels in 8 of 14 wells declined in response to pumping. Estimates of aquifer transmissivity determined using Theis-curve fitting ranged from 683 to 2,382 ft^2/d. These estimates were similar in magnitude to the range (515 to 6,080 ft^2/d) of whole-well transmissivities determined from aquifer-interval-isolation tests. The spatial distribution of the eight wells that responded to pumping are along strike and in the down-dip direction of producing zones of the pumped well. The spatial distribution of the eight responding wells suggests that dip of the beds has some control over hydraulic connections in the aquifer.

In addition, water levels were monitored continuously in four wells in the area from October 2002 through September 2006 and streamflow was measured quarterly at two sites on Wissahickon Creek from December 2002 through September 2005. Water- level monitoring in four wells showed the seasonal rise and decline of levels for the period and generally were higher than when measured in 2000 and 2001. Water levels in two wells near Wissahickon Creek were evaluated in relation to streamflow on dates of quarterly streamflow measurements. The Wissahickon Creek was a losing stream between the two measurement sites and ground-water levels were lower than the stream-channel bottom for most dates. Water levels measured in the 2-square mile area around and including North Penn Area 7 in December 2004, June 2005, and September 2005 confirm previous findings that the ground-water-level surface is relatively flat in the immediate vicinity of the North Penn Area 7 site and generally is similar to the topography except in areas affected by large amounts of ground-water withdrawal. Comparison of water levels measured in boreholes completed at different depths in well clusters shows predominantly upward vertical gradients east of Wissahickon Creek, except where affected by nearby pumping, and predominantly downward vertical gradients west of Wissahickon Creek. The distribution of vertical gradients appears to be controlled by topography, geologic structure, and pumping.

Results of geophysical logging, aquifer tests, and water-level measurements are consistent with the conceptual model of a layered leaky aquifer where the dip of the beds has a strong control on hydraulic connections in the ground-water flow system.

Acknowledgments

The cooperation of well owners who made their wells accessible for water sampling, water-level measurements, and geophysical logging is greatly appreciated, especially those owners who allowed repeated sampling or continued monitoring of their wells. The well owners include NPWA; Merck & Co., Inc.; Ken Steigelman; and residents in areas in and near Lansdale and Upper Gwynedd Township. William Berry, Jonathan Hartzell, and others of NPWA are recognized for providing information about pumping schedules and coordination in conducting field work. NWWA also provided information about pumping rates and schedules. Robert Cavett and Jason Szefcak of Merck & Co., Inc. are recognized for providing water-level and other hydrologic data. The cooperation of USEPA project manager Deana Moultrie and her successor, David Turner, and USEPA's contractor, Camp, Dresser, and McKee (CDM) Federal Programs Corporation, was integral to geophysical logging of new monitoring wells, disposal of wastewater from aquifer tests, and other aspects of the study.

USGS personnel who conducted packer tests and collected water-level, streamflow, and other data include Peter Cinotto, Robert Rosman, Leif Olson, Abdul Mohammad, and Albert Ruddy.

References Cited

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1976, Standard methods for the examination of water and wastewater: Washington, D.C., 1193 p.

Barton, G.J., Risser, D.W., Galeone, D.G., and Goode, D.J., 2003, Case study for delineating a contributing area to a well in a fractured siliciclastic-bedrock aquifer near Lansdale, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 02-4271, 46 p.

Bear, Jacob, 1979, Hydraulics of groundwater: New York, McGraw-Hill, 567 p.

Berg, T.M., Edmunds, W.E., Geyer, A.R., and others, comps., 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th Series, Map 1, 2nd edition, scale 1:250,000, 2 sheets.

Berg, T.M., Barnes, J.H., Sevon, W.D., Skema, V.W., Wilshusen, J.P., and Yannacci, D.S., 1989, Physiographic Provinces of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 13, scale 1:2,000,000.

Biesecker, J.E., Lecinsky, J.B., and Wood, C.R., 1968, Water resources of the Schuylkill River Basin: Pennsylvania Department of Environmental Protection Water Resources Bulletin, no. 3, 198 p.

Black & Veatch Waste Science, Inc., 1994, Remedial Investigation Feasibility Study Report North Penn Area 6 Site Source Control Operable Unit, Lansdale, Pennsylvania. Work assignment no. 91-19-3LW9, contract no. 68-W8-0091. Prepared for the U.S. Environmental Protection Agency, December 20, 1994.

Black & Veatch Waste Science, Inc., 1999, Remedial Investigation Feasibility Study Report North Penn Area 6 Site Groundwater Operable Unit (OU3), Lansdale, Pennsylvania. Work assignment no. 004-RICO03W9, contract no. 68-S8-3002. Prepared for the U.S. Environmental Protection Agency, August 1999.

Brown, E.T., Green, S.J., and Sinha, K.P., 1981, The influence of rock anisotropy on hole deviation in rotary drilling—A review: International Journal of Rock Mechanics and Mining Sciences, v. 18, no. 5, p. 387-401.

CH2M Hill, Inc., 1992, North Penn Area 7 Phase II RI/FS Work Plan. Work assignment no. 05-3LX1.0, contract no. 68-W8-0090. Prepared for the U.S. Environmental Protection Agency, February 1992.

Conger, R.W., 1999, Evaluation of geophysical logs at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania: U.S. Geological Survey Open-File Report 99-271A, 149 p.

Converse Consultants East,1994, Report: Task 2 - Investigation of regional and site ground-water quality Ford Electronics and Refrigeration Corporation (FERCO) - Church Road Facility, Lansdale, Pennsylvania, Project No. 91-37322-07: Parsippany, New Jersey, Sept. 20, 1994, 2 vols.

Cooper, H.H., Jr., and Jacob, C.E., 1946, A generalized method for evaluating formation constants and summarizing well-field history: Transactions American Geophysical Union, v. 27, no. 4, p. 526-534.

Geraghty & Miller, Inc., 1993, Evaluation of groundwater pumpage and containment at the Merck & Co., Inc., West Point, Pennsylvania, Plant: Reston, Virginia, Dec. 3, 1993.

Goode, D.J., and Senior, L.A., 1998, Review of aquifer test results for the Lansdale Area, Montgomery County, Pennsylvania, 1980-95: U.S. Geological Survey Open-File Report 98-294, 70 p.

HACH Company, 1997, DR/2010 Spectrophotometer procedures manual: Loveland, Colorado, 794 p.

Longwill, S.M. and Wood, C.R., 1965, Ground-water resources of the Brunswick Formation in Montgomery and Berks Counties, Pennsylvania: Pennsylvania Geological Survey, 4th Ser., Ground Water Report W22, 59 p.

Longwill, S.M. and Wood, C.R., 1965, Ground-water resources of the Brunswick Formation in Montgomery and Berks Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Ground Water Report W22, 59 p.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic map of the Newark 1° × 2° Quadrangle, New Jersey, Pennsylvania and New York: U.S. Geological Survey Miscellaneous Investigations Map I-1715, scale 1:250,000.

McLamore, R.T., 1971, The role of rock strength anisotropy in natural hole deviation: Journal of Petroleum Technology, v. 23, no. 11, p. 1313-1321, Nov. 1971.

National Oceanic and Atmospheric Administration, National Climactic Data Center, 2000, Climatological data annual summary Pennsylvania, v. 105, no. 13, ISSN-0364-5843.

National Oceanic and Atmospheric Administration, National Climactic Data Center, 2001, Climatological data annual summary Pennsylvania, v. 106, no. 13, ISSN-0364-5843.

National Oceanic and Atmospheric Administration, National Climactic Data Center, 2007, Annual Climactic Summary, http:// cdo.ncdc.noaa.gov/ancsum/ACS accessed October 23, 2007, for various years (2002-2006) and meteorological stations.

Newport, T.G., 1971, Ground-water resources of Montgomery County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Ground Water Report W29, 83 p.

Olsen, P.E., Kent, D.V., Cornet, Bruce, Witte, W.K., and Schlische, R.W., 1996, High-resolution stratigraphy of the Newark rift basin (early Mesozoic, eastern North America): GSA Bulletin, v. 108, no. 1, p. 40-77.

Rima, D.R., 1955, Ground-water resources of the Lansdale area, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Prog. Report 146, 24 p.

Schlische, R.W., 1992, Structural and stratigraphic development of the Newark extensional basin, eastern North America—Evidence for growth of the basin and its bounding structures: Geological Society of America Bulletin, v. 104, p. 1,246-1,263.

Senior, L.A., Rowland, C.A., and Prieto, D.A., 1998, Altitude and configuration of the potentiometric surface in Lansdale and vicinity, Montgomery County, Pennsylvania, August 22-23, 1996: U.S. Geological Survey Open-File Report 98-253, 1 plate, scale 1:24,000.

Senior, L.A., and Goode, D.J., 1999, Ground-water system, estimation of aquifer hydraulic properties, and effects of pumping on ground-water flow in Triassic sedimentary rocks in and near Lansdale, Pennsylvania: U.S. Geological Survey Water- Resources Investigations Report 99-4228, 112 p.

Senior, L.A., and Ruddy, A.J., 2003, Altitude and configuration of the water-level surface in Mesozoic sedimentary rocks at and near the North Penn Area 7 Superfund site, Upper Gwynedd Township, Montgomery County, Pennsylvania, December 4-6, 2000: U.S. Geological Survey Open-File Report 2004-1006, 1 plate, scale 1:24,000.

Senior, L.A., Cinotto, P.J., Conger., R.W., Bird, P.H., and Pracht, K.A., 2005, Interpretation of geophysical logs, aquifer tests, and water levels in and near the North Penn Area 7 Superfund Site, Upper Gwynedd Township, Montgomery County, Pennsylvania, 2000-02: U.S. Geological Survey Scientific Investigations Report 2005-5069, 129 p.

Shapiro, A.M., and Hsieh, P.A., 1998, How good are estimates of transmissivity from slug tests in fractured rock?: Ground Water, v. 36, no. 1, p. 37-48.

Sloto, R.A., and Crouse, M.Y., 1996, HYSEP—A computer program for hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Transactions American Geophysical Union, v. 16, p. 519-524.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at *http://pubs.water.usgs.gov/twri9A*

Wilson, G.E., 1976, How to drill a usable hole Part 1- Why deviation occurs: World Oil, v. 183, no. 2, p. 40-43.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

Table 79. Characteristics of and water levels measured in selected existing wells in and near North Penn Area 7, Montgomery County, Pennsylvania, October 2002–December 2006.

[NAD 83, North American Datum 1983; NAVD 88, North American Vertical Datum 1988; ft bls, ft below land surface; ft, feet; in., inches; --, no data]

USGS local well number MG-	Well name	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Date well drilled (YYYY MM DD)	Altitude of land surface, (ft above NAVD 88)	Well depth (ft bls)	Casing length (ft)	Casing diameter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
64	NPWA L-5	401429075165601	401428	751654	19101101	362.7	1,103	18	8	19541104	83
76	NPWA L-17	401334075163301	401332	751632	19490701	349	388	37	12	1949072	23
171	Precision Tube well 2	401328075170101	401329	751701	1952	357.2	500	68	8	19541012	117
171										19960805	26.91
171										19960823	27.10
171										20001205	53.50
202	NPWA L-22	401329075164001	401326	751641	19550101	351	647		12	19550119	54
204	Precision Tube well 1	401328075170401	401328	751703	19550501	364	500	66	8	19550519	52
917	NPWA	401733075171401	401734	751712	19710526	349	500	40	8	19970910	10.32
917										20020820	11.54
917										20021107	9.66
917										20030114	8.31
917										20030306	8.74
917										20030522	9.60
917										20030718	9.61
917										20030729	9.53
917										20030826	9.33
917										20031027	8.11
917										20031216	7.36
917										20040213	8.61
917										20040330	7.88
917										20040521	8.57
917										20040714	9.40
917										20040827	9.25
917										20040830	9.31
917										20041123	8.12
917										20050303	7.59
917										20050506	8.52
917										20050623	9.98
917										20050628	10.08
917										20050707	9.72
917										20051103	9.18
917										20060110	8.31
917										20060201	7.91
917										20060315	8.71
917										20060710	7.83
917										20060821	9.90
917										20061005	8.89
917										20061128	7.39
1145	Teleflex T-14	401314075171401	401312	751711	1986	330.62	83		6	19890414	14.78
1145										20001205	24.18
1145										20041102	8.89
1145										20041122	7.07
1145										20041209	6.33
1145										20041215	6.74
1145										20050204	8.37
1145										20050209	6.45
1145										20050316	7.20
1145										20050316	7.19

Table 79. Characteristics of and water levels measured in selected existing wells in and near North Penn Area 7, Montgomery County, Pennsylvania, October 2002–December 2006.— Continued

[NAD 83, North American Datum 1983; NAVD 88, North American Vertical Datum 1988; ft bls, ft below land surface; ft, feet; in., inches; --, no data]

USGS local well number MG-	Well name	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Date well drilled (YYYY MM DD)	Altitude of land surface, (ft above NAVD 88)	Well depth (ft bls)	Casing length (ft)	Casing diameter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
1145										20050415	6.63
1145										20050527	10.64
1145										20050606	11.20
1145										20050721	9.45
1145										20050909	22.39
1145										20051017	14.15
1145										20051104	11.66
1145										20051207	9.35
1145										20060124	6.19
1145										20060327	13.64
1145										20060327	17.87
1145										20060428	10.49
1145										20060811	9.80
1146	Teleflex T-4	401318075171101	401319	751710	1986	343.8	84		6	19890414	32.70
1146										20001205	34.26
1146										20041102	20.94
1146										20041122	19.50
1146										20041123	19.48
1146										20041209	18.89
1146										20050204	19.78
1146										20050204	19.88
1146										20050316	19.27
1146										20050415	18.16
1146										20050527	21.42
1146										20050606	22.20
1146										20050721	21.27
1146										20050909	31.64
1146										20051017	28.49
1146										20051104	24.50
1146										20051207	22.60
1146										20060124	19.20
1146										20060327	24.89
1146										20060327	23.83
1146										20060428	23.17
1146										20060811	21.16
1897	Clearline 3	401317075165201	401317	751650	--	336.16	288	44		20010917	31.58
1897										20020102	28.91
1897										20020325	18.34
1897										20041206	5.03
1897										20050606	10.85
1897										20050908	19.99
1897										20051017	17.24
1897										20060327	11.22

Table 80. Characteristics of and water levels measured in wells logged by U.S. Geological Survey in and near North Penn Area 7, Montgomery County, Pa., October 2002–December 2006.

USGS local well number MG-	Well name	Property	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Drilling date Recon-struction date (YYYY MMDD)	Altitude of land surface, (ft above NAVD 88)	Hole depth (ft bls)	Com-pleted well depth (ft bls)	Casing length (ft)	Casing diam-eter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
151	5	FORD	401332075165201	401332	751651	19540901	364	500	500	78	8	19541106	100
151													
175	RI-7I	SPRA-FIN	401306075164401	401306	751643	--	361.32	160	103	14	6	20001031	34.92
175						20040724			102	92	2	20001205	38.96
175												20010725	
175												20050916	30.08
175												20051017	35.45
175												20060327	27.42
1841		SPRA-FIN	401308075165401	401307.86	751643.18		360.65	100	100	17	5.5	20001031	36.40
1841												20001205	38.32
1841												20041209	23.00
1841												20050608	26.63
1841												20050909	31.95
1841												20051017	34.99
1841												20060327	26.77
1920		FORD	401337075165901	401336.64	751658.82		372.9	125	125	47	6	20040322	40.50
1920												20040401	39.42
2080	RI-1D	FORD	401344075165601	401343.98	751655.84	20050520	372.65	300		17.5	8	20050908	46.26
2080						20050804			164	144	4	20051017	50.15
2080												20060327	44.17
2081	RI-2D	MERCK	401313075170501	401313.25	751705.19	20040706	329.31	300		19	8	20041129	20.25
2081						20040819			296	276	4	20041209	23.27
2081												20050606	54.60
2081												20050908	67.52
2081												20051017	67.04
2081												20060327	57.89
2082	RI-2I	MERCK	401313075170502	401313.24	751705.27	20040812	329.08	191		18		20041129	18.48
2082						20040826			186	176	2	20041209	21.06
2082												20050606	49.94
2082												20050908	61.66
2082												20051017	58.85
2082												20060327	52.68
2083	RI-2S	MERCK	401313075170503	401313.22	751705.35	20040831	328.86	61		18	6	20041209	5.60
2083						20040902			60	40	2	20050606	11.38
2083												20050908	22.83
2083												20051017	13.62
2083												20060327	12.47
2084	RI-3D	FORD	401331075165801	401330.67	751658.22	20040108	371.45	300		16	8	20041130	44.15
2084						20040824			202	182	4	20041209	44.20
2084												20050606	46.87
2084												20050908	55.98
2084												20051017	52.78
2084												20060327	48.01
2085	RI-3I	FORD	401331075165802	401330.61	751658.24	20040727	368.77	136		18	6	20041209	40.62
2085						20040824			135	115	2	20050518	41.93
2085												20050606	42.85
2085												20050908	51.44
2085												20051017	49.40
2085												20060327	43.88
2086	RI-3S	FORD	401331075165803	401330.57	751658.26	20040803	366.56	65.5		18	6	20041209	38.92
2086						20040809		6	65	45	2	20050518	39.95

Table 80. Characteristics of and water levels measured in wells logged by U.S. Geological Survey in and near North Penn Area 7, Montgomery County, Pa., October 2002–December 2006.—Continued

USGS local well number MG-	Well name	Property	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Drilling date Recon-struction date (YYYY MMDD)	Altitude of land surface, (ft above NAVD 88)	Hole depth (ft bls)	Com-pleted well depth (ft bls)	Casing length (ft)	Casing diam-eter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
2086												20050606	40.89
2086												20050908	48.85
2086												20051017	47.91
2086												20060327	41.99
2087	RI-4D	TELEFLEX	401322075171001	401321.61	751710.44	20040122	348.77	300		24	8	20041123	23.74
2087						20040701			212	192	4	20041206	23.34
2087												20050606	26.82
2087												20050908	37.90
2087												20051017	29.88
2087												20060327	28.07
2088	RI-4!	TELEFLEX	401322075171002	401321.58	751710.36	20040715	348.5	135		18	6	20041206	23.50
2088						20040802			88	78	2	20050606	26.47
2088												20050908	36.35
2088												20051017	31.99
2088												20060327	27.92
2089	RI-4S	TELEFLEX	401322075171003	401321.55	751710.29	20040803	348.47	70		19	6	20041206	22.74
2089						20040810			68	58	2	20050606	25.35
2089												20050908	34.02
2089												20051017	31.65
2089												20060327	25.99
2090	RI-5D	ZENITH	401339075171101	401339.05	751710.93	20040129	351.99	300		18.5	8	20041208	23.43
2090						20040708			300	280	4	20050608	23.23
2090												20050816	18.67
2090												20050908	32.48
2090												20051017	33.56
2090												20060327	26.24
2091	RI-5I	ZENITH	401339075171102	401339.04	751711.02	20040719	350.85	95.1		17.5	6	20041208	19.44
2091						20040729			95	75	2	20050608	20.18
2091												20050908	26.67
2091												20051017	30.77
2091												20060327	21.74
2092	RI-5S	ZENITH	401339075171103	401339.10	751711.00	20040729	351.85	60		18	6	20041208	18.58
2092						20040805			60	40	2	20050415	16.36
2092												20050608	19.28
2092												20050908	25.75
2092												20051017	29.80
2092												20060327	20.92
2093	RI-6D	PECO	401322075163901	401322.19	751639.05	20040210	344.18	300		22	8	20041129	9.88
2093						20040817			189	169	4	20041206	9.28
2093												20050606	14.37
2093												20050908	22.81
2093												20051017	23.32
2093												20060327	14.70
2094	RI-6S	PECO	401322075163902	401322.22	751639.10	20040727	343.87	65.5		18	6	20041129	7.76
2094						20040817			60	40	2	20050606	11.05
2094												20051017	15.42
2094												20060327	11.33
2095	RI-7D	SPRA-FIN	401306075164301	401306.18	751643.22	20040115	361.64	245		18	8	20041208	19.94
2095						20040708			195	175	4	20050606	23.34
2095												20050908	29.46
2095												20051017	32.66

Table 80. Characteristics of and water levels measured in wells logged by U.S. Geological Survey in and near North Penn Area 7, Montgomery County, Pa., October 2002–December 2006.—Continued

USGS local well number MG-	Well name	Property	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Drilling date Recon-struction date (YYYY MMDD)	Altitude of land surface, (ft above NAVD 88)	Hole depth (ft bls)	Com-pleted well depth (ft bls)	Casing length (ft)	Casing diam-eter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
2095												20060327	23.18
2096	RI-7S	SPRA-FIN	401306075164302	401306.14	751643.30	20040802	361.58	72.4		18	6	20041208	19.68
2096						20040826			72	52	2	20050606	27.15
2096												20050908	33.87
2096												20051017	36.05
2096												20060327	27.99
2097	RI-8D	MERCK	401259075165401	401258.53	751654.42	20040713	344.81	300		18	8	20041208	3.45
2097						20040827			260	240	4	20050606	7.38
2097												20050908	13.11
2097												20051017	16.18
2097												20060327	6.75
2098	RI-8I	MERCK	401259075165402	401258.51	751654.50	20040831	344.69	80		18.5	6	20041208	9.30
2098						20040902			80	50	2	20050606	12.78
2098												20050908	18.20
2098												20051017	19.35
2098												20060327	12.79
2099	RI-8S	MERCK	401259075165403	401258.48	751654.60	20040908	344.64	40		18	6	20040908	18.04
2099						20040909	344.64		40	20	2	20041208	9.38
2099												20050606	12.74
2099												20051017	19.11
2099												20060327	12.77
2100	RI-9D	MERCK	401255075171701	401254.62	751717.21	20040708	335.26	286		18.5	8	20050606	32.75
2100						20040827			270	250	4	20050908	41.24
2100												20051017	44.25
2100												20060327	33.88
2101	RI-9I	MERCK	401255075171702	401254.57	751717.29	20040830	335.52	187.1		18.5	6	20041130	27.89
2101						20040902			186	166	2	20041209	29.80
2101												20050606	61.72
2101												20050908	75.06
2101												20051017	71.14
2101												20060327	64.93
2102	RI-9S	MERCK	401255075171703	401254.51	751717.38	20040907	335.85	104		18	6	20041209	32.26
2102						20040909			100	80	2	20050606	67.80
2102												20050908	83.19
2102												20051017	77.01
2102												20060327	71.71
2119	RI-10D	SMURFIT	401324075172601	401323.92	751726.25	20040130	365.51	290.1		15.5	8	20041208	41.25
2119						20040713			230	210	4	20050606	43.39
2119												20050725	43.73
2119												20050908	51.47
2119												20051017	51.84
2119												20060327	45.24
2120	RI-10I	SMURFIT	401324075172602	401323.87	751726.69	20040728	365.92	140		19	6	20041208	39.23
2120						20040806			130	110	2	20050606	40.22
2120												20050908	47.16
2120												20051017	50.43
2120												20060327	41.91
2121	RI-10S	SMURFIT	401324075172603	401323.81	751726.63	20040810	366.06	88		19	6	20041208	39.16
2121						20040827			87	67	2	20050606	40.01
2121												20050908	46.84
2121												20051017	50.37

Table 80. Characteristics of and water levels measured in wells logged by U.S. Geological Survey in and near North Penn Area 7, Montgomery County, Pa., October 2002–December 2006.—Continued

USGS local well number MG-	Well name	Property	Site identification number	Latitude (NAD 83)	Long-itude (NAD 83)	Drilling date Recon-struction date (YYYY MMDD)	Altitude of land surface, (ft above NAVD 88)	Hole depth (ft bls)	Com-pleted well depth (ft bls)	Casing length (ft)	Casing diam-eter (in.)	Date of water level (YYYY MMDD)	Depth to water (ft bls)
2121												20060327	41.60
2122	RI-11D	TIMBERLANE	401310075164601	401310.39	751645.88	20040630	355.61	299.4		24	8	20041123	15.58
2122						20040908			270	250	4	20041206	14.36
2122												20050606	17.61
2122												20050908	23.60
2122												20051017	26.84
2122												20060327	17.14
2123	RI-11I	TIMBERLANE	401310075164602	401310.38	751645.97	20040809	354.95	100		19	6	20041123	20.82
2123						20040908			100	80	2	20041206	19.95
2123												20050606	23.21
2123												20050908	28.71
2123												20051017	31.05
2123												20060327	23.46
2124	RI-11S	TIMBERLANE	401310075164603	401310.36	751646.05	20040902	354.5	61		19	6	20041123	20.84
2124						20040908			60	40	2	20041206	19.86
2124												20050606	24.44
2124												20050908	31.02
2124												20051017	32.76
2124												20060327	24.71
2125	RI-12D	ZENITH	401350075171301	401350.13	751712.94	20040113	357.85	300		20	8	20041208	44.67
2125						20040720			188	168	4	20050606	46.12
2125												20050908	52.58
2125												20051017	54.70
2125												20060327	46.82
2126	RI-13D	ZENITH	401336075171701	401336.05	751716.94	20040127	355.52	279		19.5	8	20041208	26.73
2126						20040720			230	210	4	20050606	27.47
2126												20050908	34.48
2126												20051017	38.05
2126												20060327	29.41
2127	RI-13I	ZENITH	401336075171702	401335.98	751717.00	20040805	355.58	137		19	6	20041208	24.49
2127						20040810			136	116	2	20050606	24.93
2127												20050908	31.48
2127												20051017	35.72
2127												20060327	26.71
2128	RI-13S	ZENITH	401336075171703	401335.93	751717.06	20040811	355.5	72		19	6	20041208	24.61
2128						20040827			72	52	2	20050606	25.20
2128												20050908	31.79
2128												20051017	35.66
2128												20060327	26.94
2129	RI-14D	FORD	401337075165601	401337.08	751655.52	20050518	378.3	300		53	8	20050908	54.58
2129						200507			162	142	4	20060327	49.91
2130	RI-14S	FORD	401337075165602	401336.99	751655.52	2005	378.61	116		15	6	20050916	55.14
2130						2005			93	83	2	20060327	49.36
2131	RI-15DD	FORD	401334075170601	401334.48	751706.07	20050524	373.31	300			8	20060327	49.95
2131						2005			256	236	4		
2132	RI-15D	FORD	401334075170602	401334.38	751706.13		372.05	222	215	16	8	20060327	47.74
2132											4		
2133	RI-15I	FORD	401334075170603	401334.29	751706.18		371.76	132.3	108	18.5		20060327	44.08
2133													
2134	RI-15S	FORD	401334075170604	401334.19	751706.23		371.36	100	77	18	6	20060327	43.31
2134													

Appendix 1 - Geophysical logs for shallow and intermediate monitor wells

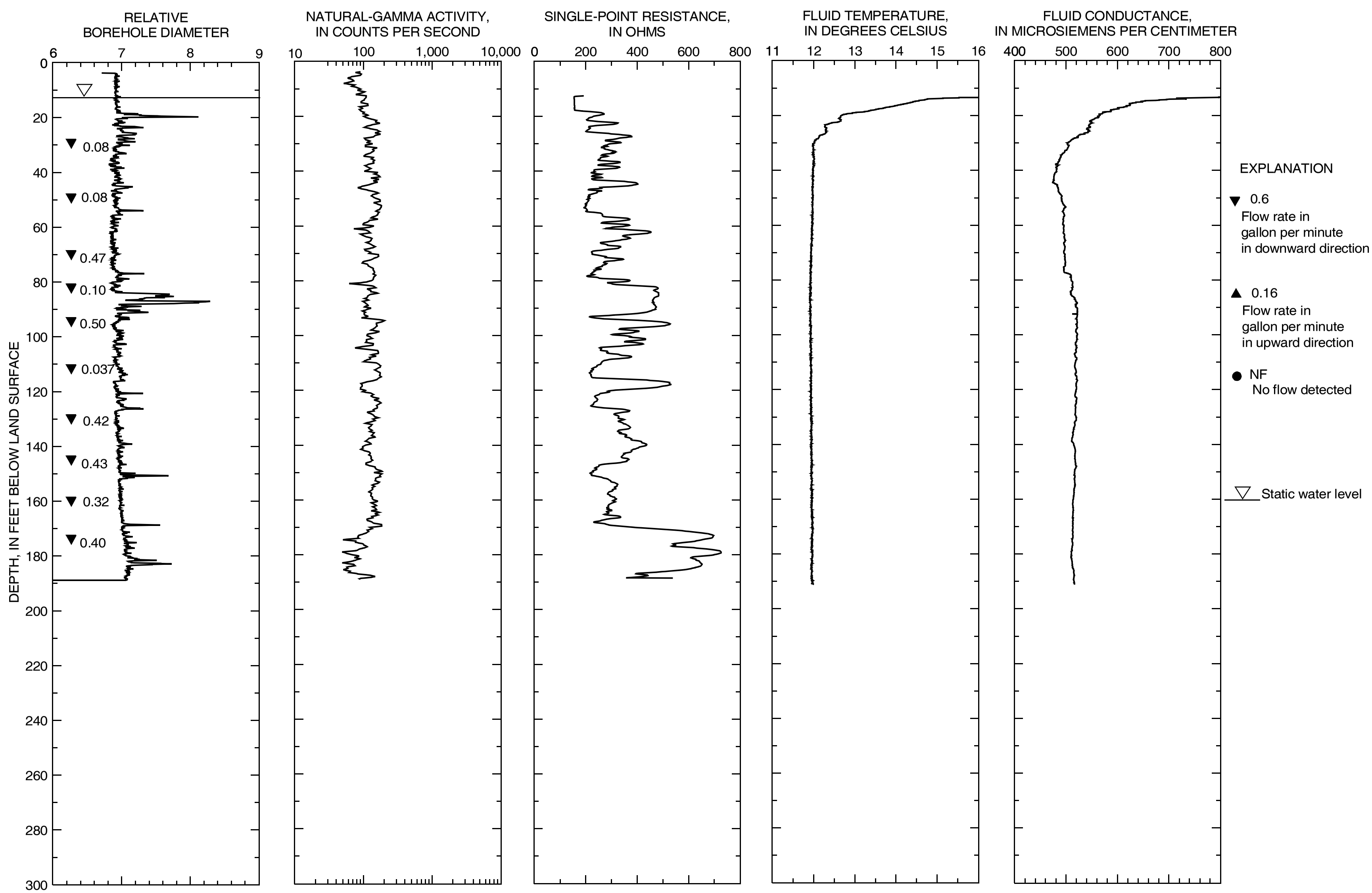


Figure 1-1. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2082 (RI-2I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 16, 2004. Depicted flow was measured with no diverter on heatpulse flowmeter because borehole flow was greater than instrument's upper limit of 1 gallon per minute, and therefore, flow should be interpreted as a relative rate rather than an accurate rate.

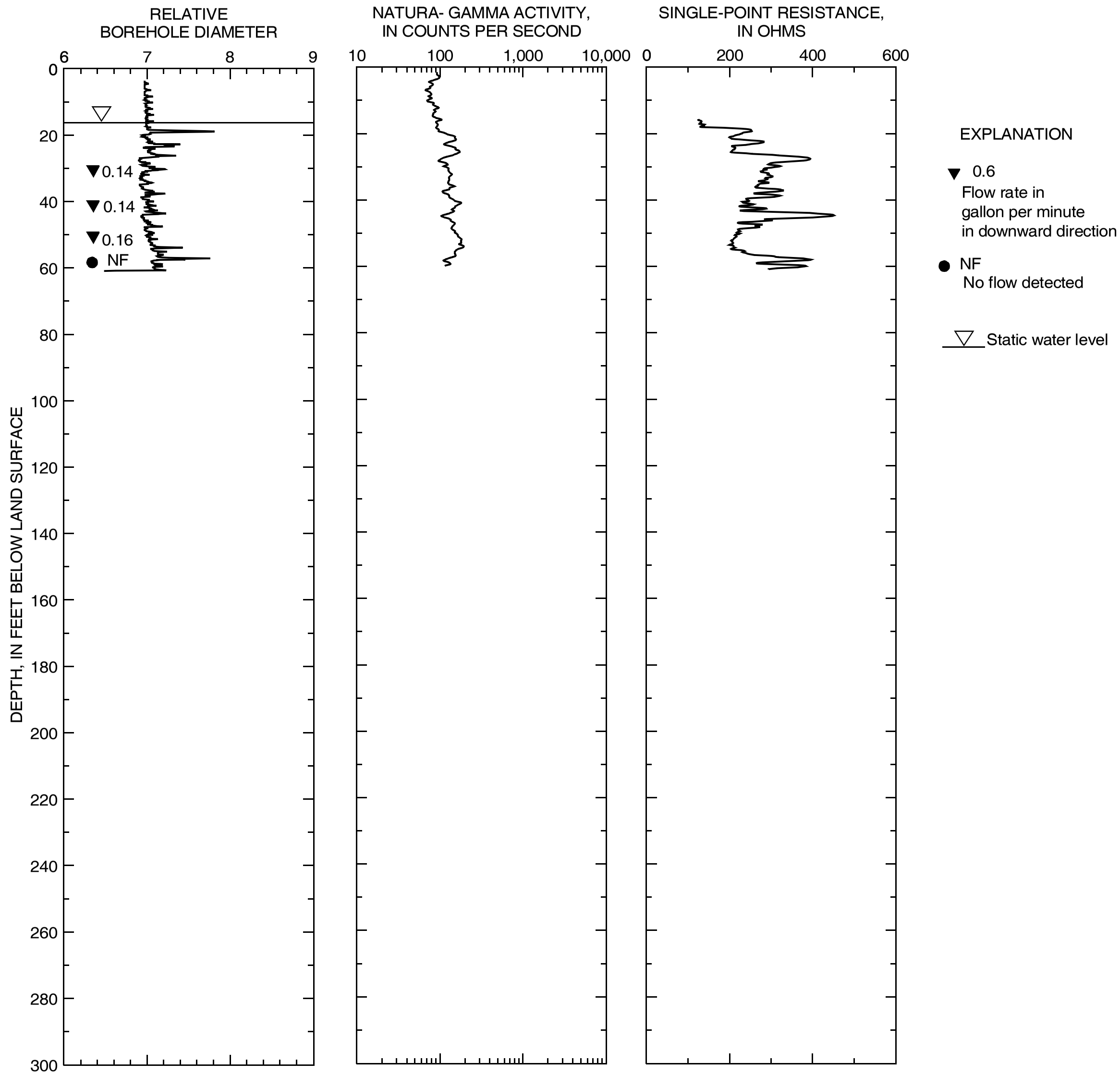


Figure 1-2. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2083 (RI-2S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 2, 2004.

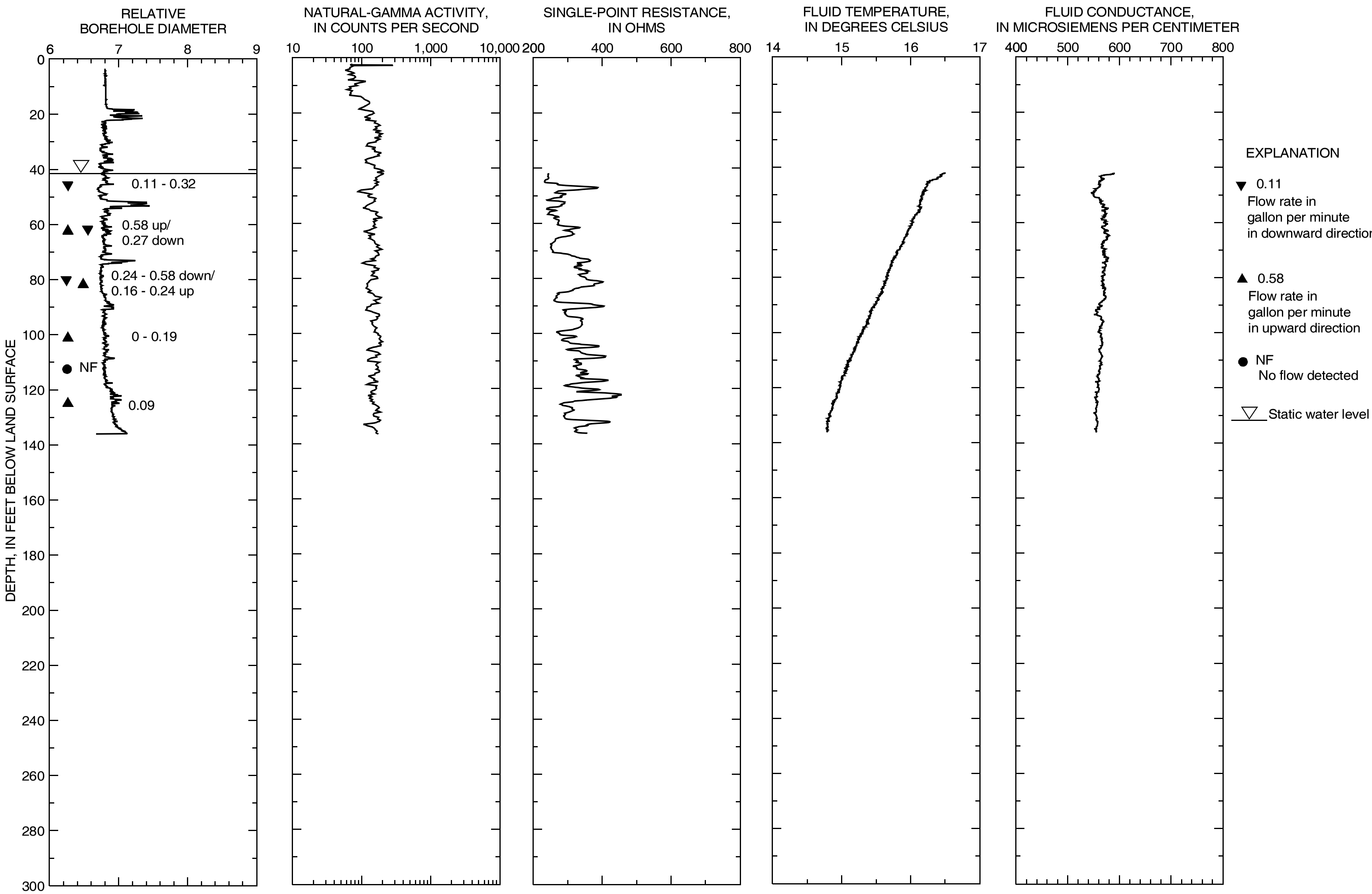


Figure 1-3. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2085 (RI-3I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 27, 2004. Measured flow rates and directions variable probably due to nearby transient pumping.

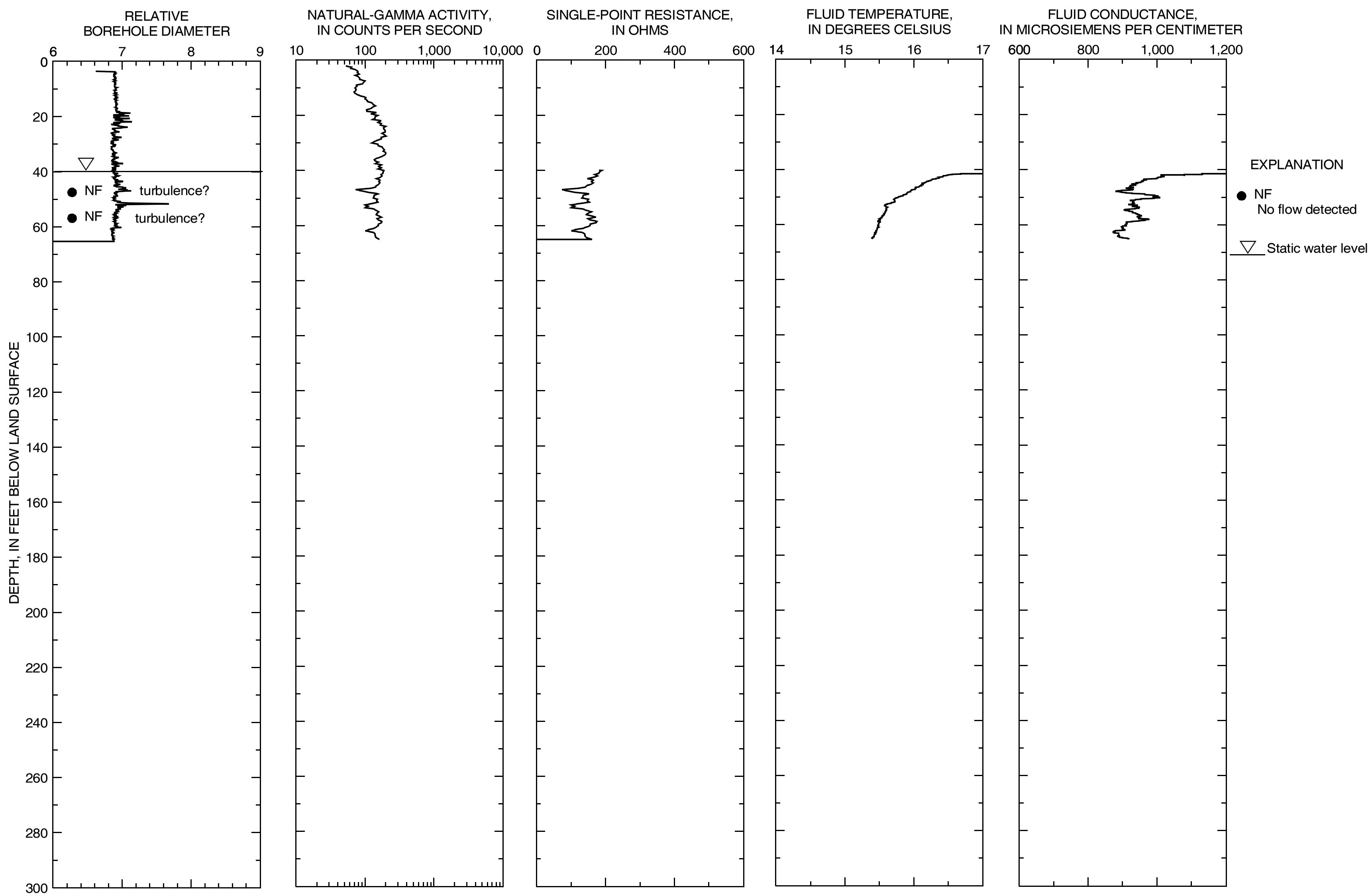


Figure 1-4. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2086 (RI-3S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 27, 2004. Possible turbulence and lateral flow at depths of measurements.

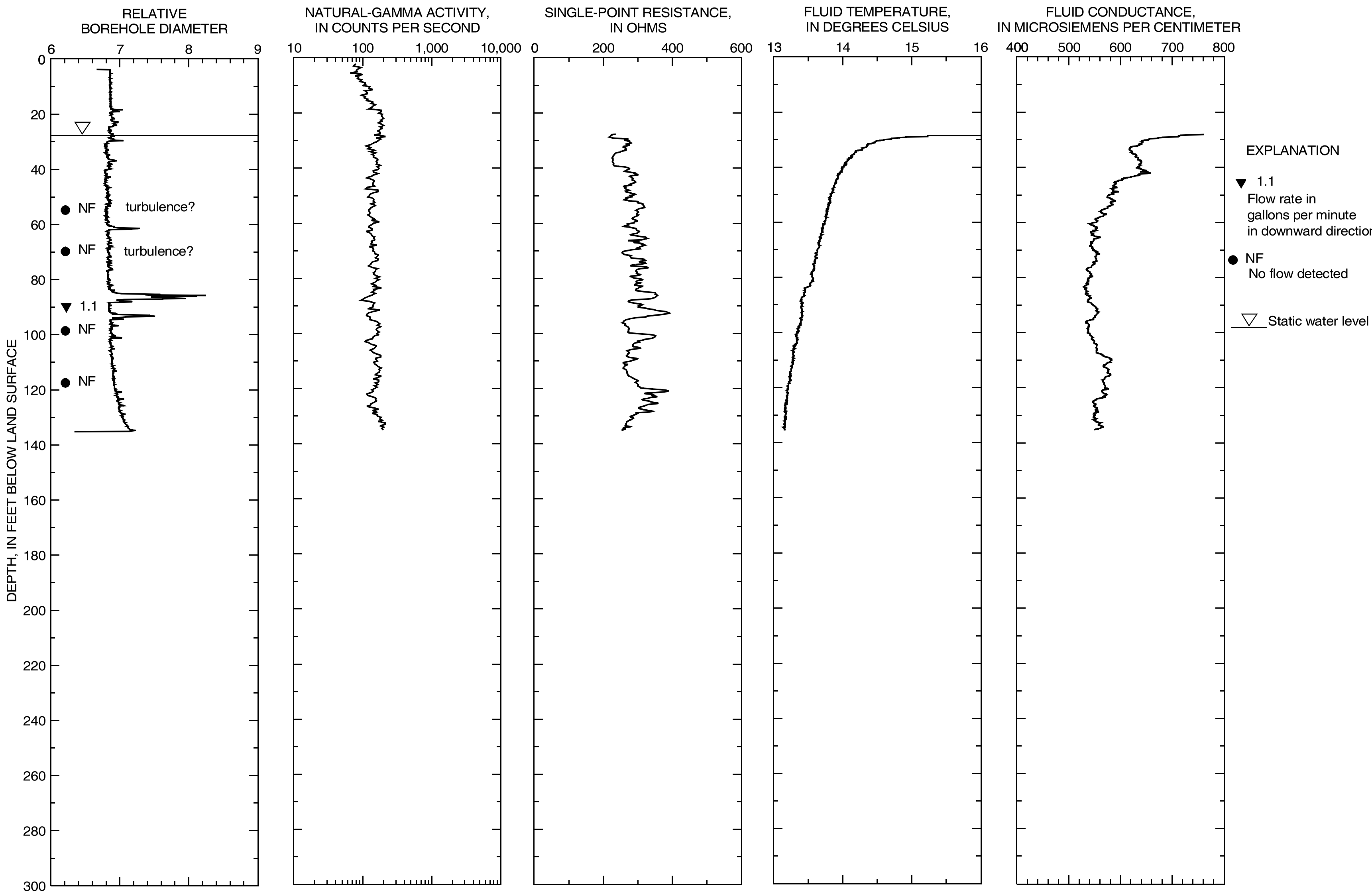


Figure 1-5. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2088 (RI-4I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 23, 2004. Possible turbulence at 56 and 70 feet below land surface.

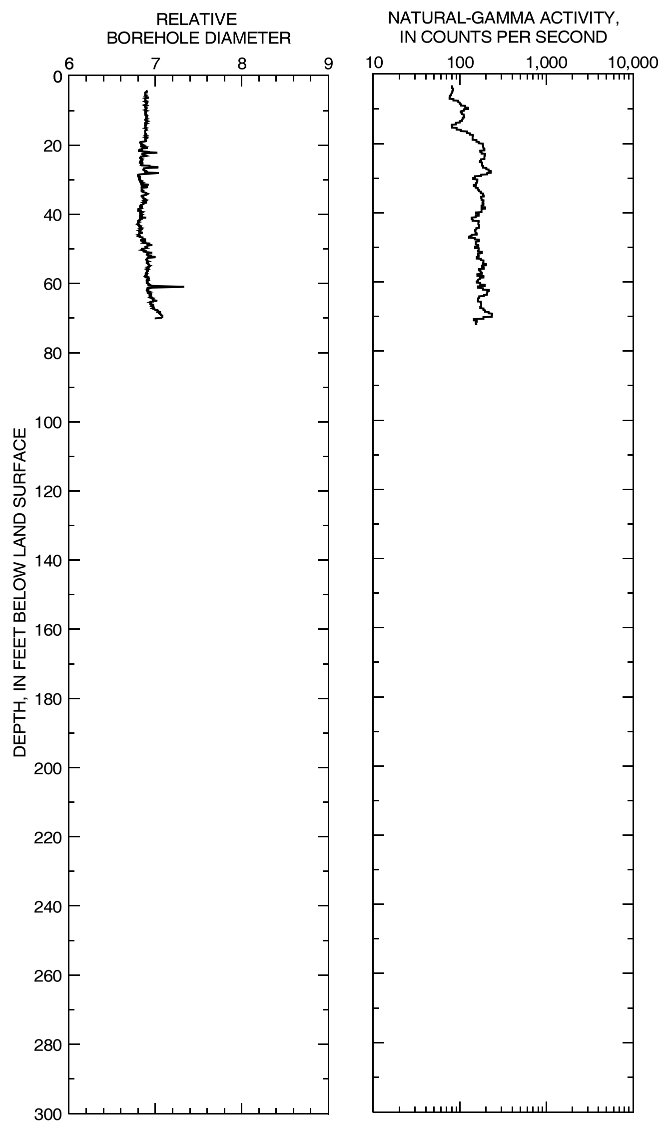


Figure 1-6. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2089 (RI-4S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 3, 2004.

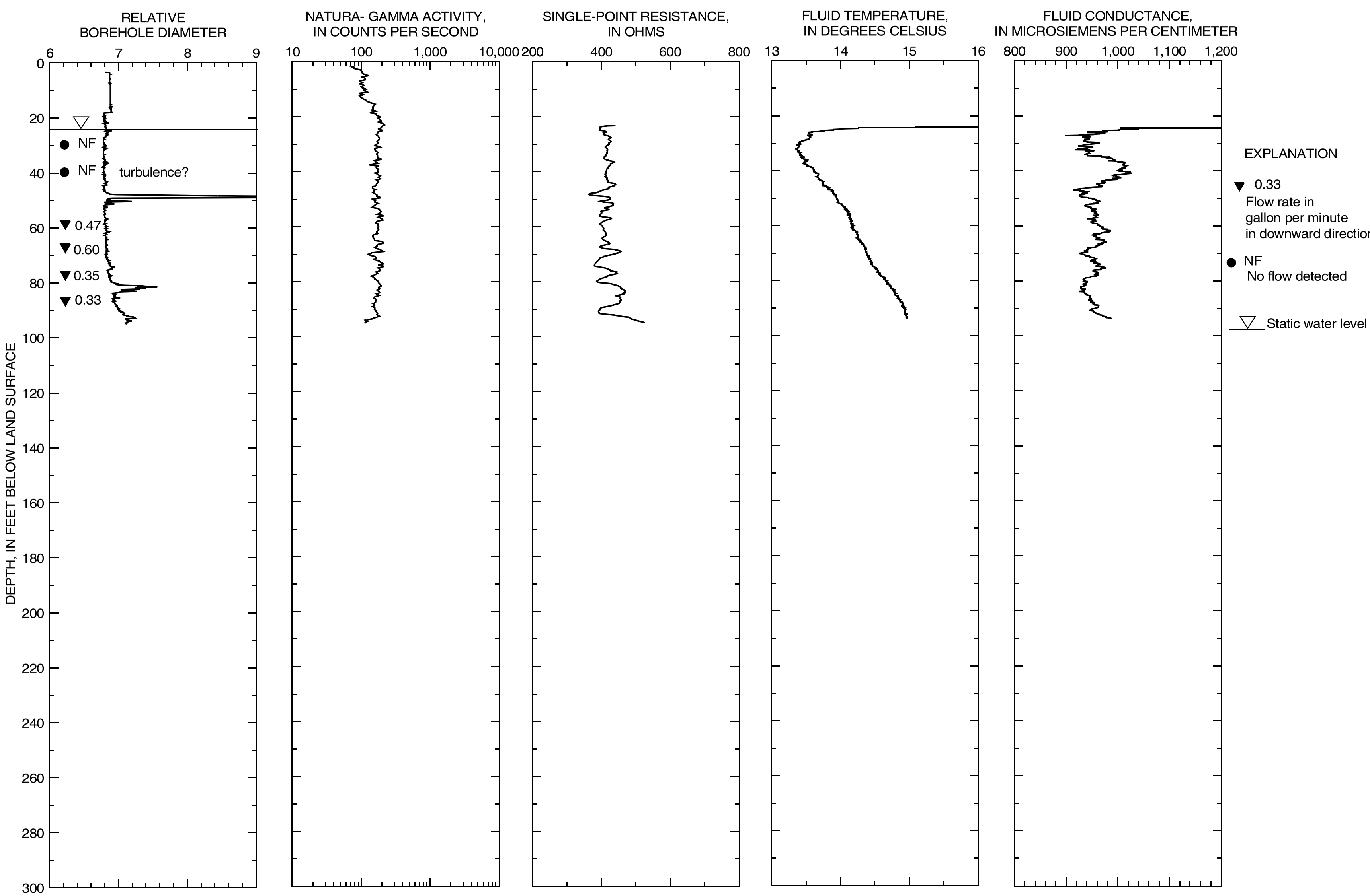


Figure 1-7. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2091 (RI-5I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 23, 2004. Possible turbulence at 40 feet below land surface.

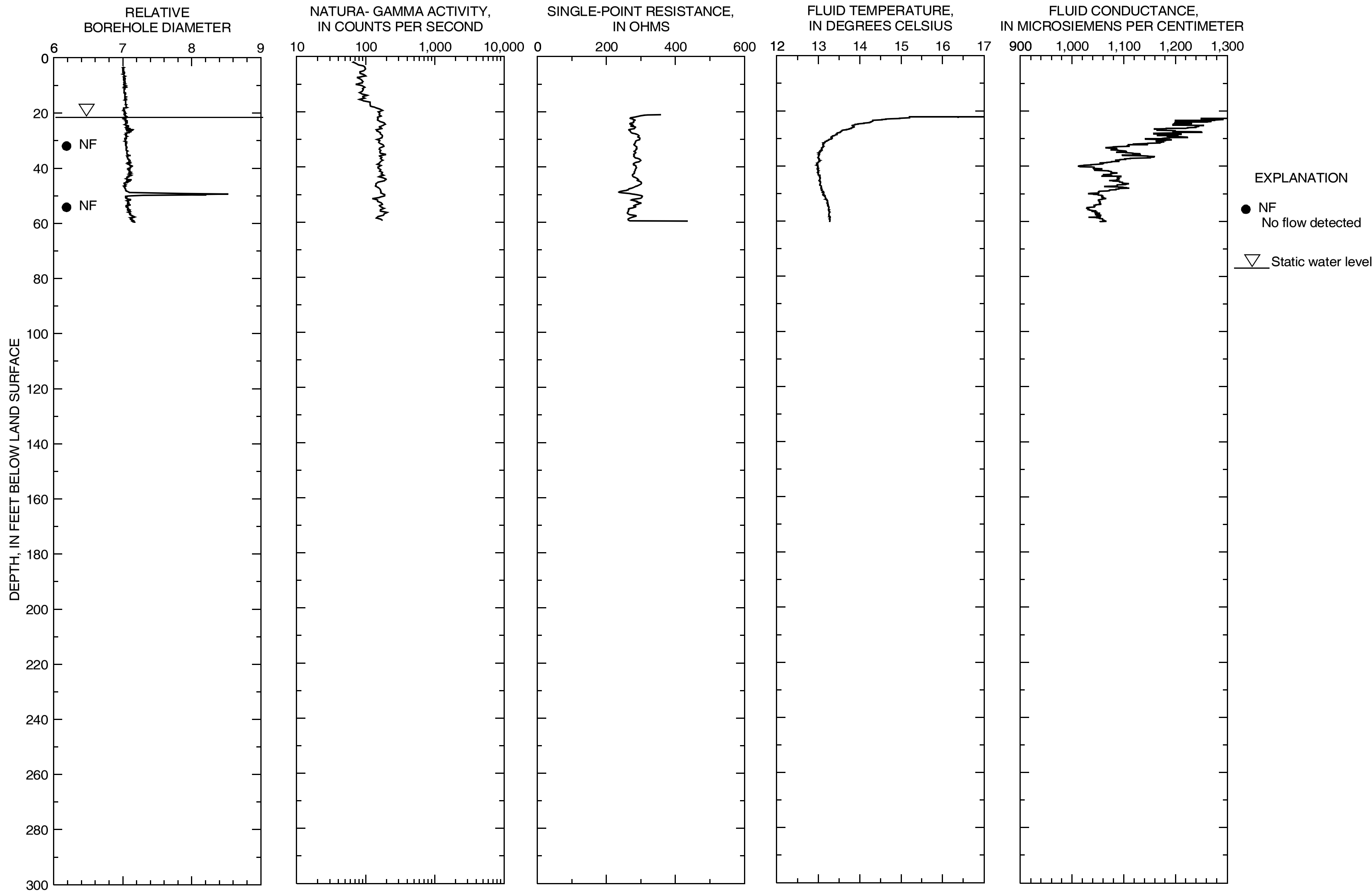


Figure 1-8. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2092 (RI-5S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 4, 2004.

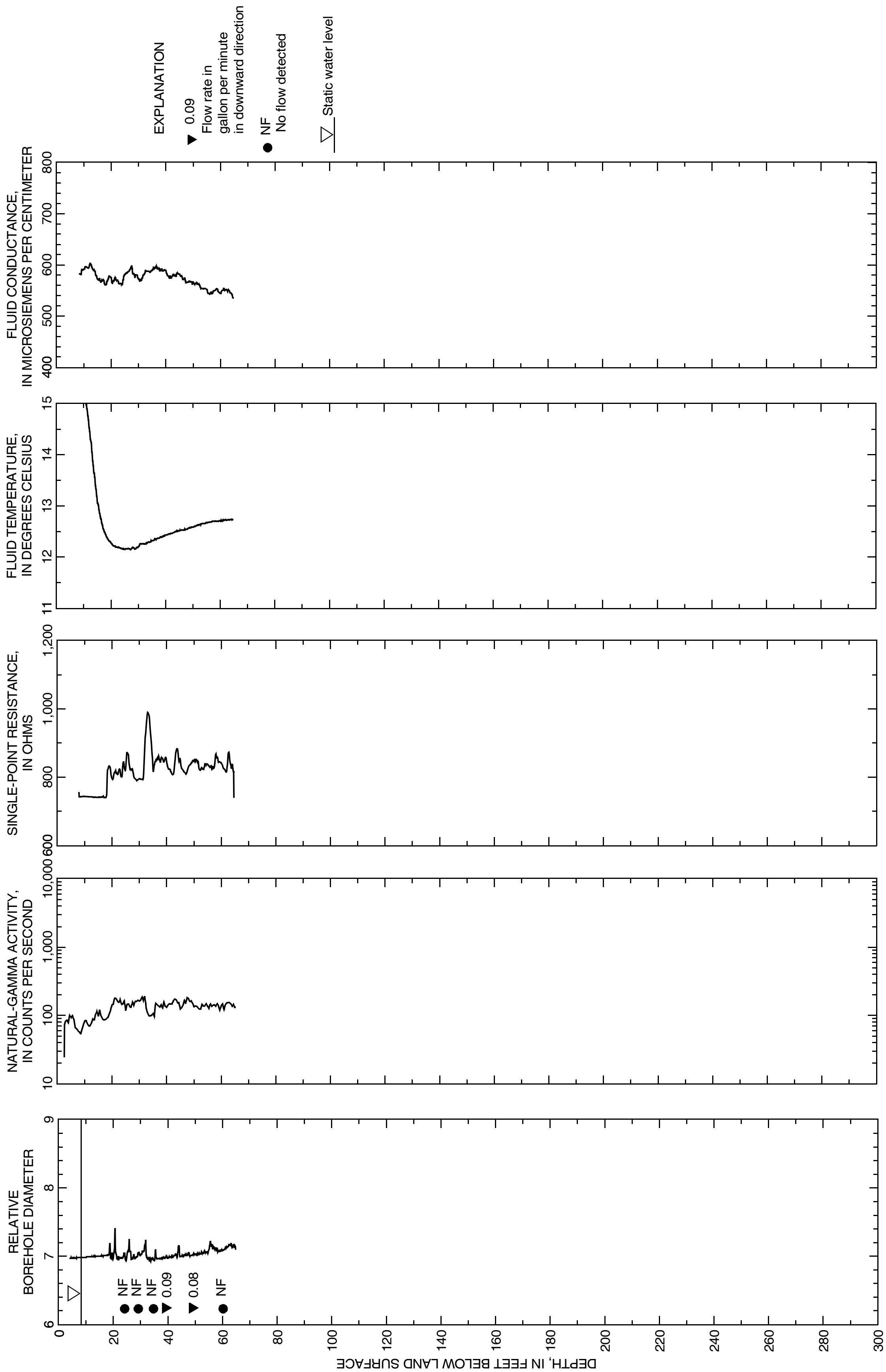


Figure 1-9. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2094 (RI-6S), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 28, 2004.

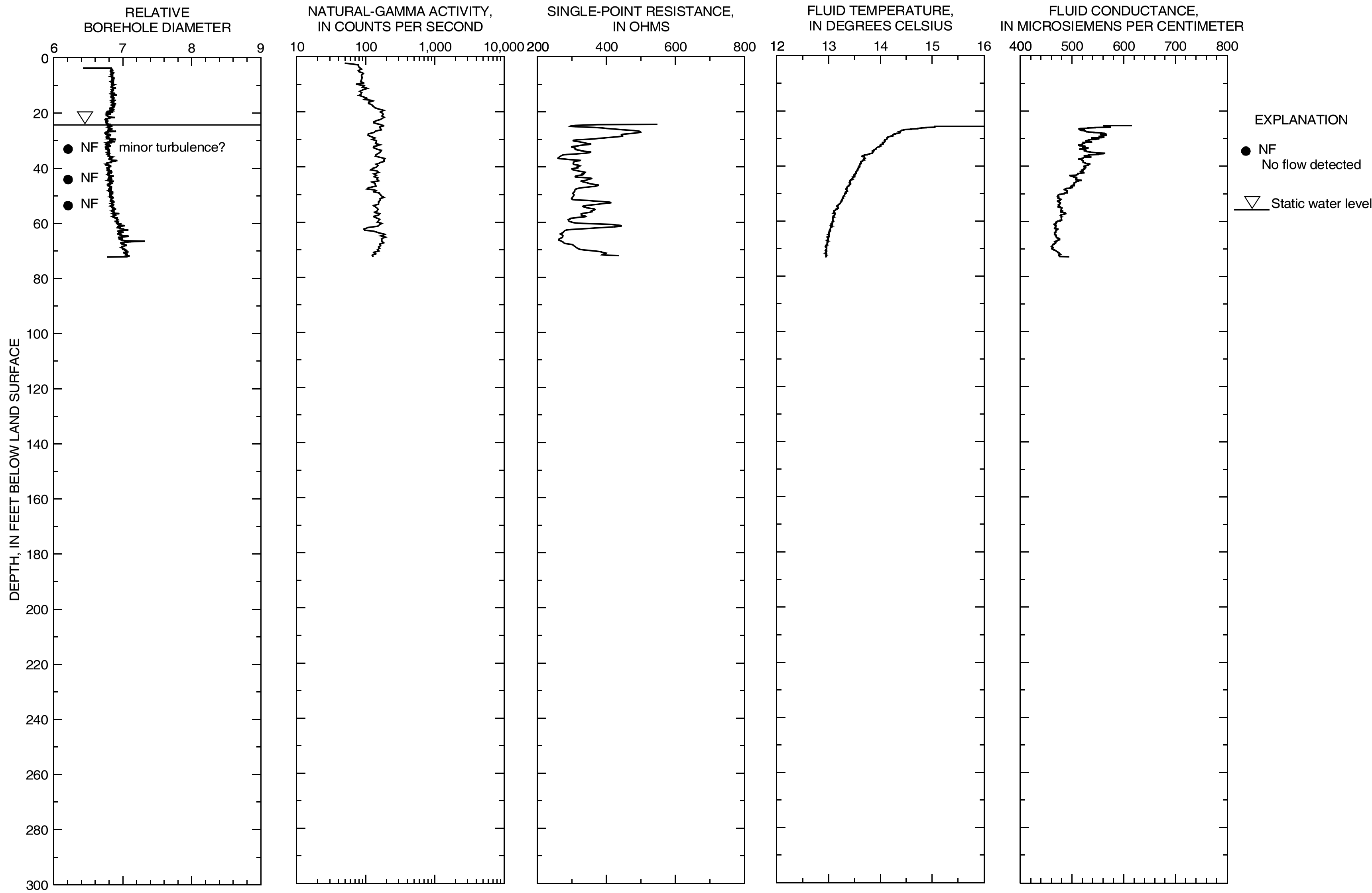


Figure 1-10. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2096 (RI-7S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 3, 2004. Possible turbulence at 34 feet below land surface.

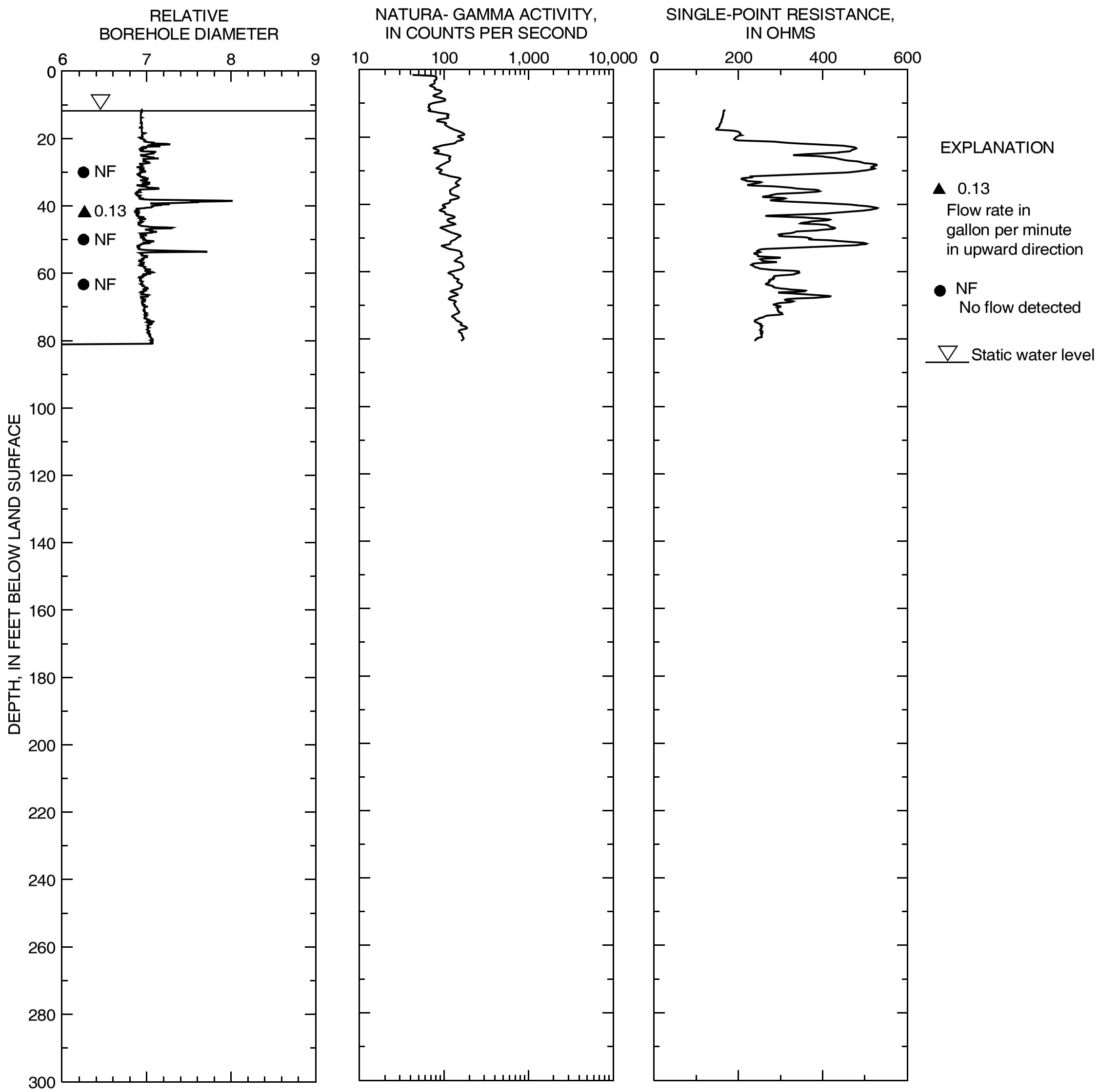


Figure 1-11. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2098 (RI-8I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 1, 2004.

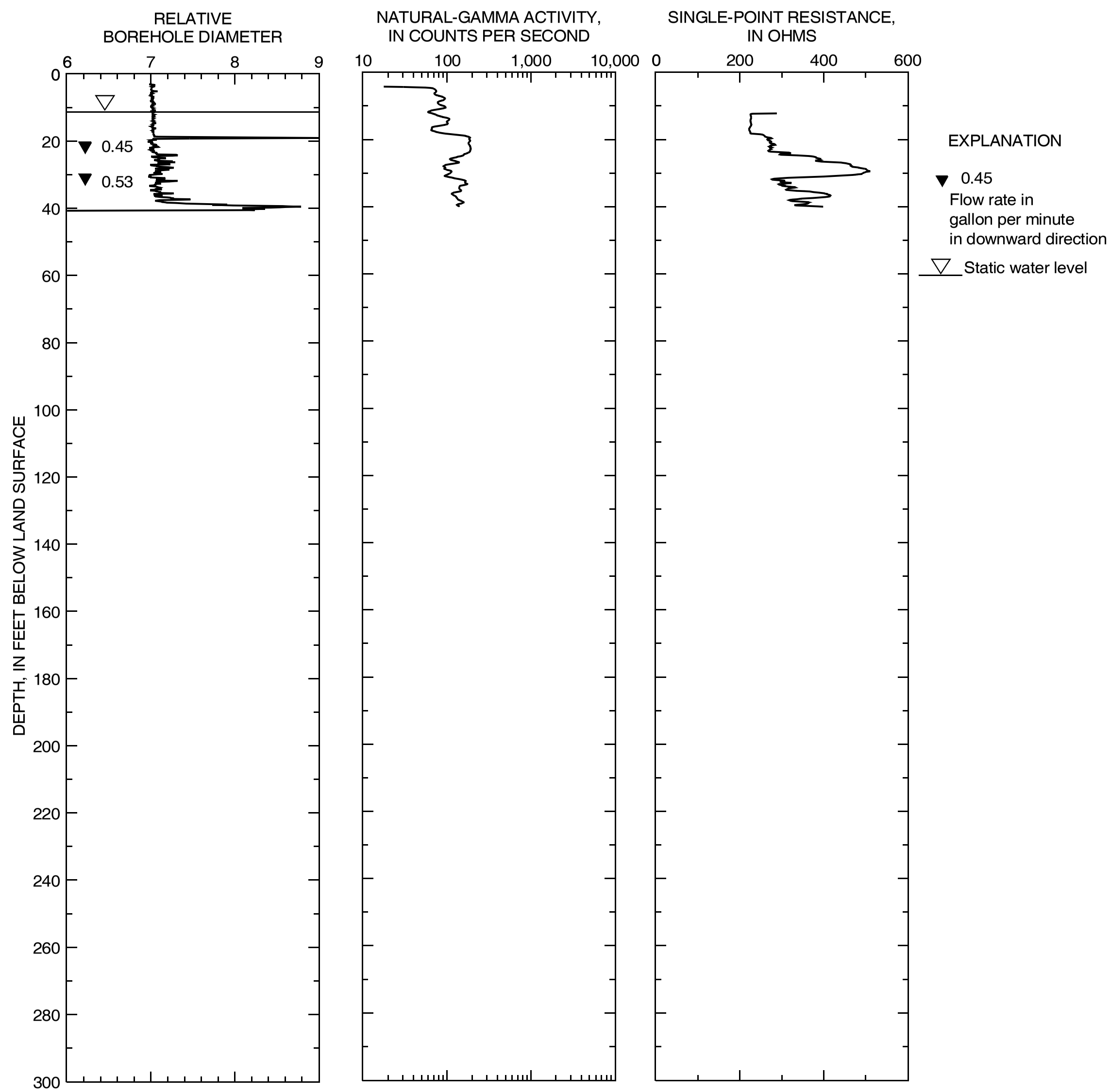


Figure 1-12. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2099 (RI-8S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 1, 2004.

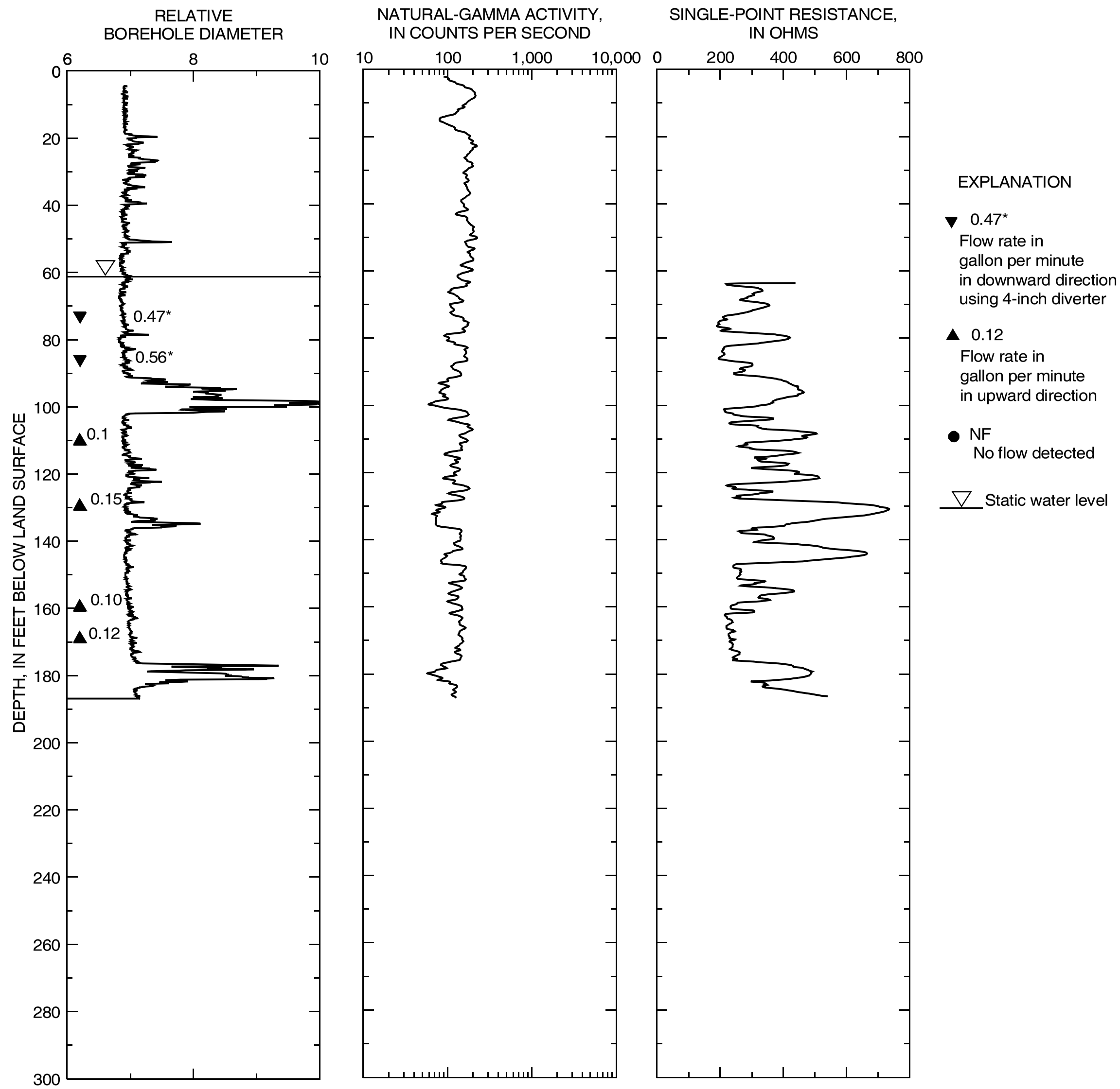


Figure 1-13. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2101 (RI-9I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 1, 2004. Depicted flow was measured with no diverter, or 4-inch-diameter diverter where noted, on heatpulse flowmeter because borehole flow was greater than instrument's upper limit of 1 gallon per minute, and therefore, flow should be interpreted as a relative rate rather than an accurate rate.

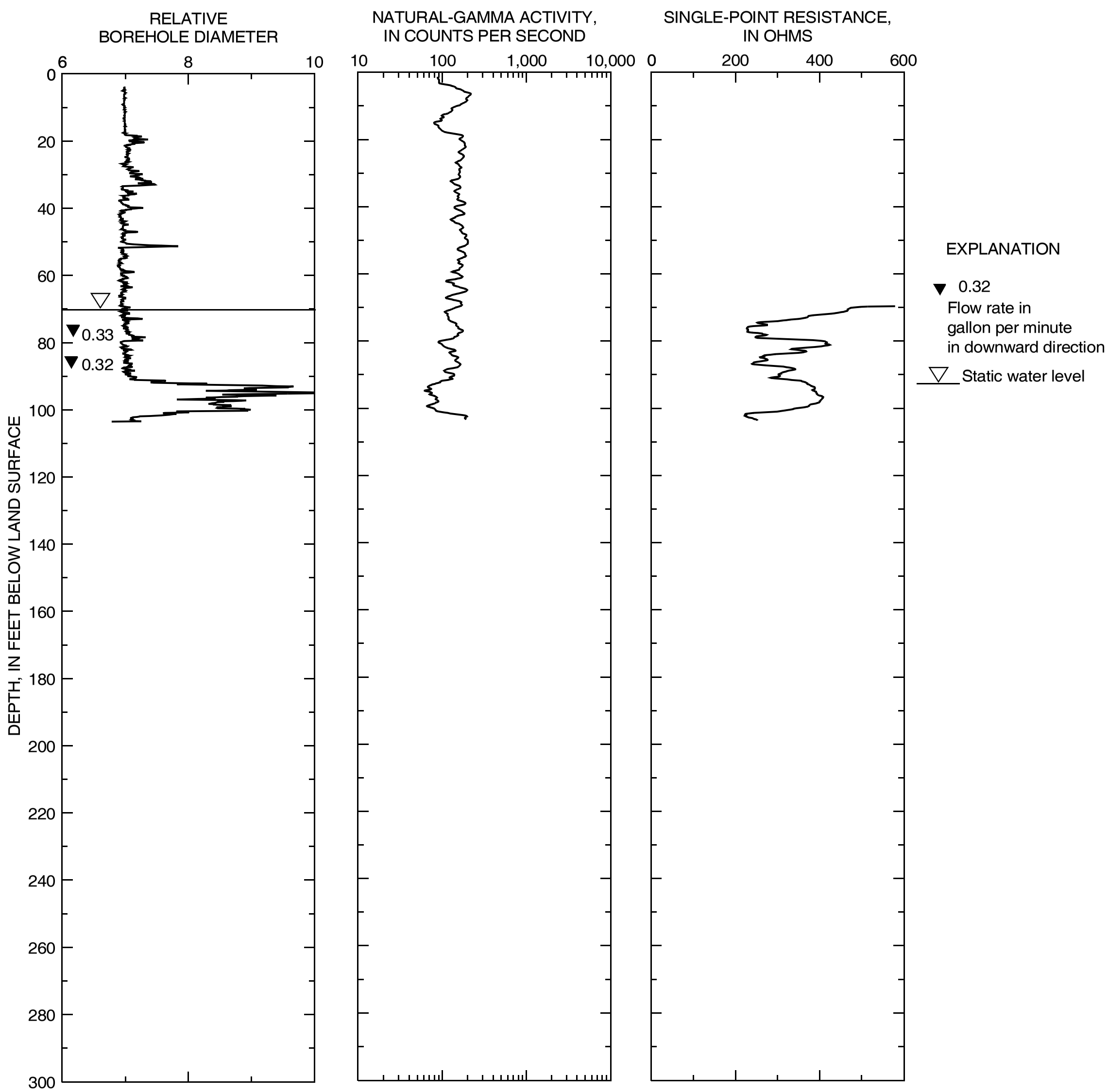


Figure 1-14. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2102 (RI-9S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 8, 2004.

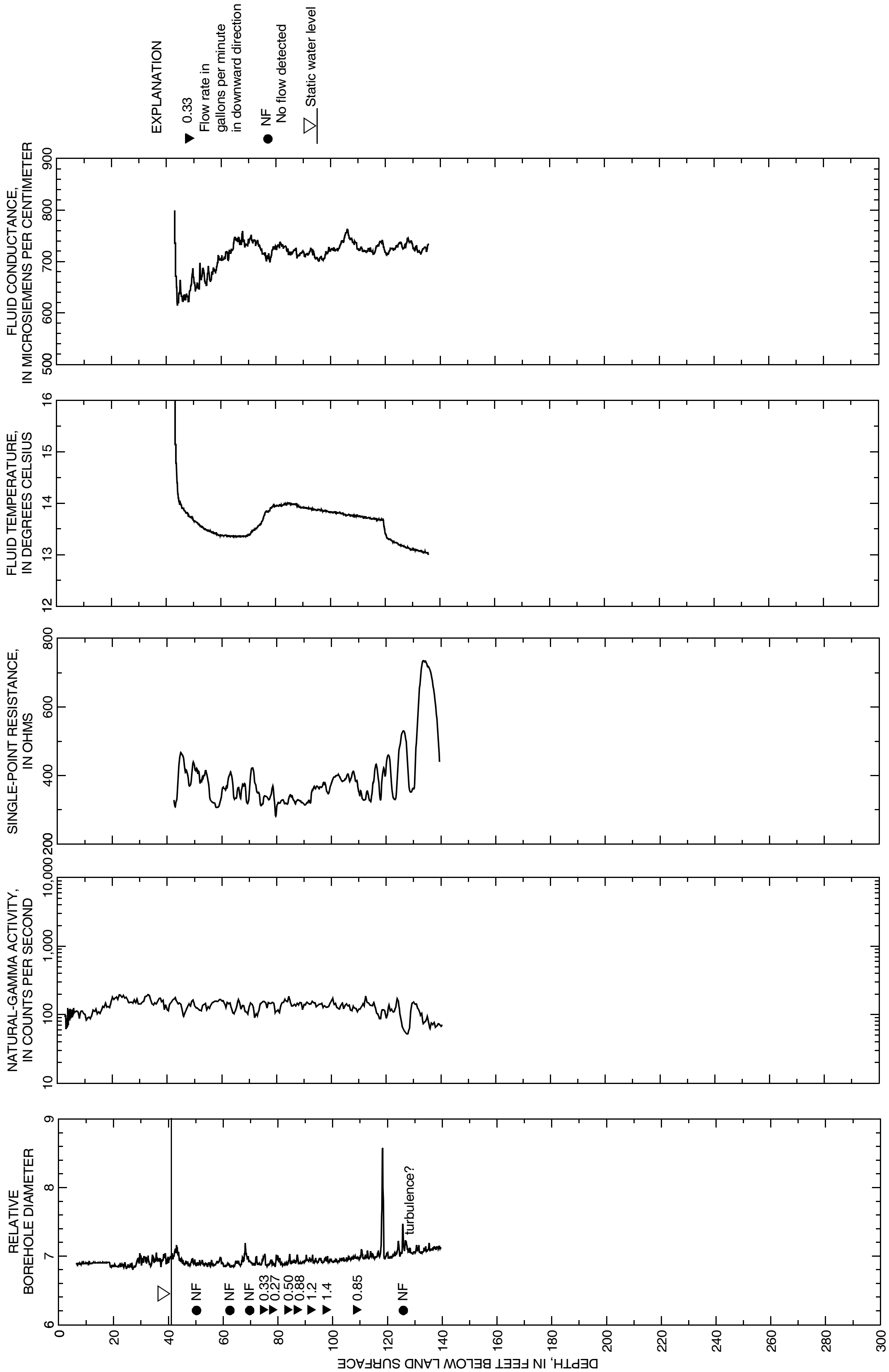


Figure 1-15. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2120 (RI-10I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 29, 2004.

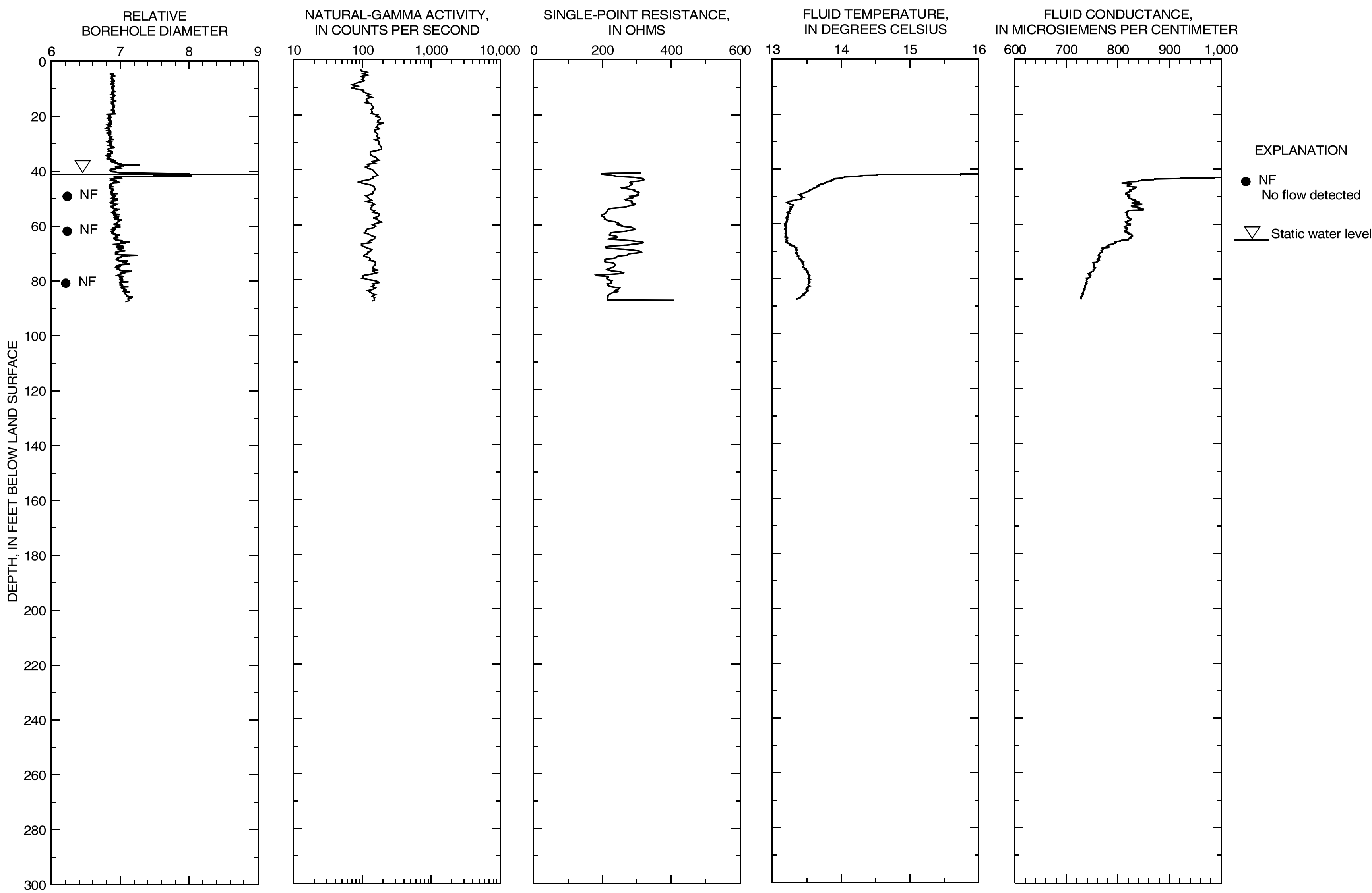


Figure 1-16. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2121 (RI-10S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 11, 2004.

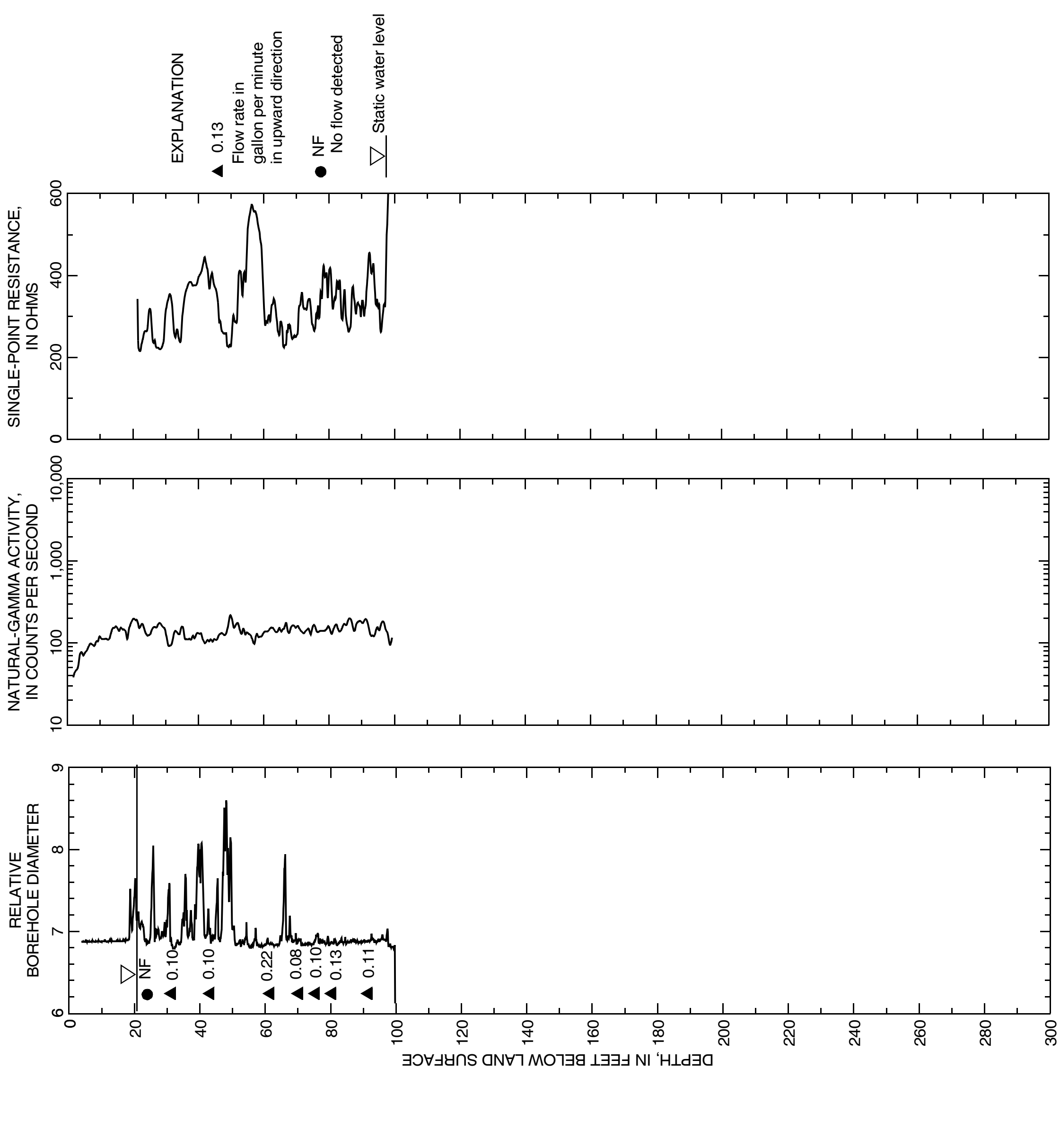


Figure 1-17. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2123 (RI-11I), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 10, 2004.

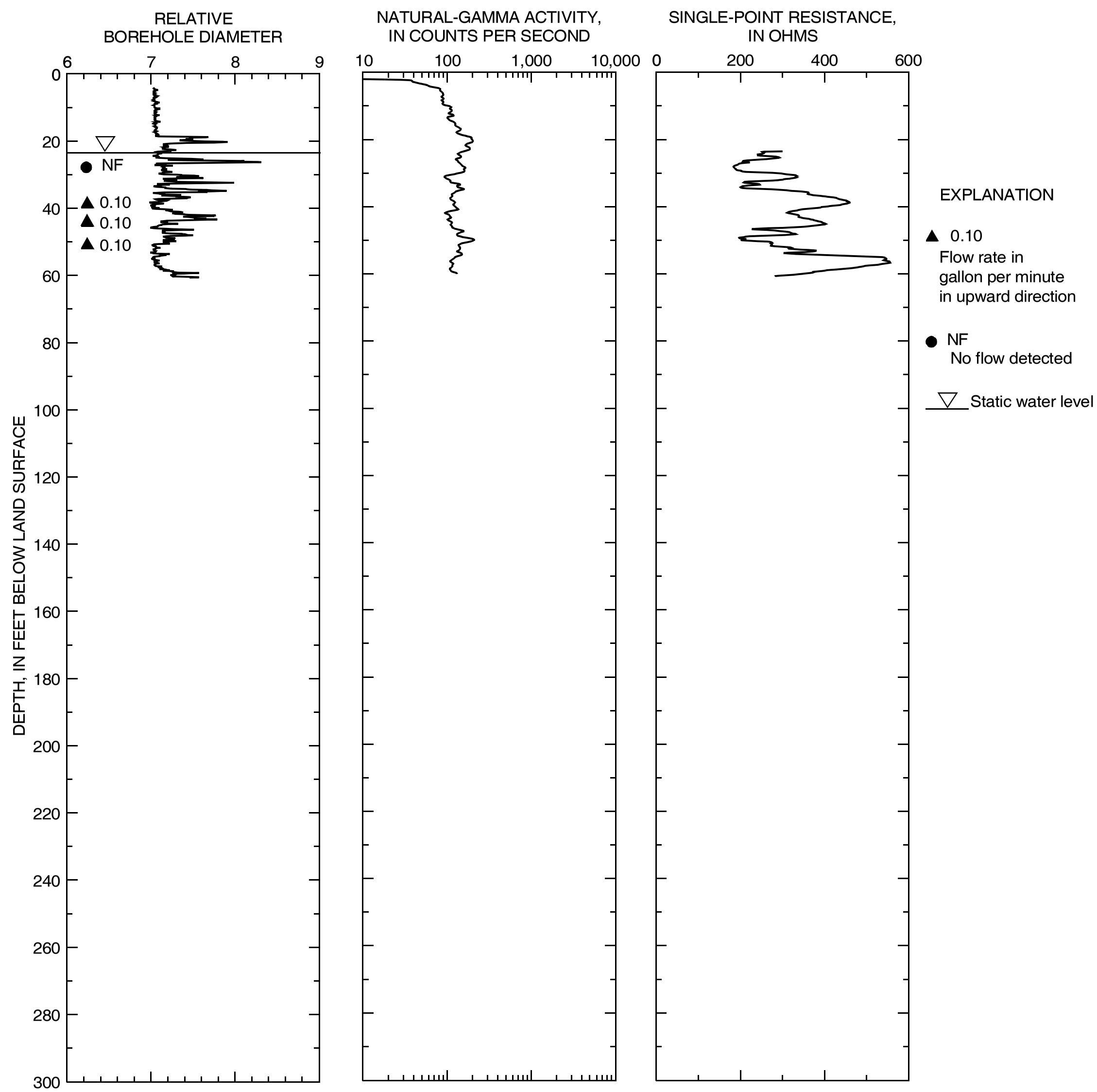


Figure 1-18. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2124 (RI-11S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., September 3, 2004.

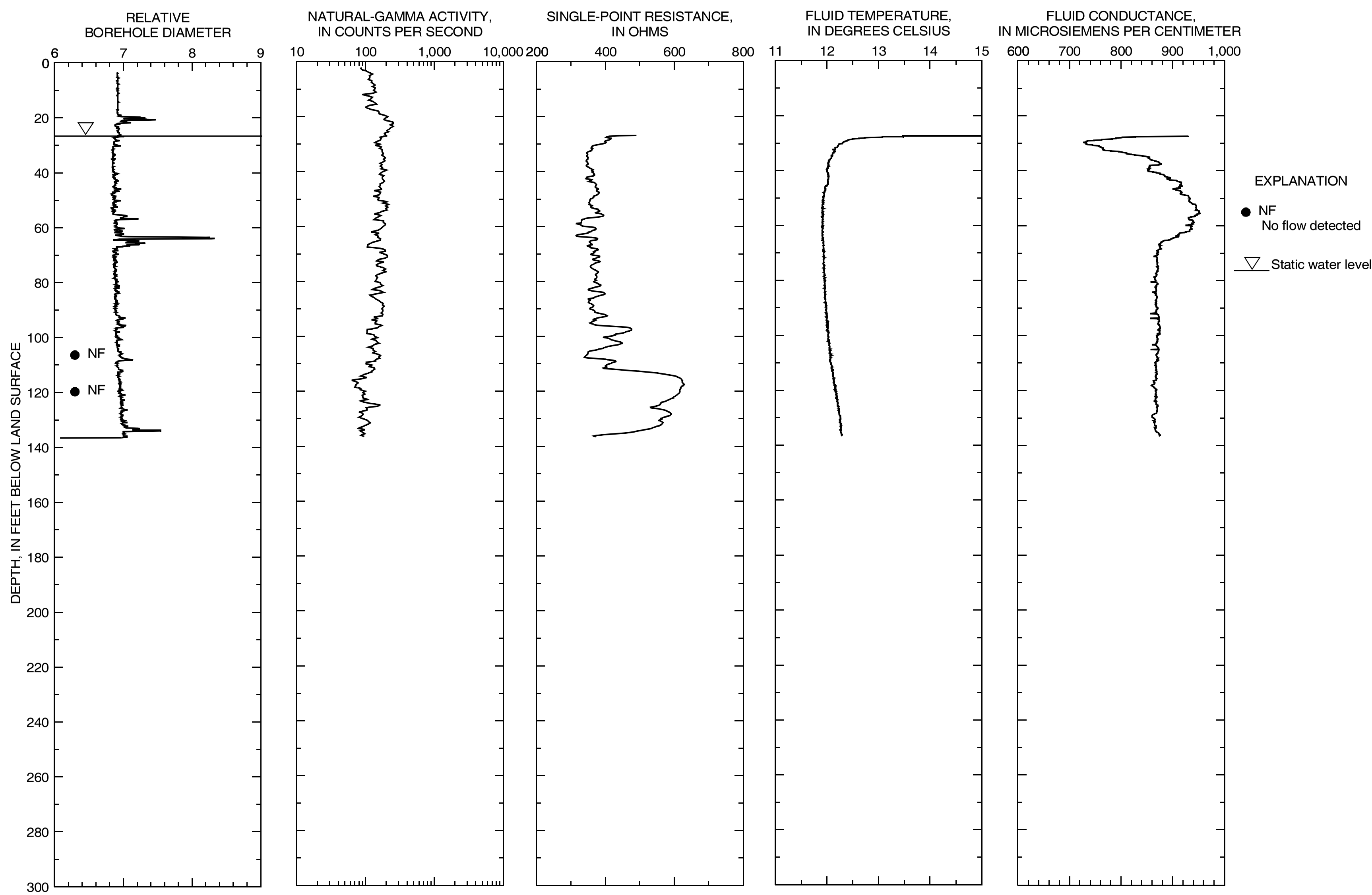


Figure 1-19. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2127 (RI-13I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 7, 2004.

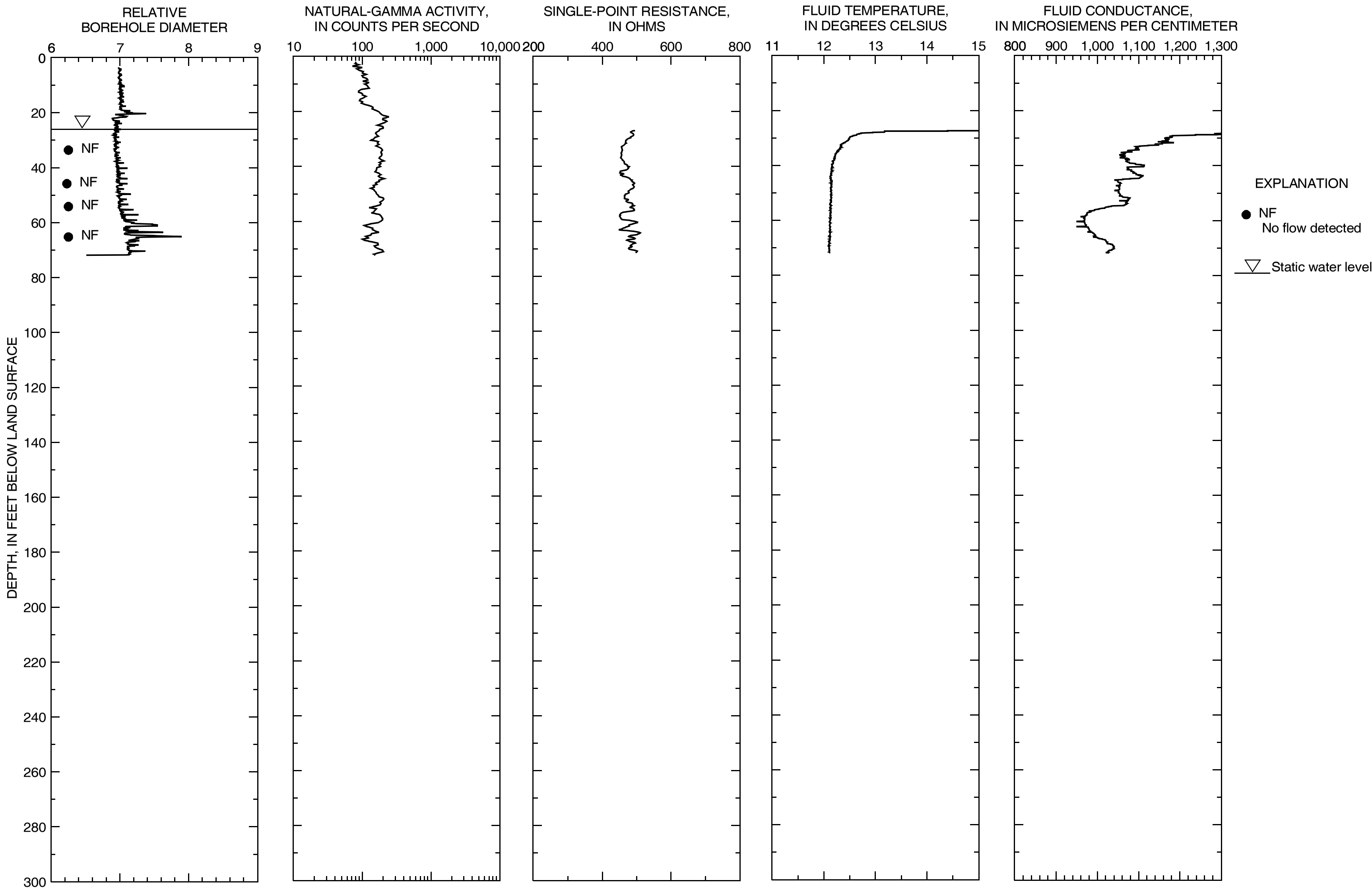


Figure 1-20. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2128 (RI-13S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., August 12, 2004.

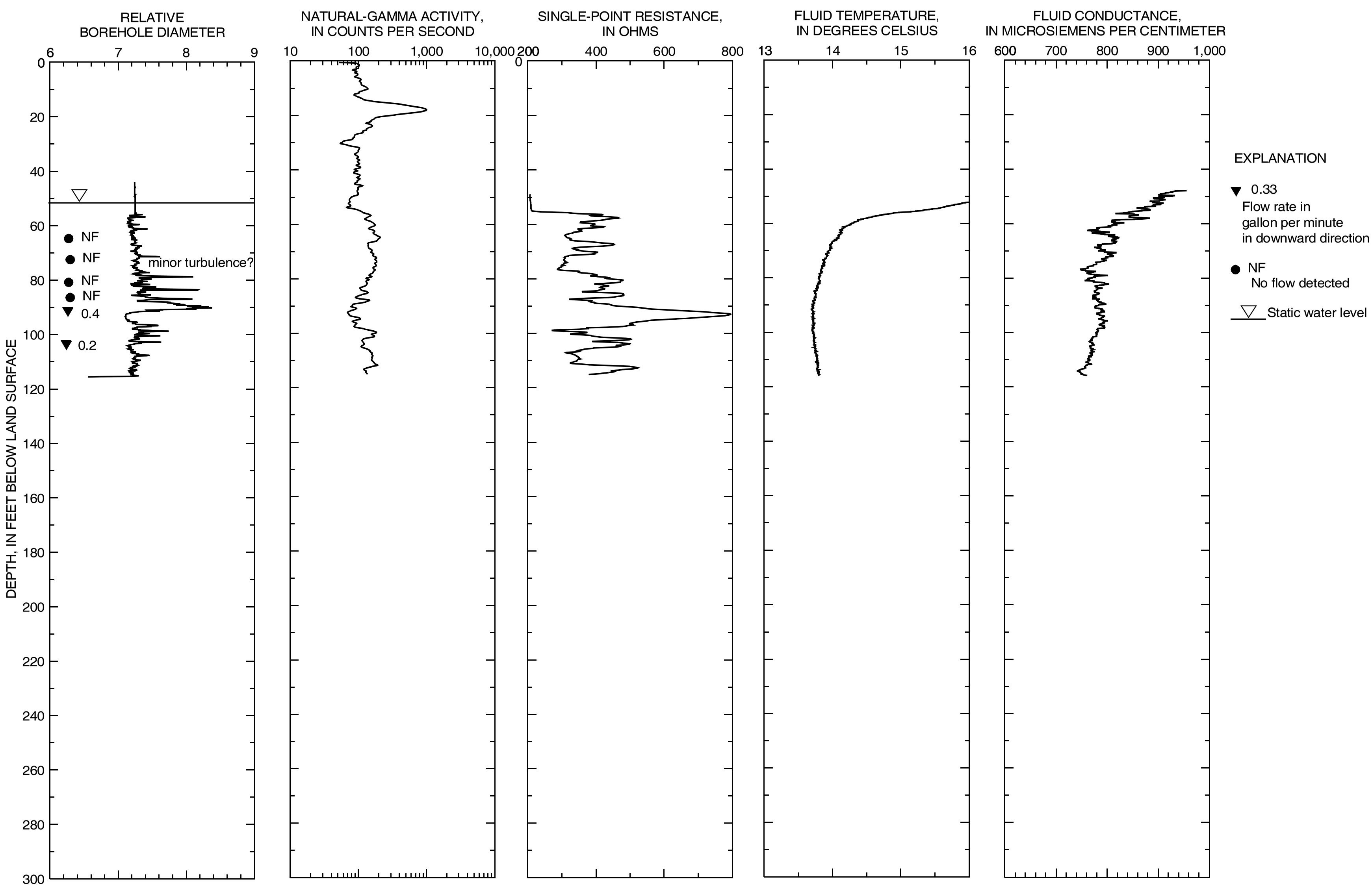


Figure 1-21. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2130 (RI-14S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 20, 2005.

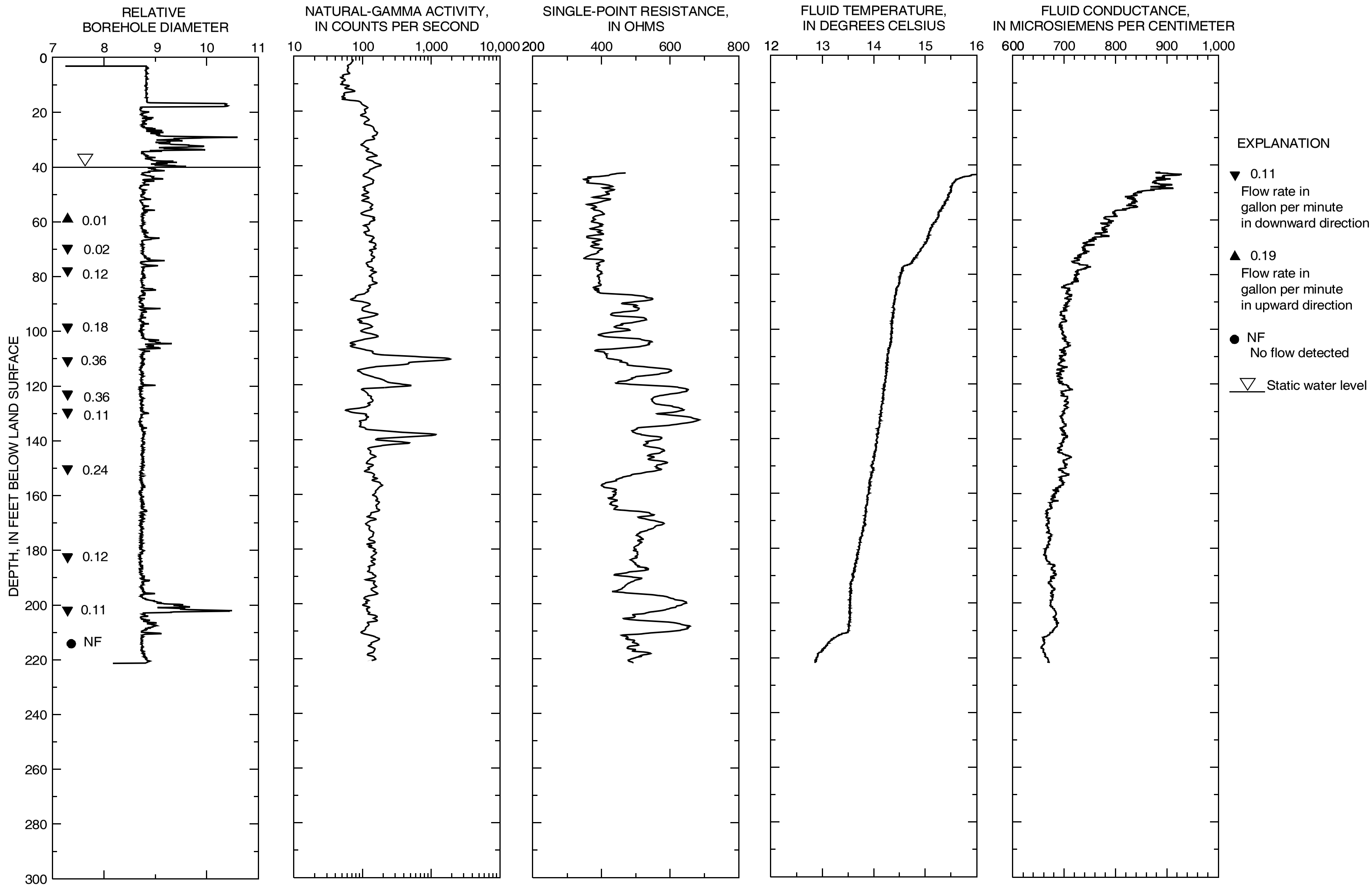


Figure 1-22. Borehole geophysical logs and direction of flow under non-pumping conditions within 8-inch-diameter borehole MG-2132 (RI-15D), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 14, 2005. Depicted flow was measured with 8-inch-diameter diverter on heatpulse flowmeter.

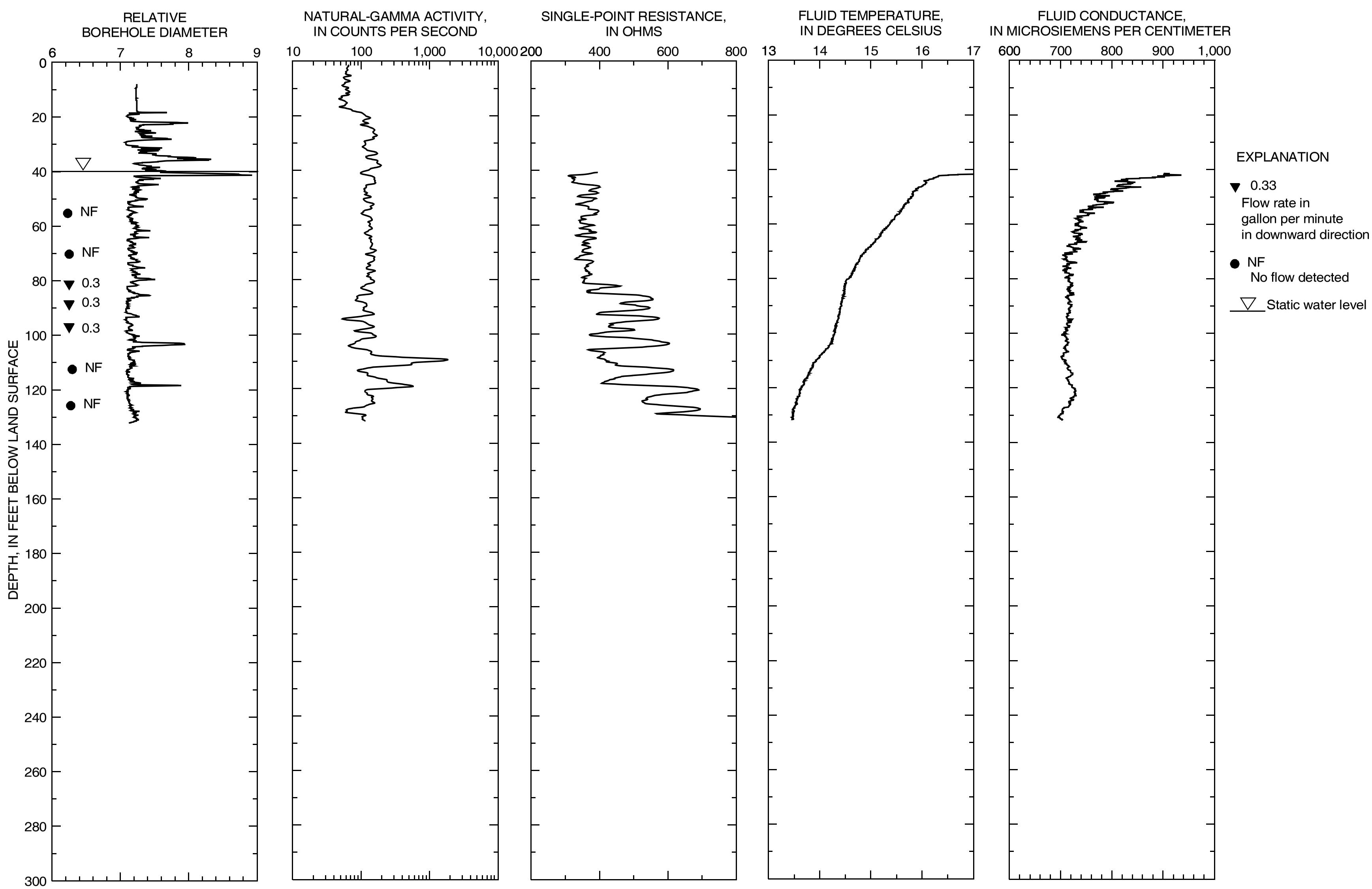


Figure 1-23. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2133 (RI-15I), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 19, 2005.

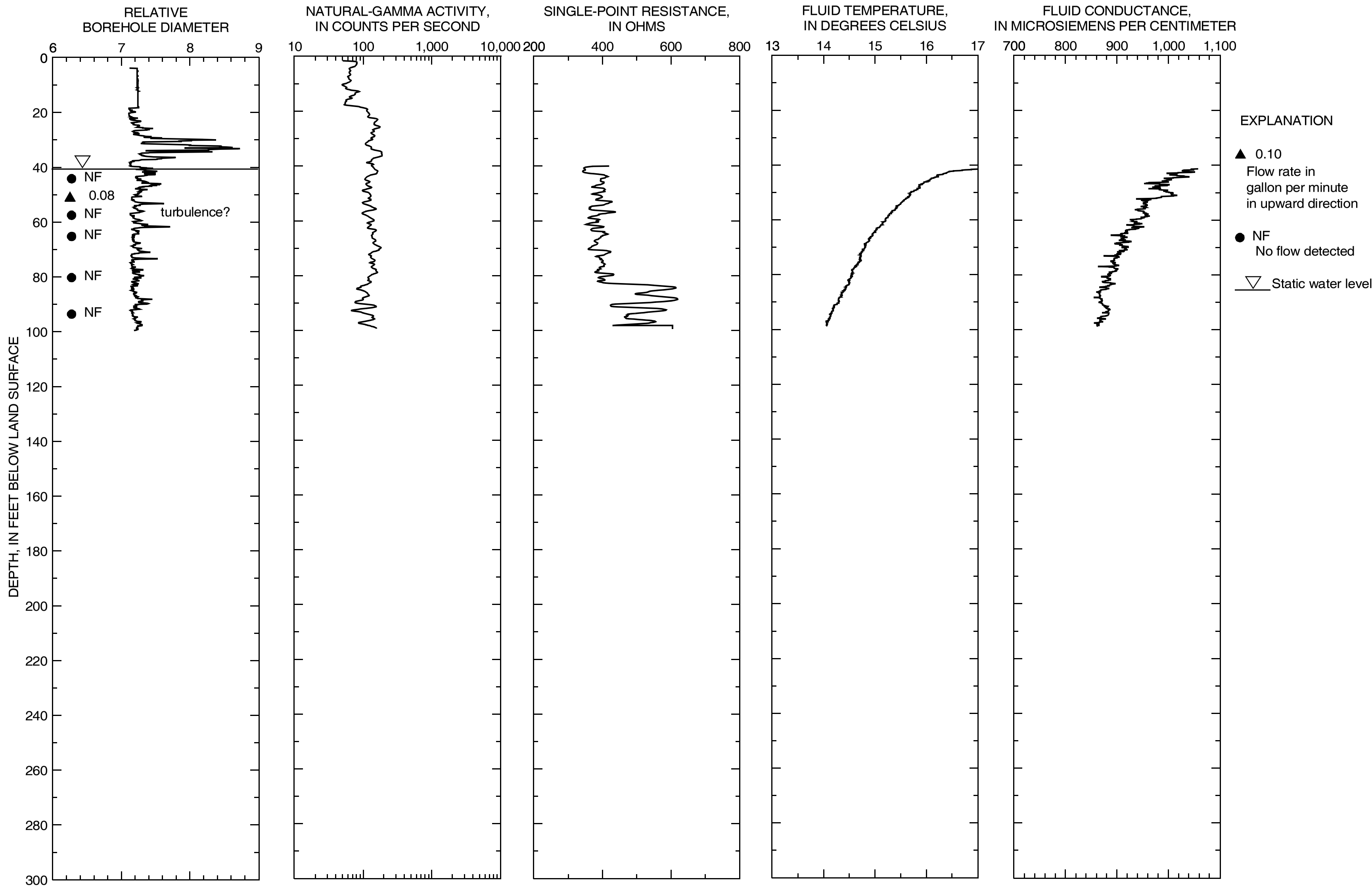


Figure 1-24. Borehole geophysical logs and direction of flow under non-pumping conditions within 6-inch-diameter borehole MG-2134 (RI-15S), North Penn Area 7, Upper Gywnedd Township, Montgomery County, Pa., July 20, 2005.

Appendix 2. Orientation of possible water-bearing fractures identified from interpretation of acoustic televiewer logs

The orientations are listed in terms of the azimuth, in degrees relative to true north, and dip angle, in degrees from horizontal. The direction of strike is 90 degrees to that of dip. Notes from the borehole video log are included with list of water-bearing features where applicable.

MG-151 (Ford #5)

Interpretation of the acoustic-televiewer log was difficult because of zones with poor resolution. The interpreted orientation of water-producing and water-receiving fractures at 88, 137, 141, 301, 302, 307, 308, 365, 366, and 372 ft bls indicate fractures dip from low to high angles (table 2-1), with mostly from low to moderate angles, some of which may be bedding-plane separations. The water-bearing fractures had range of orientations, striking east-west, northwest-southeast, and northeast.

Table 2-1. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; ft^2/d, --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
88	327	38	vertical fracture 88–90 ft bls water-producing
137	9	19	horizontal fracture
141	2	31	horizontal fracture 140 ft bls
301	197	9	vertical fracture 299–306 ft bls, water-producing
302	189	75	
307	197	4	--
308	277	4	--
364	32	38	vertical fracture 358–365 ft bls, water-producing
366	216	25	--
372	303	17	horizontal fracture at 370 ft bls, water-producing

MG-1920 (Ford MW-1)

Interpretation of the acoustic-televiewer log indicates that water-producing and water-receiving fractures intersect the borehole at high angles (from 18 to 78 degrees) (table 2-2), suggesting water is primarily transmitted through high angle fractures. The water-bearing fractures had range of orientations, with most striking northeast-southwest.

Table 2-2. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
59	302	18	horizontal fracture, water-producing
60	122	73	vertical fracture, hazy
71	21	22	vertical fracture
83	149	72	lithologic contact
84	150	77	vertical fracture
87	152	78	lithologic contact, at 86 ft bls
112	348	23	overlapping vertical and horizontal fractures, water-producing
112.2	337	23	

MG-2080 (RI-1D)

Interpretation of the acoustic-televiewer log indicate that water-producing fractures intersect the borehole at low to high angles (from 20 to 84 degrees)(table 2-3). The water-bearing fractures had a predominant strike of northeast-southwest with fractures dipping both northwest and southeast.

Table 2-3. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
66	275	20	vertical fracture 62–65 ft bls, turbulence
80	335	32	banding 78 ft bls, white bed 81 ft bls
129	145	84	filled vertical fracture at 128 ft bls
132	67	84	vertical fractures 132–140 ft bls
134	136	86	
135	142	81	
138	145	84	
140	145	84	
151	13	22	--
248	148	81	--
256	143	84	vertical fracture 251256 ft bls

MG-2081 (RI-2D)

Interpretation of the acoustic-televiewer log indicates that water-bearing fractures intersect the borehole at low to high angles (from 3 to 85 degrees) (table 2-4), with a strike to the east-northeast and dipping to the northwest.

Table 2.-4. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
19	--	--	vertical fractures, water cascading
22	--	--	vertical fractures, water cascading
26	--	--	vertical fractures, water cascading
45	168	84	vertical fracture 42–)47 ft bls, turbulence; white bed at 46 ft bls
47	179	6	
52	232	39	horizontal fracture at 53 ft bls
52	343	22	
53	15	27	
54	331	19	
69	--	--	horizontal fracture; turbulence; high velocity injection
150	340	25	large fracture
174	215	84	vertical fracture at 173 ft bls
178	133	77	--
179	156	75	vertical fracture
180	236	80	vertical fracture at 181 ft bls
182	339	82	
218	56	14	filled vertical fracture
219	213	67	
293	225	5	--
293	53	29	--
294	24	6	horizontal fracture
294	170	78	
297	150	75	--

MG-2084 (RI-3D)

Interpretation of the acoustic-televiewer log plotted on stereo nets indicates that water-producing fractures intersect the borehole at low to high angles (from 33 to 80 degrees) (table 2-5). Orientation of a water-producing fracture at 124 ft bls could not be determined from the acoustic televiewer log because of poor resolution but appeared to be a high-angle fracture on the borehole video. The water-bearing fractures had a general strike of northeast-southwest and dipping both to the northwest and southeast.

Table 2-5. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
55	135	80	High-angle fracture from 52-54 ft bls
76	320	33	High-angle fracture at 73 ft bls
110	170	77	High-angle fracture at 108 ft bls
124	--	--	High-angle fracture at 123 ft bls
172	134	33	High-angle fracture and void from 170–172 ft bls
191	100	51	High-angle fracture from 189–192 ft bls
193	159	80	
229	--	--	High-angle fracture
267	153	80	High-angle fracture from 265–272 ft bls
274	76	36	

MG-2087 (RI-4D)

Interpretation of the acoustic-televiewer log indicates that water-bearing fractures intersect the borehole at low to high angles (from 13 to 85 degrees) (table 2-6). Orientation of a water-producing fracture at 292 ft bls could not be determined from the acoustic televiewer log because of poor resolution but appeared to be a high-angle fracture on the borehole video. At the time of geophysical logging, the water-producing fractures had a predominant strike of northeast-southwest with a dip to the northwest. Only one water-receiving fracture zone was identified at 87 to 95 ft bls.

Table 2-6. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
62	58	14	horizontal and possible oblique fracture 60–64 ft bls
69	20	9	water-producing vertical fracture 68 ft bls
70	356	14	bedding plane separation
74	42	13	--
76	27	24	--
78	297	9	mineral filled vertical fracture 79 ft bls
87	321	12	vertical fracture 86–90 ft bls
89	187	78	
90	180	81	
91	194	84	vertical fracture 91–95
92	56	25	
95	190	85	
120	160	75	water-producing vertical fracture 123–127 ft bls
128	345	23	
147	355	17	horizontal fracture 148
204	358	37	water-producing horizontal fracture 202 ft bls
208	39	13	
292	--	--	vertical fracture 289 ft bls

MG-2090 (RI-5D)

Interpretation of the acoustic-televiewer log indicates that water-bearing fractures intersect the borehole at low to high angles (from 12 to 84 degrees) (table 2-7). At the time of geophysical logging, the water-bearing fractures generally had a range of orientations, striking north-south, northeast-southwest, or east-west.

Table 2-8. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
49	283	22	vertical fracture 48 ft bls
67	316	26	horizontal fracture, possible water-producing
82	108	84	vertical fracture, 82–86 ft bls
84	108	78	
85	101	80	
86	97	82	
128	342	15	lithology change, bedding plane at 129
206	279	12	vertical fracture
272	348	32	vertical fracture at 271
297	120	75	vertical fracture at 296

MG-2093 (RI-6D)

Interpretation of the acoustic-televiewer log indicates that water-producing fractures intersect the borehole at low angles (from 4 to 23 degrees) (table 2-8), suggesting water is transmitted through bedding-plane separations. At the time of geophysical logging, there was only one water-receiving fracture zone located at 85-95 ft bls. Orientation of a fracture near 289 ft bls could not be determined from the acoustic televiewer log because of poor resolution.

Table 2-8. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
24	42	4	--
36	294	10	horizontal fracture
57	12	23	horizontal fracture water-producing at 56 ft bls
86	44	24	oblique fractures 85–90 ft bls water-producing
88	64	26	
96	274	10	--
179	---	--	horizontal fracture
264	--	--	rough, possible flow out
289			vertical fracture near 289 ft bls

MG-2095 (RI-7D)

Interpretation of the acoustic-televiewer log indicates that water-producing fractures intersect the borehole at low angles (from 17 to 87 degrees) (table 2-9), suggesting water is transmitted through bedding plane separations as well as high-angle fractures. Water-bearing fractures appear to dip to the southeast, southwest, and northwest.

Table 2-9. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
37	246	35	--
68	263	14	horizontal fracture at 67 ft bls
83	175	13	vertical fracture water-producing at 85 ft bls
88	348	26	lithologic contact at 88 ft bls
101	283	20	oblique fracture
157	310	77	vertical fractures, turbulence--
161	6	83	--
162	177	4	--
182	149	82	vertical fracture water-producing at 181–191 ft bls
182	322	17	
184	164	84	
184	223	83	
185	110	83	
245	119	87	--

MG-2097 (RI-8D)

Interpretation of the acoustic-televiewer log indicates that water-producing fractures intersect the borehole at low angles (from 6 to 87 degrees) (table 2-10), suggesting water is transmitted through bedding plane separations as well as high-angle fractures. At the time of geophysical logging there were six water-producing and water-receiving fractures located at 18.5, 54, 59, 75, 257, and 289 ft bls that dip predominantly east-northeast and less so, to the southeast and southwest.

Table 2-10. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
19	243	20	fracture below casing
54	80	23	fracture, 52–55, water-producing
59	75	37	vertical fracture, lithology change at 58 ft bls
75	159	14	horizontal fracture, turbulence, possible lithology change
109	--	--	oblique-angle fracture, upward flow
169	--	--	vertical fracture 169–176 ft bls; possible turbu lence
181	--	--	vertical fracture 181–195 ft bls; green lithology
206	--	--	filled vertical fractures at 206 ft bls; turbulence
210	--	--	vertical fractures at 210 ft bls, turbulence, water injecting
221	--	--	vertical fracture 221–225 ft bls
240	--	--	lithology change at 240 ft bls; vertical fracture 240–244 ft bls; turbulence
255	13	87	vertical fractures at 249–253 and 254–259 ft bls
287	93	6	water-producing vertical fractures at 283–292 ft bls; turbulence, water injecting; lithologic change at 289 ft bls

MG-2100 (RI-9D)

Interpretation of the acoustic-televiewer log plotted on stereo nets indicates that water-producing fractures intersect the borehole at low angles (from 16 to 76 degrees) (table 2-11), suggesting water is transmitted through bedding-plane separations as well as high-angle fractures. At the time of geophysical logging, there appear to be 16 water-producing and water-receiving fractures located at about 60, 64, 65, 93, 128, 129, 130, 137.9, 138, 138.7, 139, 140, 183, 238, 263, and 271 ft bls. Most of these fractures strike northwest and dip southwest, although some strike northeast and dip northwest.

Table 2-11. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
38	--	--	vertical fracture, cascading water
60	247	19	fracture 59–64 ft bls
64	308	29	
65	201	16	bedding plane separation
93	212	32	vertical fracture 88–96 ft bls
99	--	--	vertical fractures 99–101 ft bls
120	undetermined		vertical fracture 116–122 ft bls; flow out
128	252	21	vertical fracture 126–131 ft bls; flow out; green lithology
129	264	71	
130	59	76	lithology change
137.9	236	20	
138	234	31	
138.7	245	46	
139	195	56	lithology change; filled vertical fractures at 139 ft bls; light turbulence; flow out
140	344	46	bedding plane
175	--	--	large vertical fractures 175–182 ft bls; flow in; green lithol ogy
183	12	34	vertical fracture 183–186 ft bls
238	323	43	vertical fracture
254	--	--	vertical fracture 254–258 ft bls; turbulence; flow in
263	145	25	vertical fracture at 266–268 ft bls, water-producing
271	110	19	vertical fracture 269–273 ft bls water-producing

MG-2119 (RI-10D)

Interpretation of the acoustic-televiewer log indicates that water-producing and water-receiving fractures intersect the borehole at low to moderate angles (from 9 to 42 degrees) (table 2-12), suggesting water is primarily transmitted through separations parallel or sub-parallel to bedding planes. At the time of geophysical logging there were seven water-producing and water receiving fractures located at 62, 82, 83, 184, 185, 190, and 225 ft bls, which generally strike northeast, dipping northwest or northwest, dipping northeast.

Table 2-12. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
61	258	20	--
82	343	30	horizontal fracture at 81 ft bls
184	343	27	horizontal fracture at 185 ft bls
185	344	9	
190	63	23	
225	81	23	--

MG-2122 (RI-11D)

Interpretation of the acoustic-televiewer log indicates that water-producing and water-receiving fractures intersect the borehole at low angles (from 13 to 85 degrees) (table 2-13), suggesting water is primarily transmitted through both bedding-plane separations and high-angle fractures. At the time of geophysical logging there were twelve water-receiving fractures and two water- producing fractures. The water-producing fractures were located at 203 and 267 ft bls. The orientation of the fracture at 203 ft bls could not be determined, however the fracture at 267 ft bls had a strike of N 41° E, dipping 85° SE, indicating water is produced from a high angle fracture not a bedding plane.

Table 2-13. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
29	97	34	fracture
30	314	19	--
31	140	19	--
34	322	42	vertical fracture to 38 ft bls
37	110	80	
47	227	30	lithology change at 48 ft bls, horizontal fracture, water-producing
48	18	66	
49	344	36	horizontal fracture, water-producing at 48 ft bls
50	288	13	--
54	56	36	vertical fracture at 54–58 ft bls
56	291	12	
203	undefined	undefined	lithology change, vertical fracture at 206 ft bls
267	131	85	lithology change at 269 ft bls

MG-2125 (RI-12D)

Interpretation of the acoustic-televiewer log plotted on stereo nets indicates that water-producing and water-receiving fractures intersect the borehole at low to high angles (from 7 to 83 degrees) (table 2-14), suggesting water is primarily transmitted through both bedding-plane separations and high-angle fractures. At the time of geophysical logging there appeared to be three water-receiving fractures and seven water-producing fractures. The water-producing fractures were located at about 60, 72, 78, 82, 96, 111, 112, and 287 ft bls. Water-bearing zones dipped to the northeast, with a strike to the northwest, and dipped to the northwest, with a strike to the northeast.

Table 2-14. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
60	309	81	vertical fracture at 59 ft bls
72	146	83	vertical fracture at 70–75 ft bls
78	277	46	oblique fracture
82	7	43	vertical fracture at 79–83 ft bls
82.4	299	36	
96	45	28	vertical fracture at 96–98, water-producing
111	6	10	
112	29	33	filled vertical, numerous
149	334	17	filled vertical, numerous
158	48	44	horizontal fracture at 156–158 ft bls
176	21	7	horizontal fracture and lithologic contact, 175–177 ft bls
287	242	77	--

MG-2126 (RI-13D)

Interpretation of the acoustic-televiewer log was difficult because of poor resolution, therefore very few bedding plane and fracture orientations were determined. Water-bearing fractures generally dipped at low angles (12 to 25 degrees) (table 2-15), indicating that water is produced from bedding-plane separations. The orientation of the several water-bearing fractures, including major fractures at 64 and 65 to 68 ft bls, have a northeast strike, sipping to the northwest. The water-receiving fractures at 97 and 222 ft bls strike northwest, and dip to the northeast and northwest, respectively.

Table 2-15. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
64	329	21	horizontal fracture, large void, water-producing
67	311	17	--
68	328	25	--
97	4	16	horizontal fracture, water-receiving
132	344	25	
147	77	18	large horizontal fracture
222	22	12	lithology change, hazy

MG-2129 (RI-14D)

Interpretation of the acoustic-televiewer log indicates that water-producing fractures intersect the borehole at moderate angles (from 25 to 28 degrees)(table 2-16) and generally strike to the east-northeast. There were three water- receiving fractures in three zones that dip steeply (from 79 to 83 degrees) and strike to the northeast.

Table 2-16. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2129 (RI-14D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
56	147	79	vertical fracture at 565 ft bls
			--
71	313	28	
93	166	83	vertical fracture at 90 ft bls
			vertical fracture at 153 ft bls
154	154	79	
208	316	25	--

MG-2132 (RI-15D)

Interpretation of the acoustic-televiewer log plotted on stereo nets indicate that water-producing fractures intersect the borehole at low to high angles (from 7 to 84 degrees)(table 2-17). At the time of geophysical logging the water-producing fractures had a predominant strike of northeast with a dip to the northwest or southeast. Four of the eight water-producing or water-receiving features were observed to both produce water and receive water at different intervals during data collection.

Table 2-17. Depth and orientation of water-bearing features interpreted from acoustic televiewer log and borehole video survey for well MG-2131 (RI-15D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa.

[ft bls, feet below land surface; azimuth and dip in degrees; --, no data]

Depth of measurement (ft bls)	Orientation and type of feature determined from acoustic televiewer log		Borehole video log observations
	Azimuth of dip	Dip angle, in degrees	
79	20	18	horizontal fracture at 81 ft bls
105	--	--	vertical fracture 104–108 ft bls, turbulence, water injecting
121	317	14	horizontal fractures at 119 ft bls
122	312	7	
130	148	77	
131	143	80	
146	--	--	horizontal fracture, dark bedding
162	328	23	possible horizontal fracture
201	149	84	vertical fracture 196–203 ft bls
246	--	--	vertical fracture
252	330	24	lithologic change

Appendix 3 Water Levels Measured During Aquifer-Interval-Isolation Tests

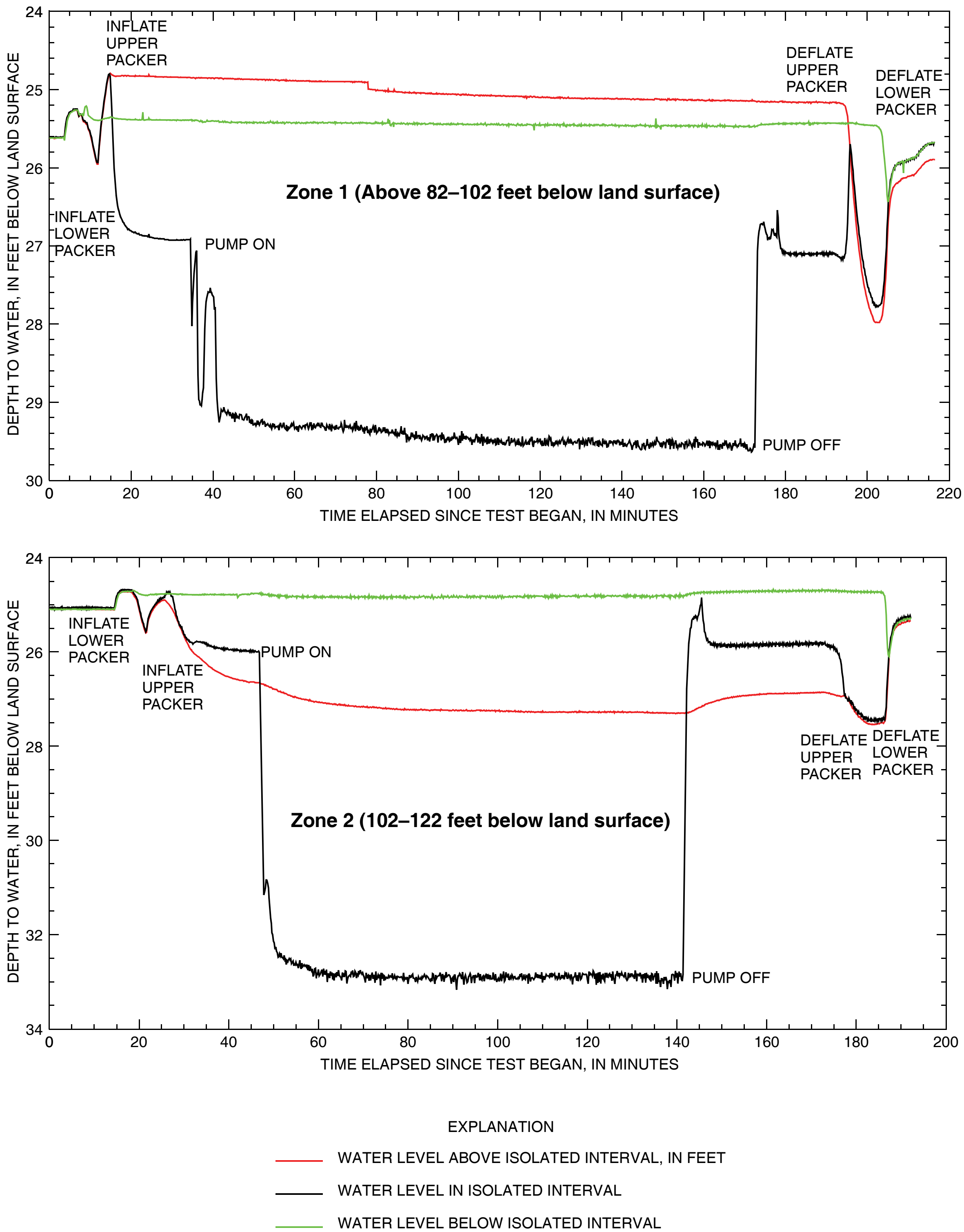


Figure 3-1. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (82–102 feet below land surface) and zone 2 (102–122 feet below land surface) in well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 30-31, 2004.

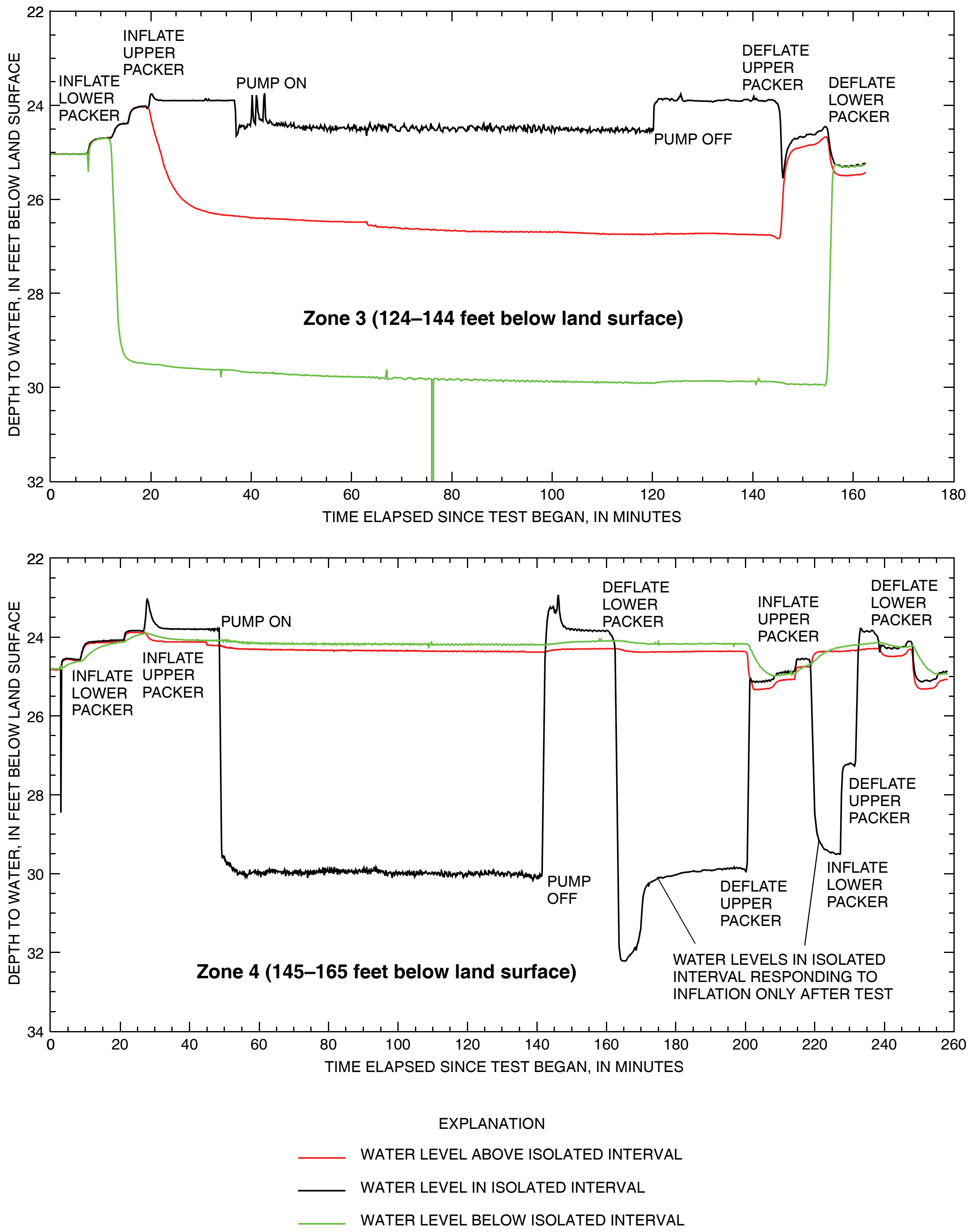


Figure 3-2. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (124–144 feet below land surface) and zone 4 (145–165 feet below land surface) in well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 30-31, 2004.

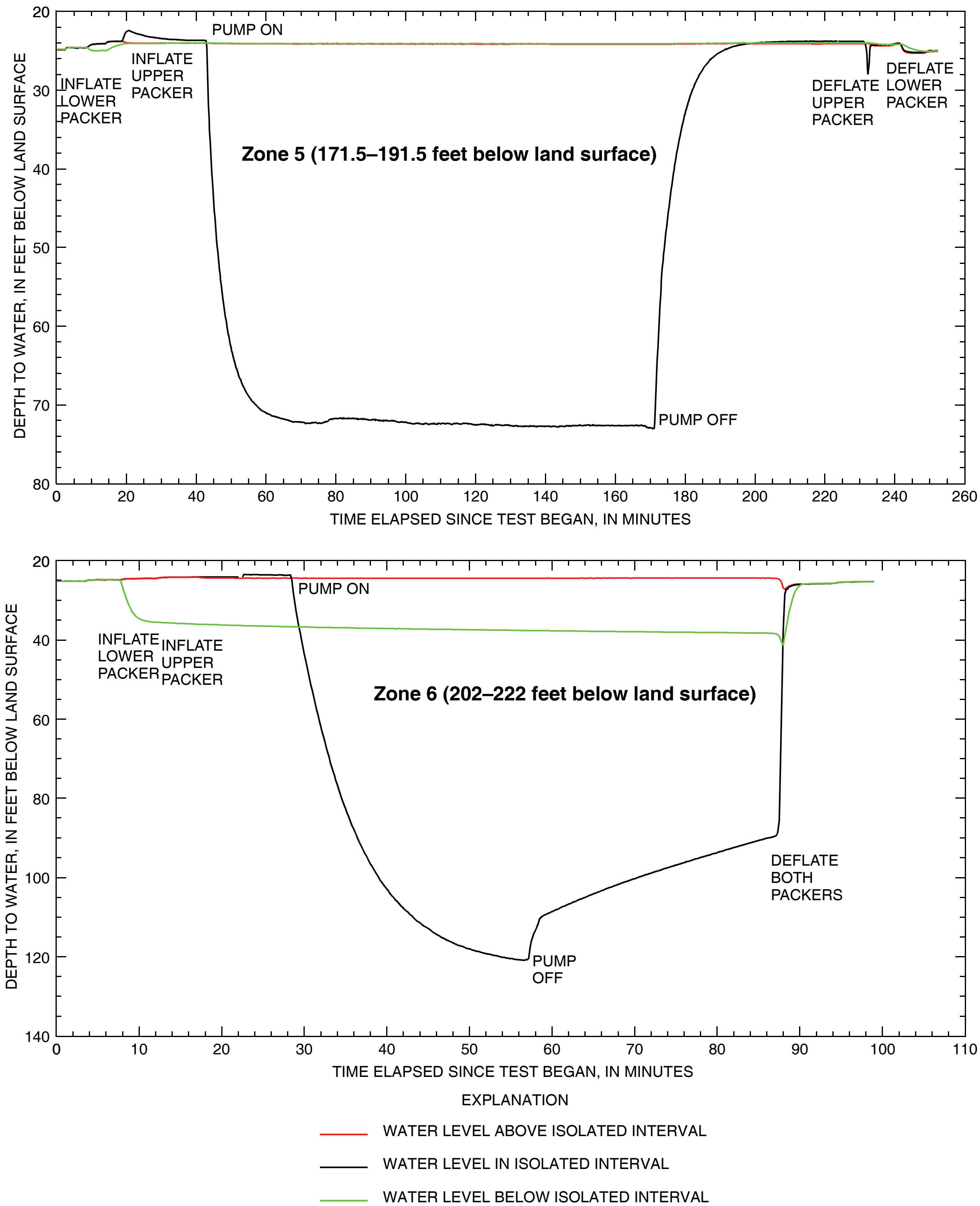


Figure 3-3. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (171.5–191.5 feet below land surface) and zone 6 (202–222 feet below land surface) in well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 1-2, 2004.

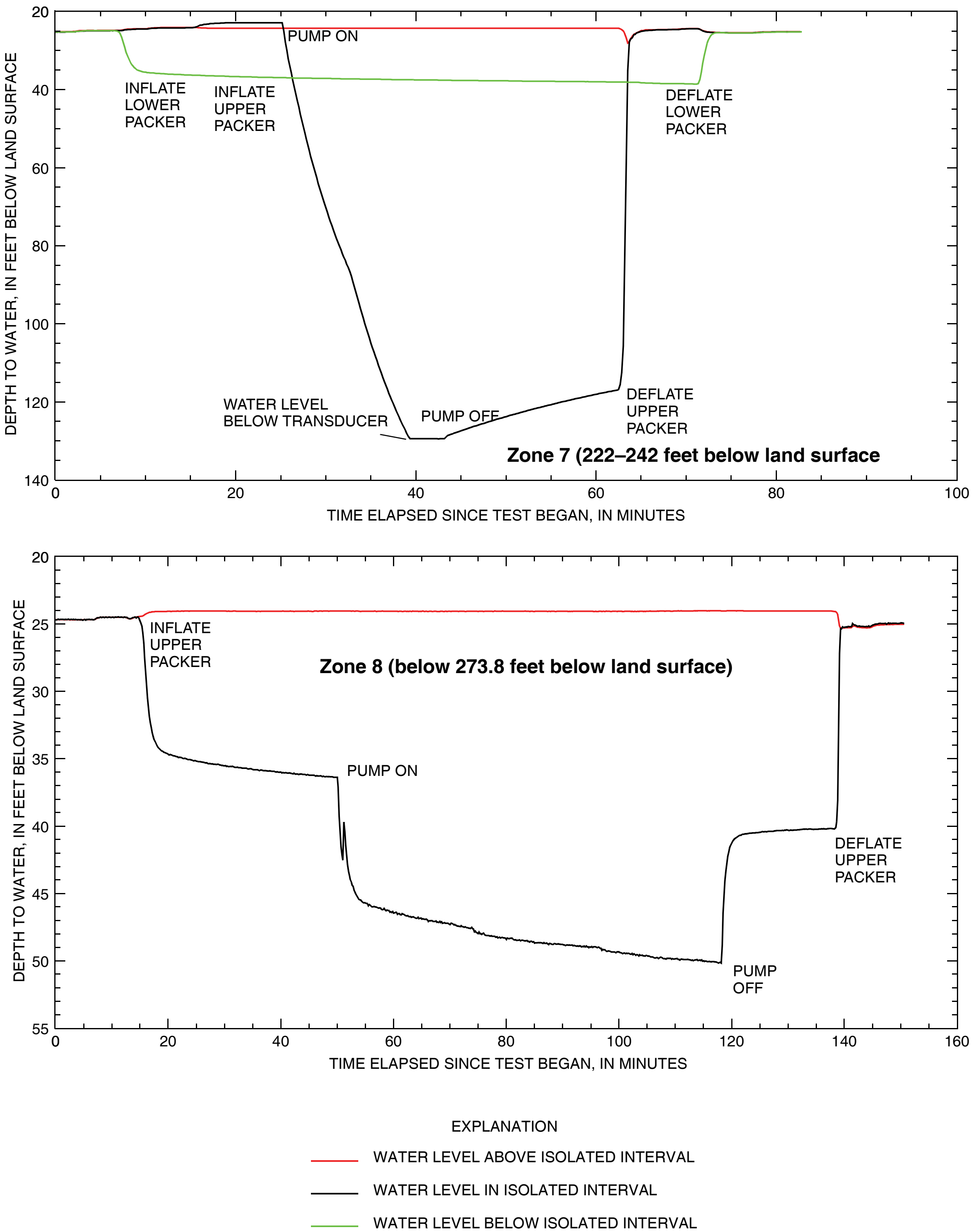


Figure 3-4. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (222–242 feet below land surface) and zone 8 (below 273.8 feet below land surface) in well MG-151 (Ford #5), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 2 and 5, 2004.

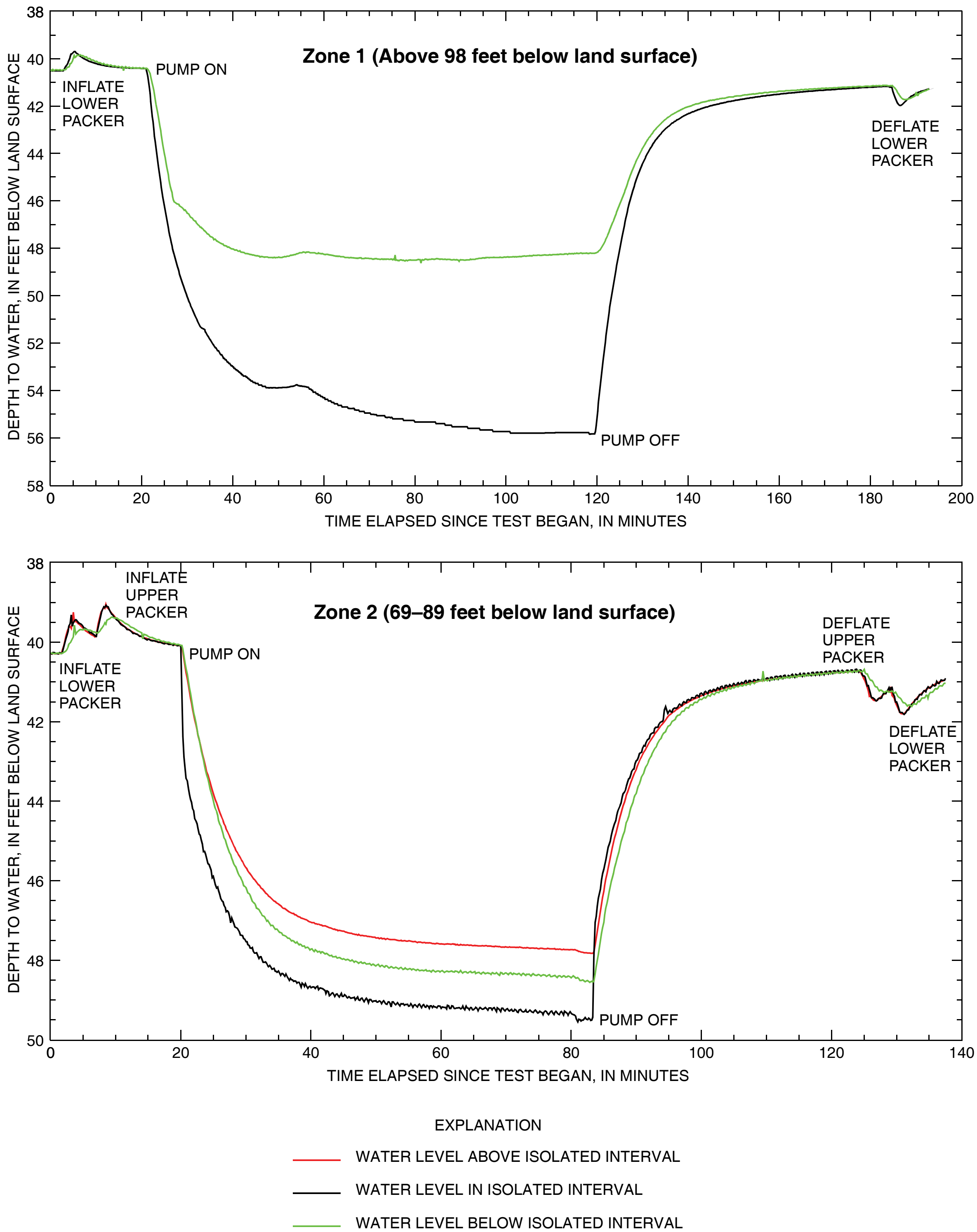


Figure 3-5. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 98 ft below land surface) and zone 2 (69–89 feet below land surface) in well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 22, 2004.

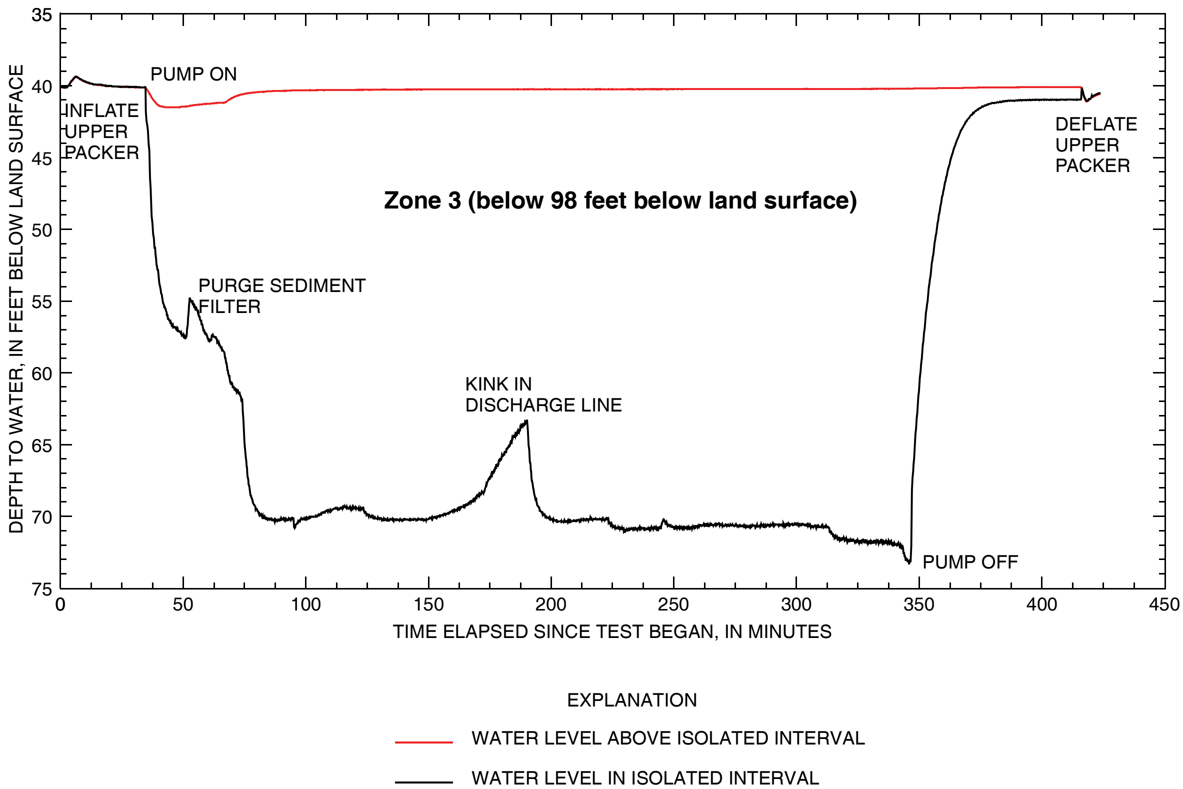


Figure 3-6. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (below 98 ft below land surface) in well MG-1920 (Ford MW-1), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 21, 2004.

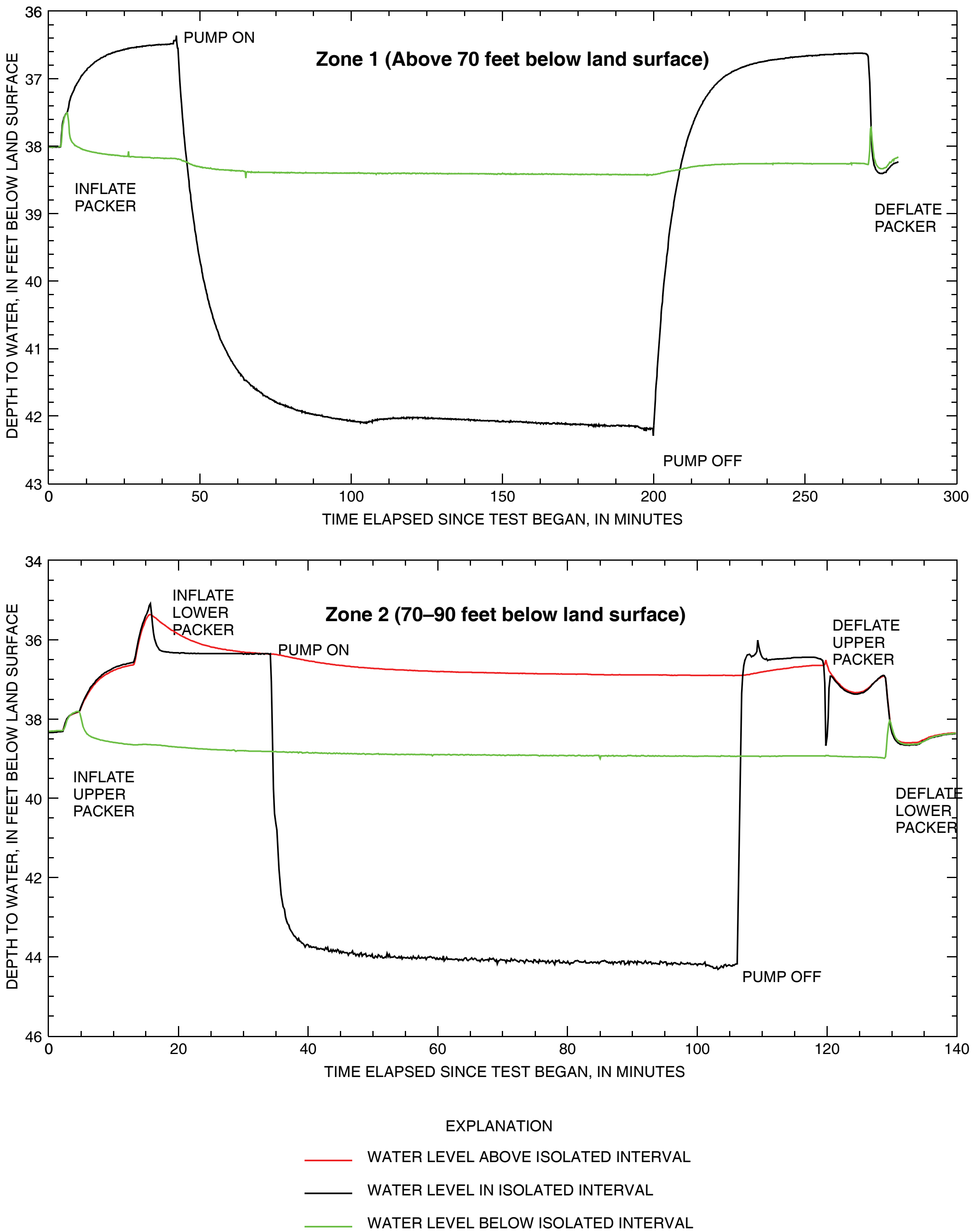


Figure 3-7. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 70 feet below land surface) and zone 2 (70–90 feet below land surface) in well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 1-2, 2005.

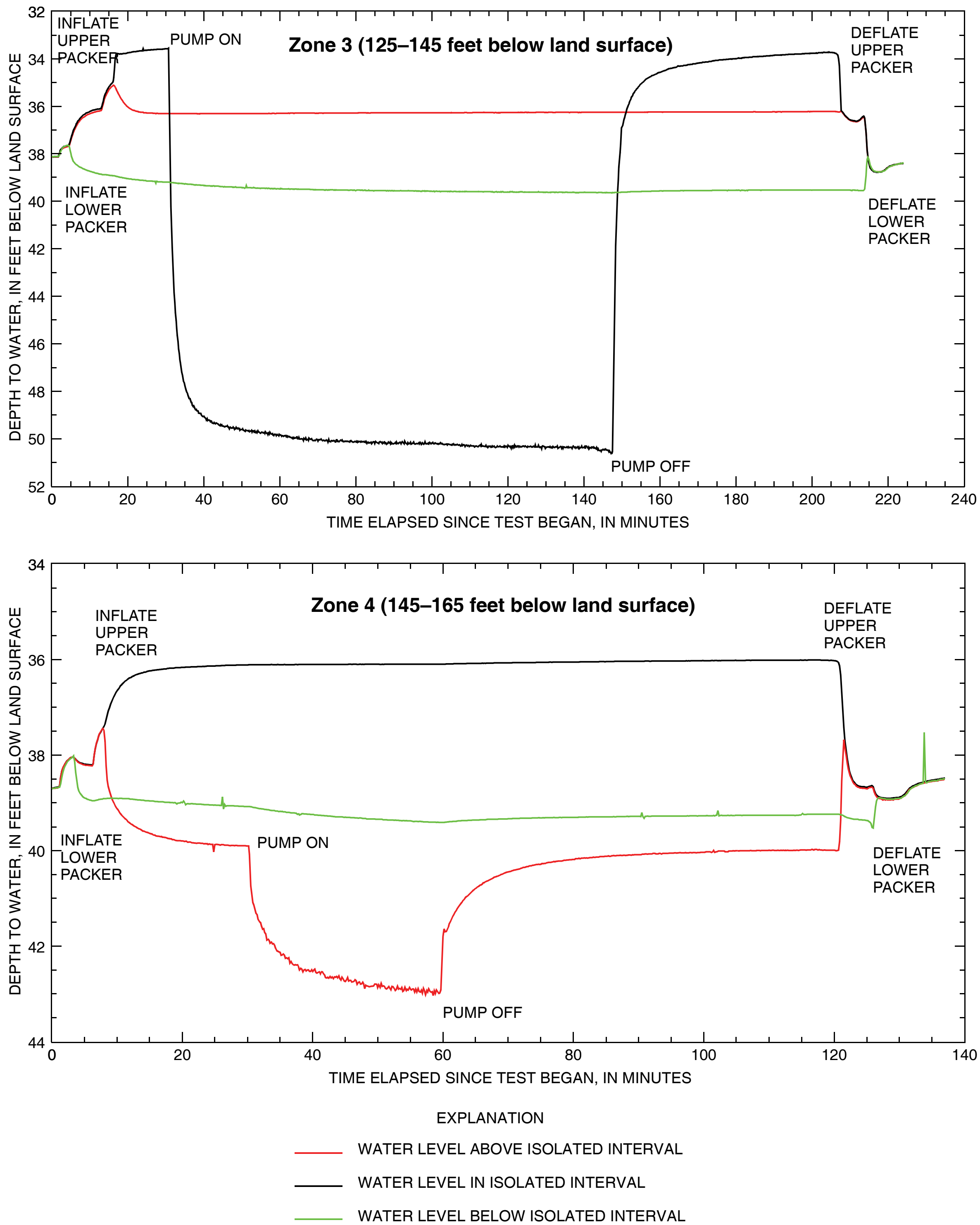


Figure 3-8. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (125–145 feet below land surface) and zone 4 (146–165 feet below land surface) in well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 2-3, 2005.

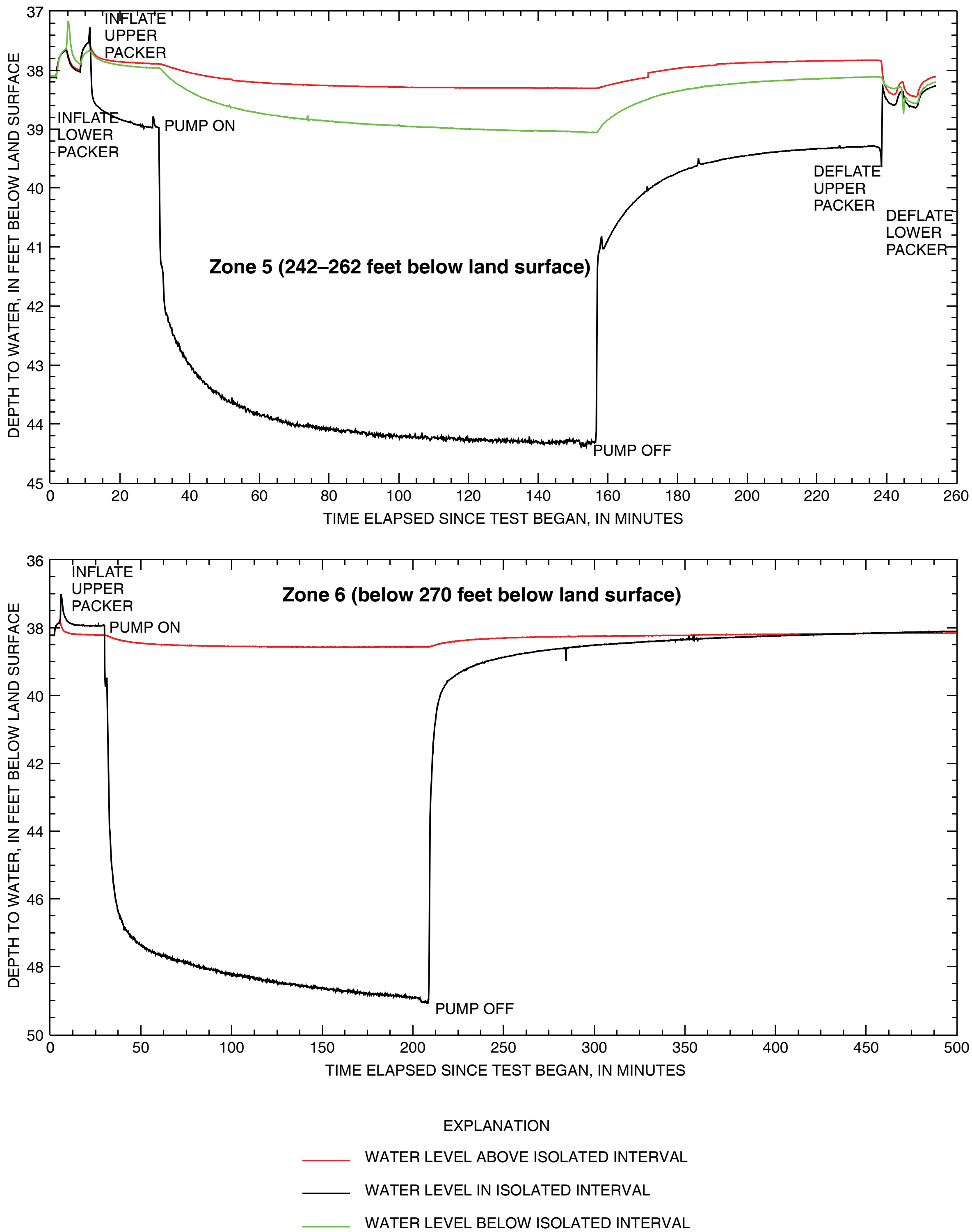


Figure 3-9. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (242–262 feet below land surface) and zone 6 (below 270 feet below land surface) in well MG-2080 (RI-1D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 3 and 7, 2005.

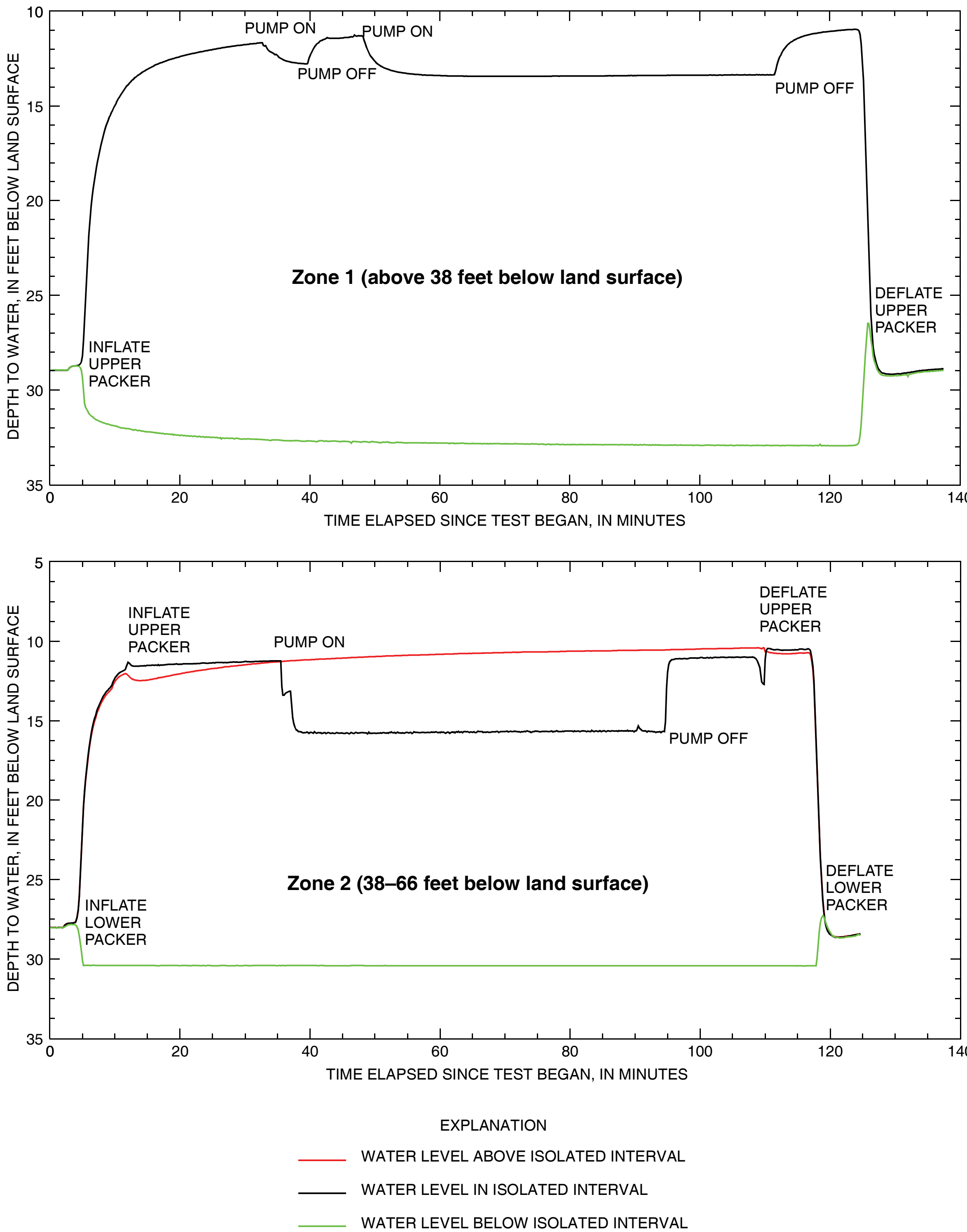


Figure3-10. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 38 feet below land surface) and zone 2 (38–66 feet below land surface) in well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 15-16, 2004.

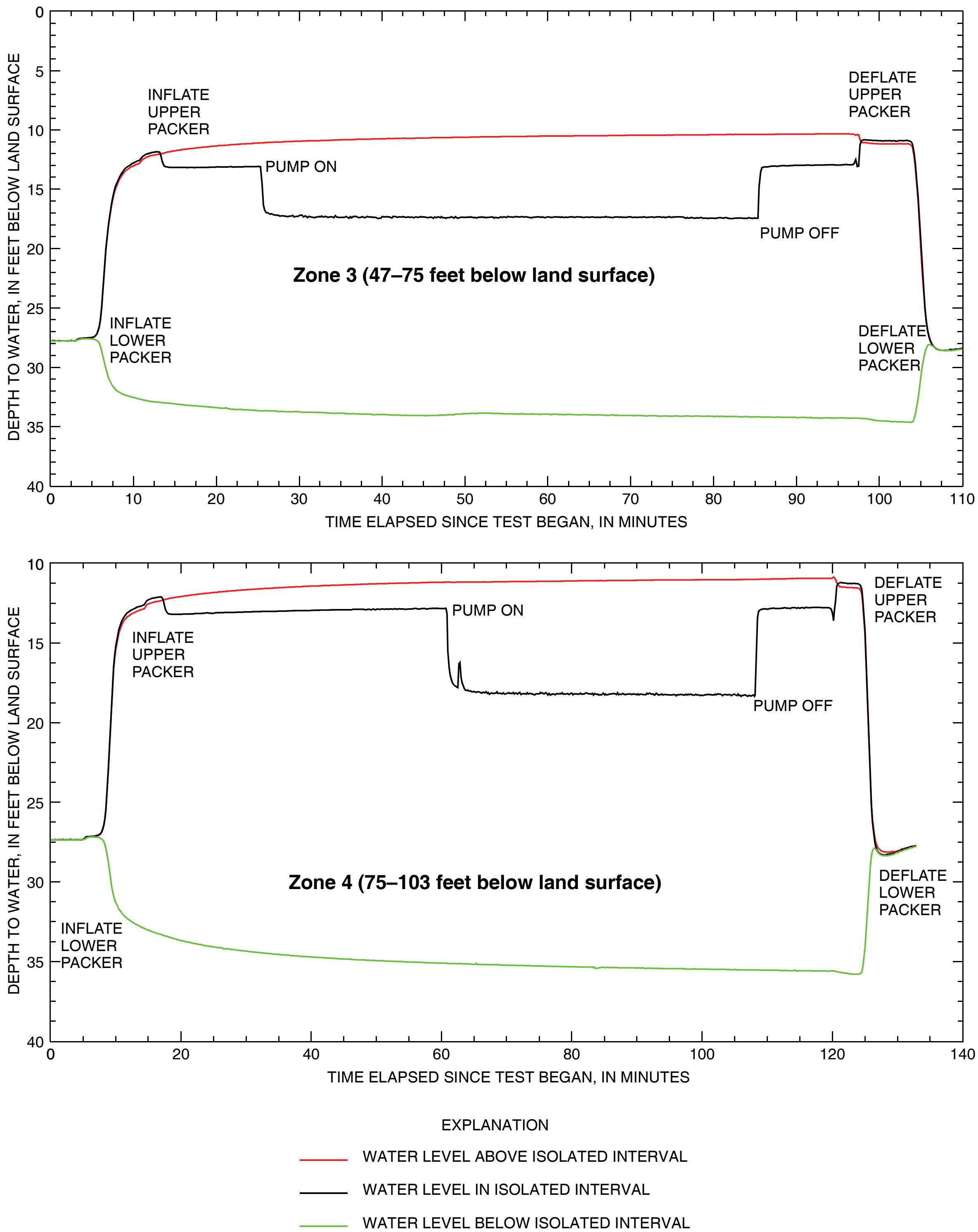


Figure 3-11. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (47–75 feet below land surface) and zone 4 (75–103 feet below land surface) in well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 16, 2004.

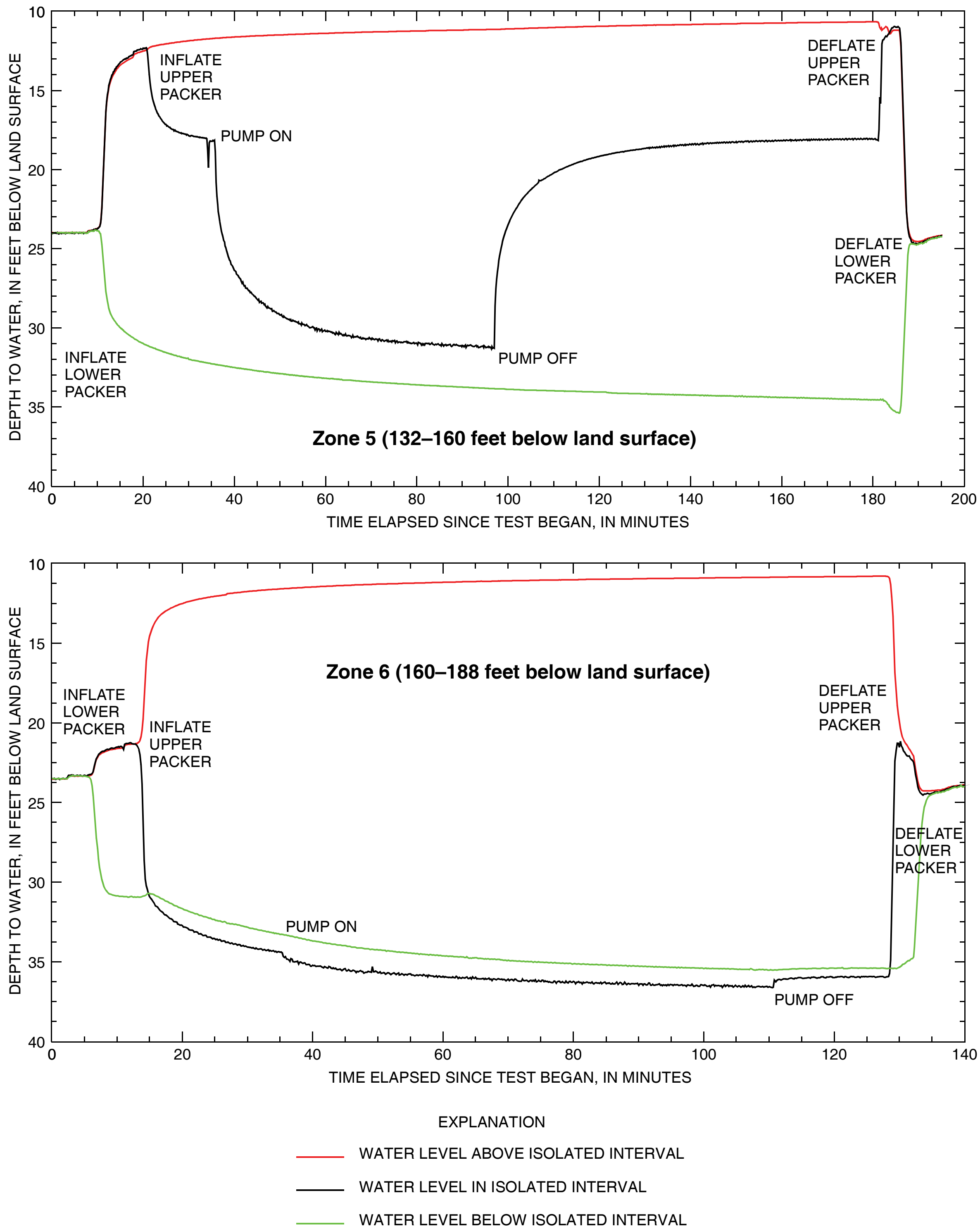


Figure 3-12. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (132–160 feet below land surface) and zone 6 (160–188 feet below land surface) in well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 19, 2004.

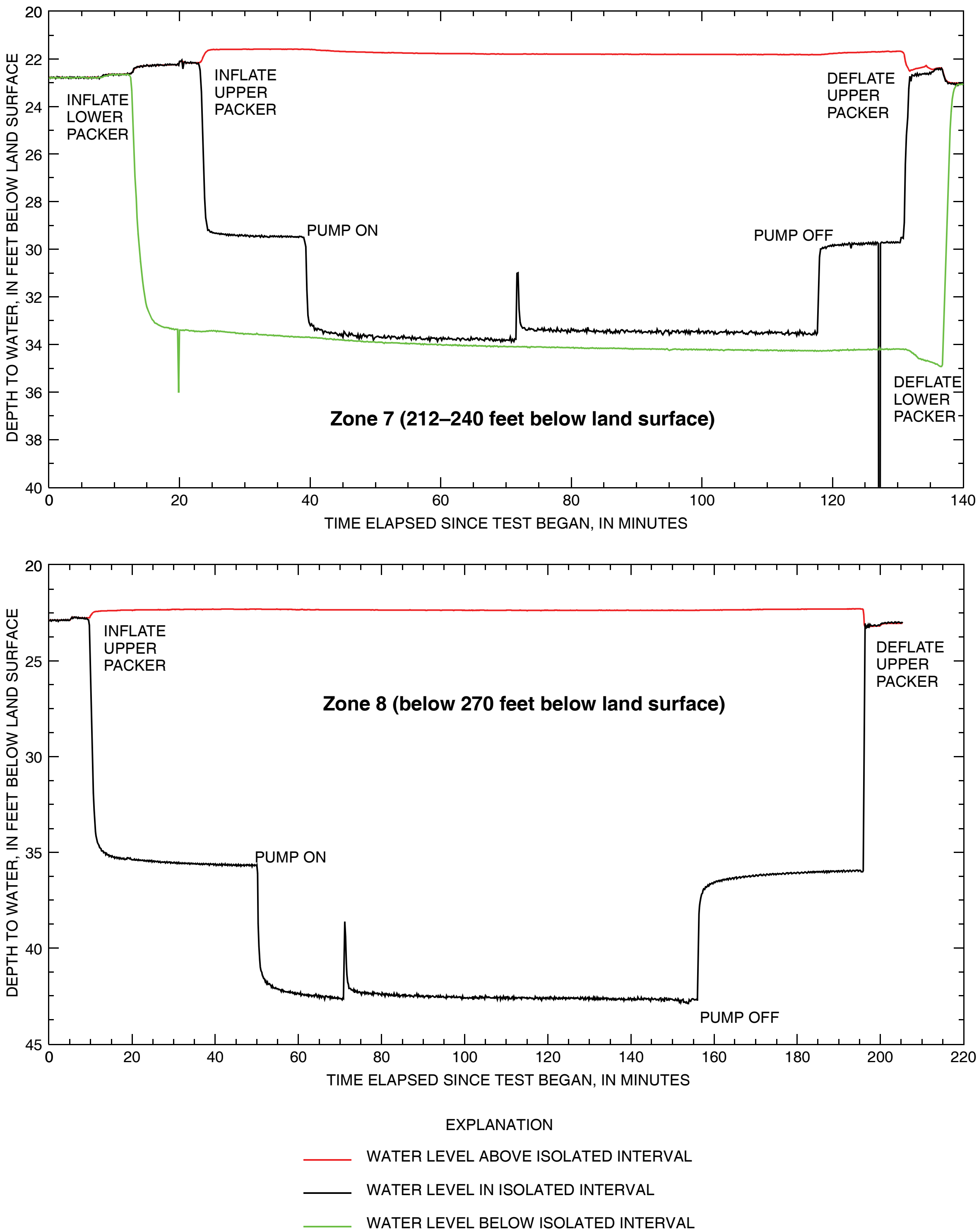


Figure 3-13. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (212–240 feet below land surface) and zone 8 (below 270 feet below land surface) in well MG-2081 (RI-2D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 20, 2004.

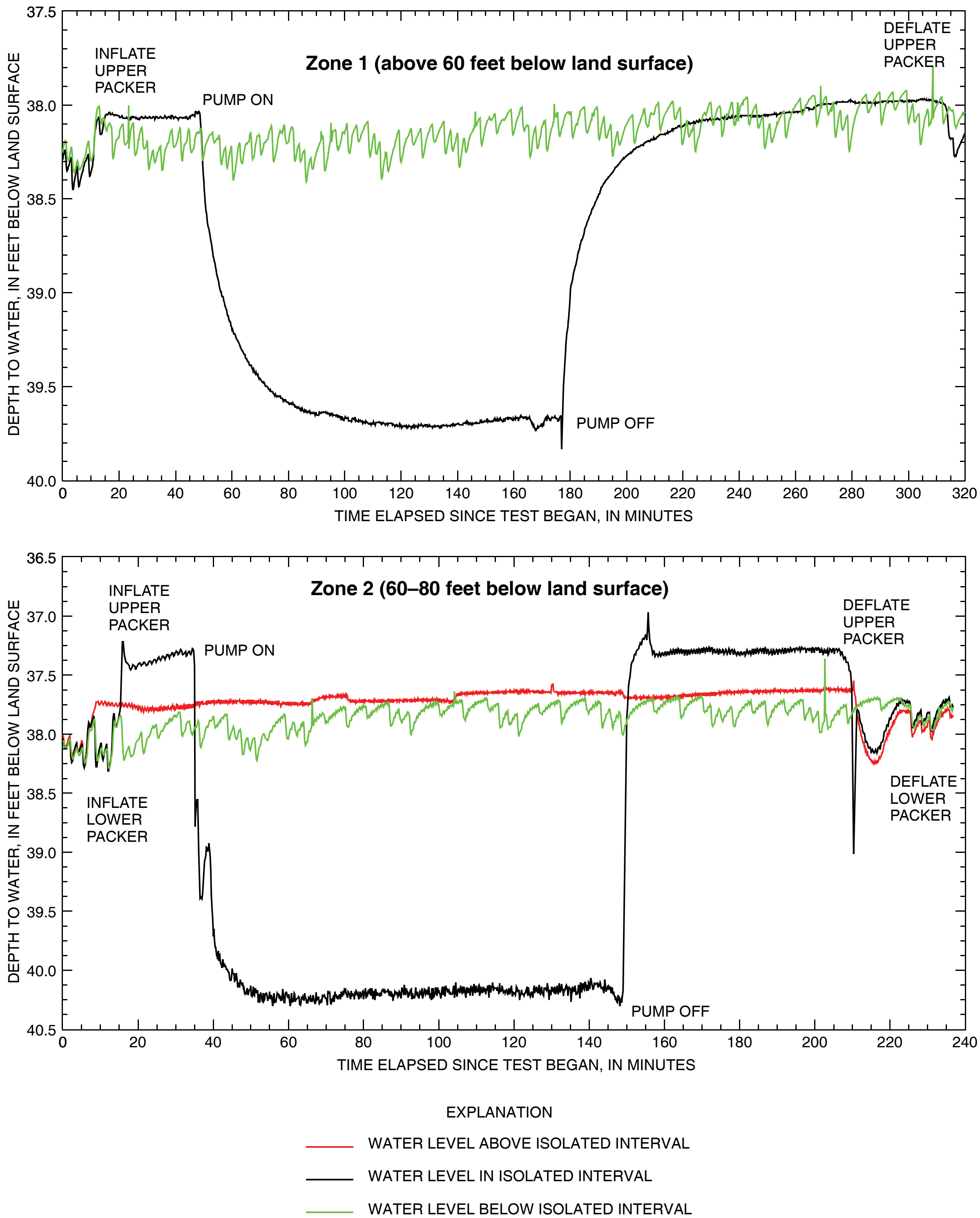


Figure 3-14. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 60 feet below land surface) and zone 2 (60–80 feet below land surface) in well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 5 and 8, 2004.

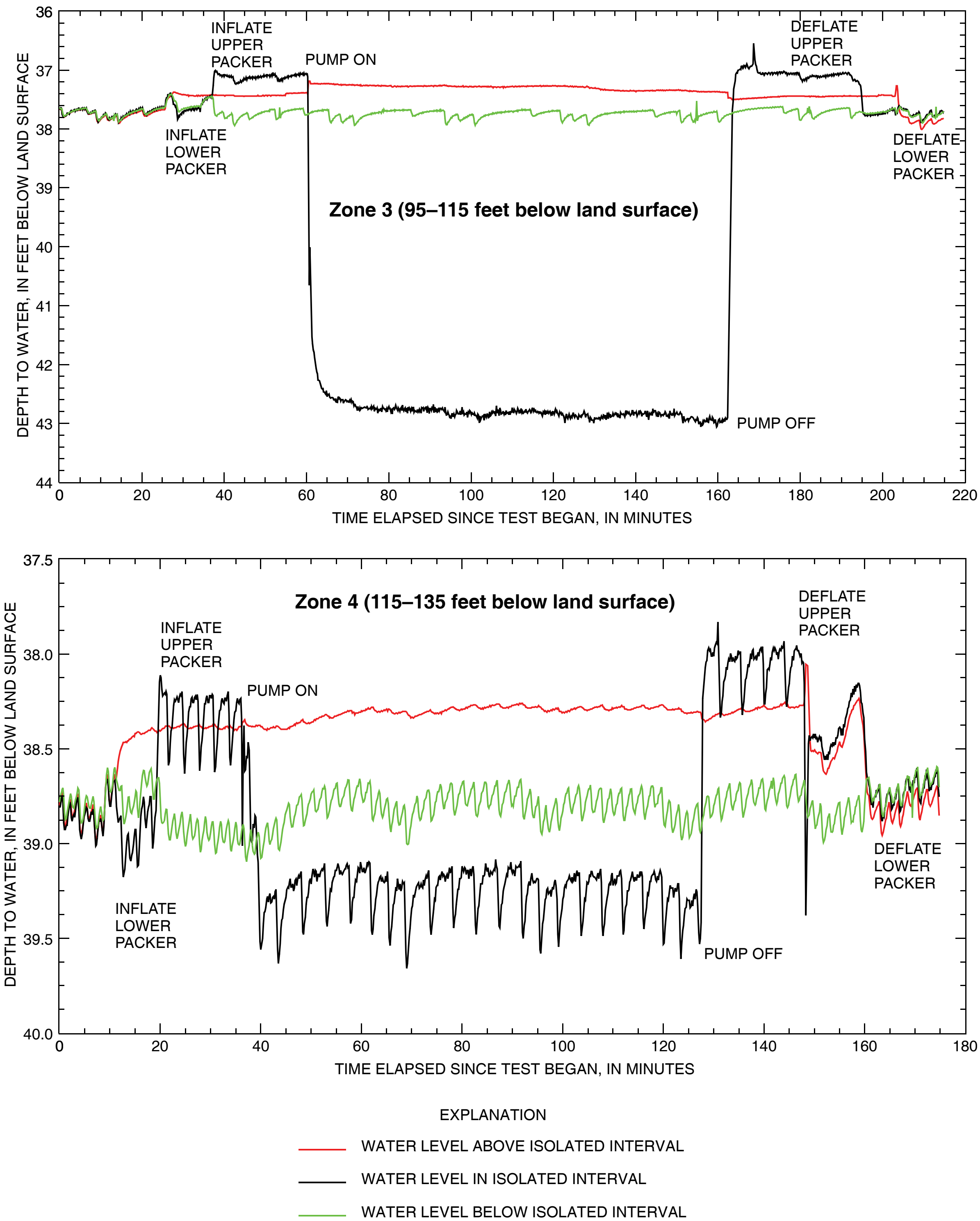


Figure 3-15. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (95–115 feet below land surface) and zone 4 (115–135 feet below land surface) in well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 8-9, 2004.

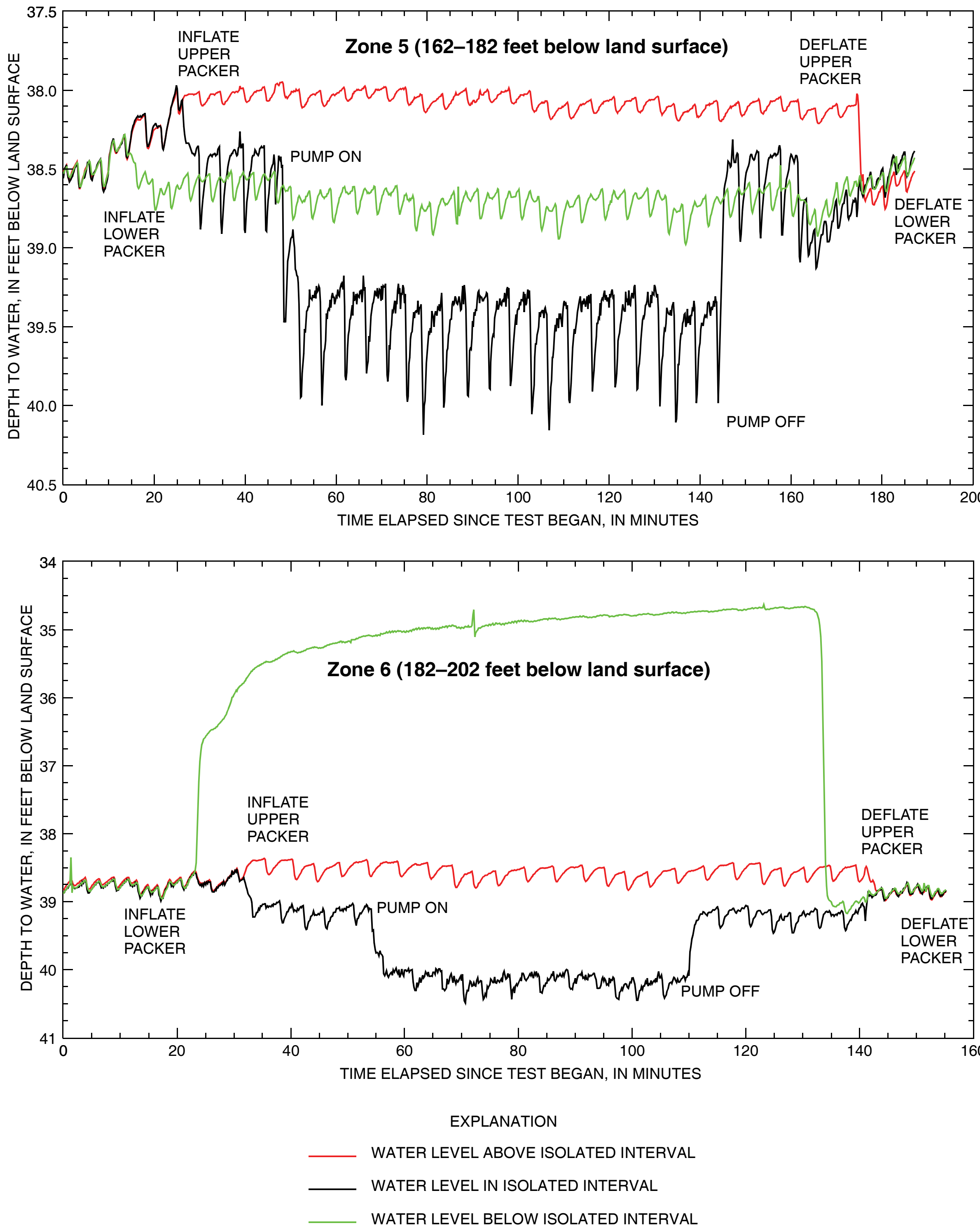


Figure 3-16. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (162–182 feet below land surface) and zone 6 (182–202 feet below land surface) in well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 9, 2004.

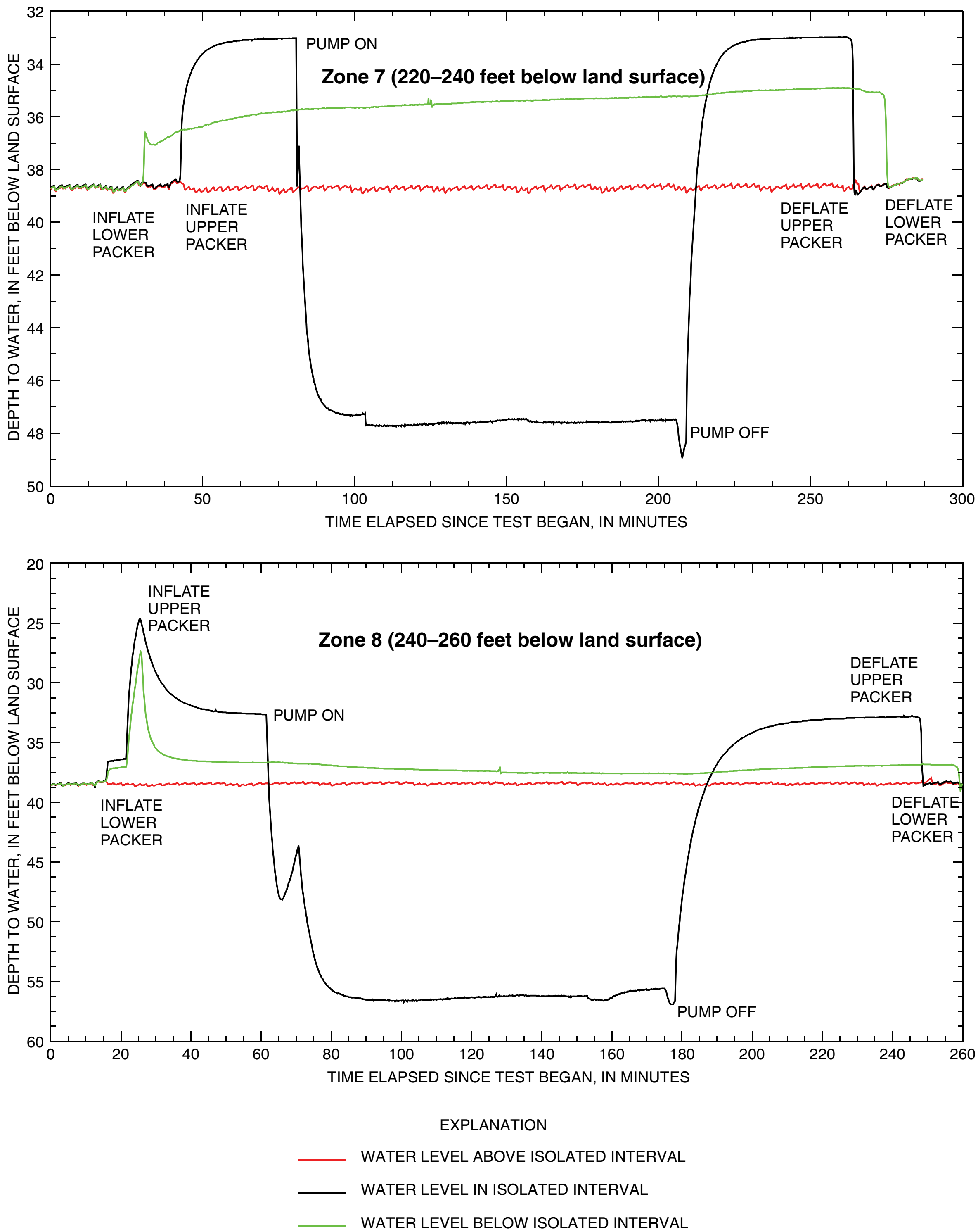
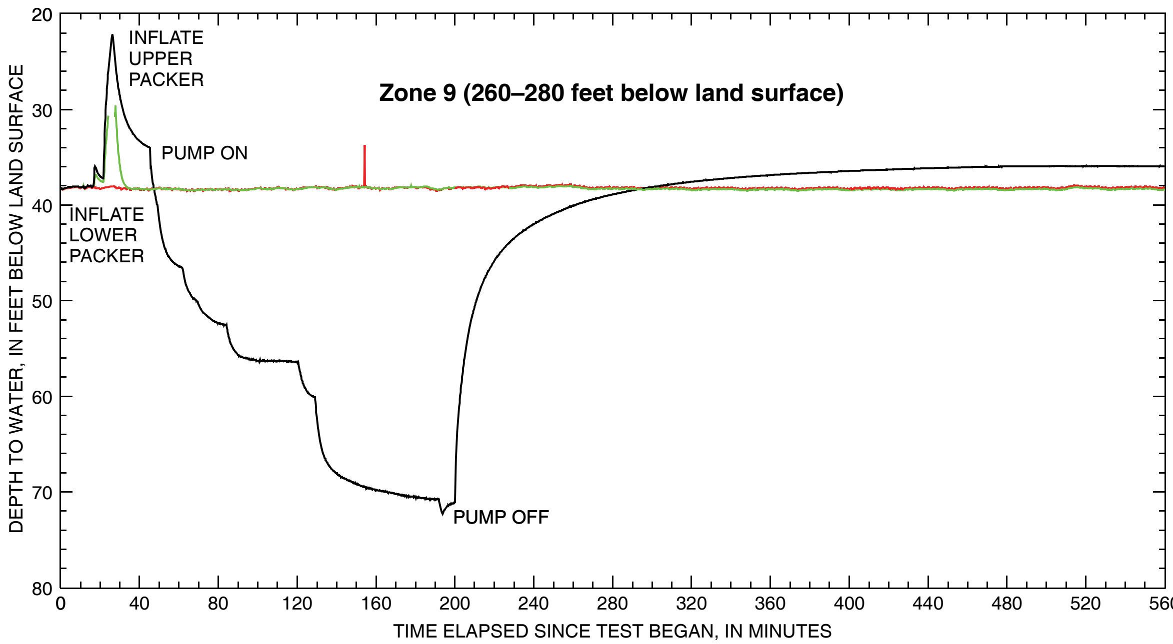


Figure 3-17. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (220–240 feet below land surface) and zone 8 (240–260 feet below land surface) in well MG-2084 (RI-3D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 10, 2004.



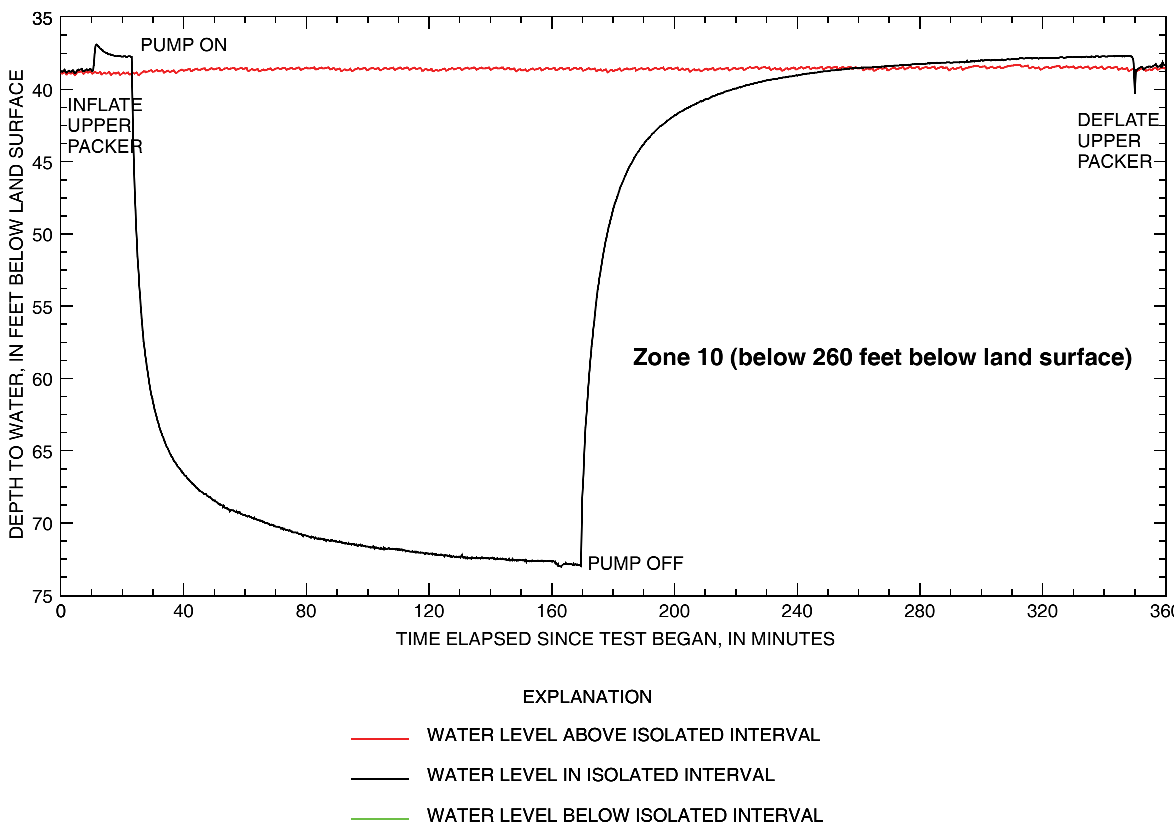


Figure 3-18. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 9 (240–260 feet below land surface) and zone 10 (below 260 feet below land surface) in well MG-2084 (RI-3D), North Penn Area 7 Superfund site, Upper Gwynedd Township, Montgomery County, Pa., March 11-12, 2004.

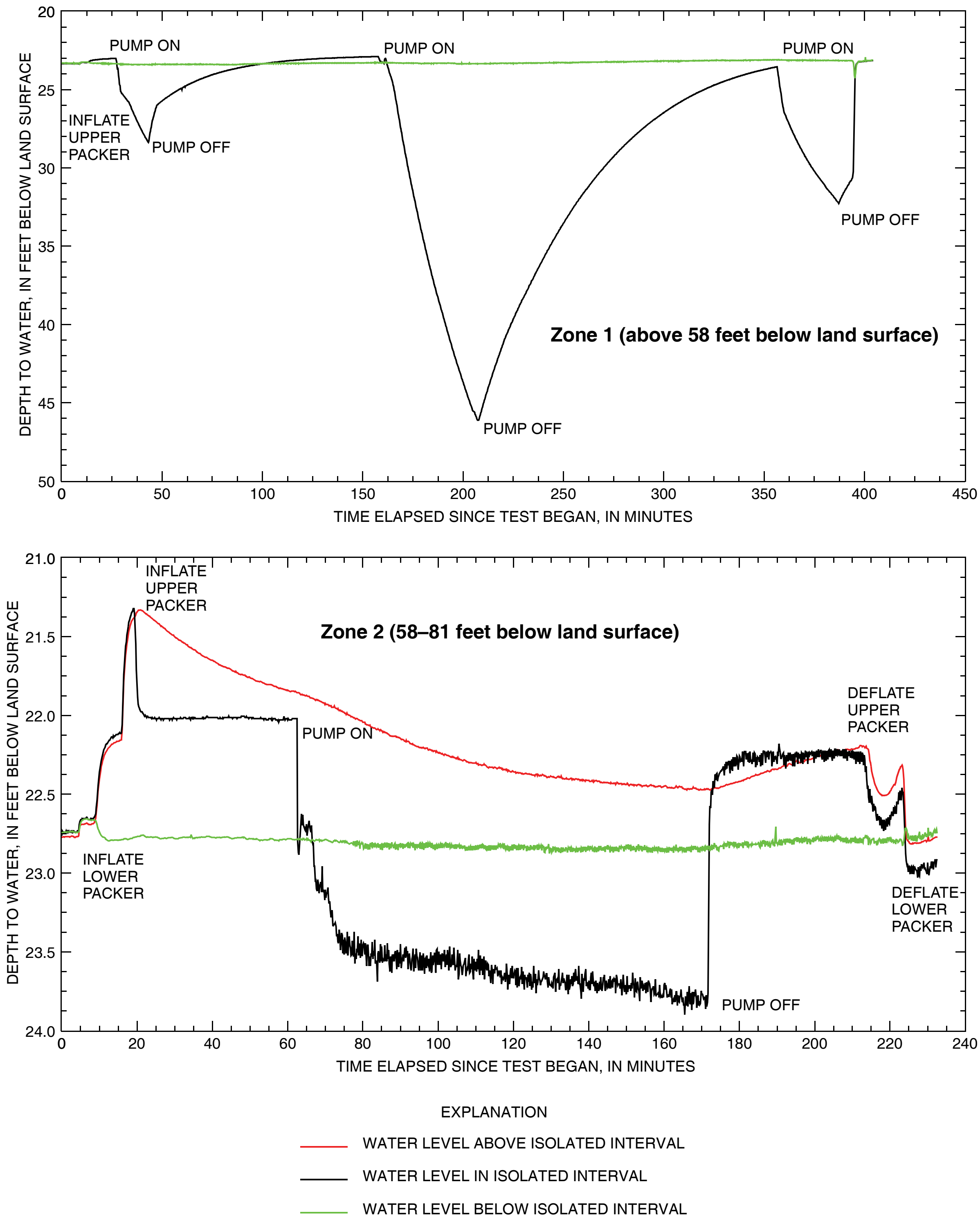


Figure 3-19. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 58 feet below land surface) and zone 2 (58–81 feet below land surface) in well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 26-27, 2004.

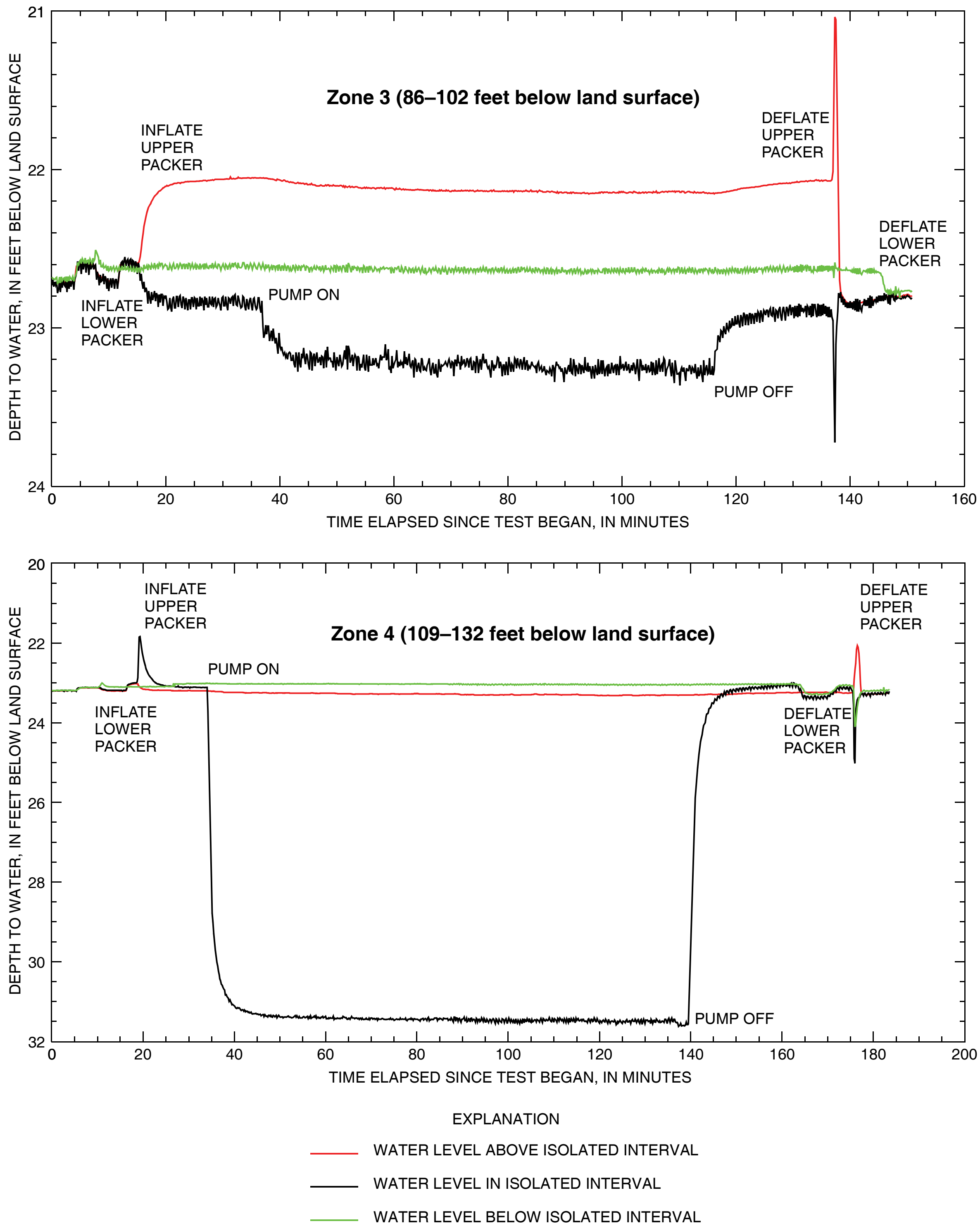


Figure 3-20. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (86–102 feet below land surface) and zone 4 (109–132 feet below land surface) in well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 27-28, 2004.

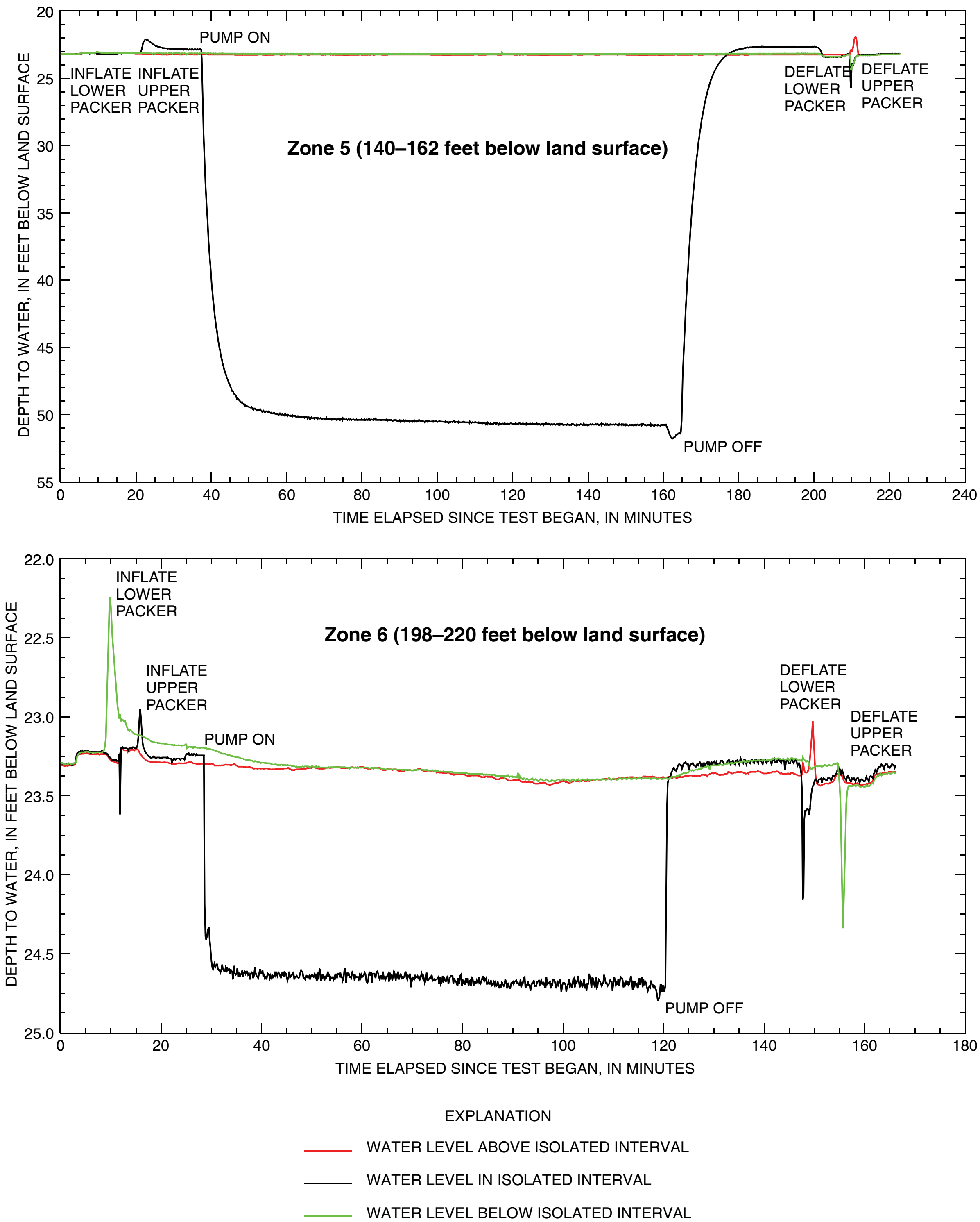


Figure 3-21. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (140–162 feet below land surface) and zone 6 (198–220 feet below land surface) in well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 28-29, 2004.

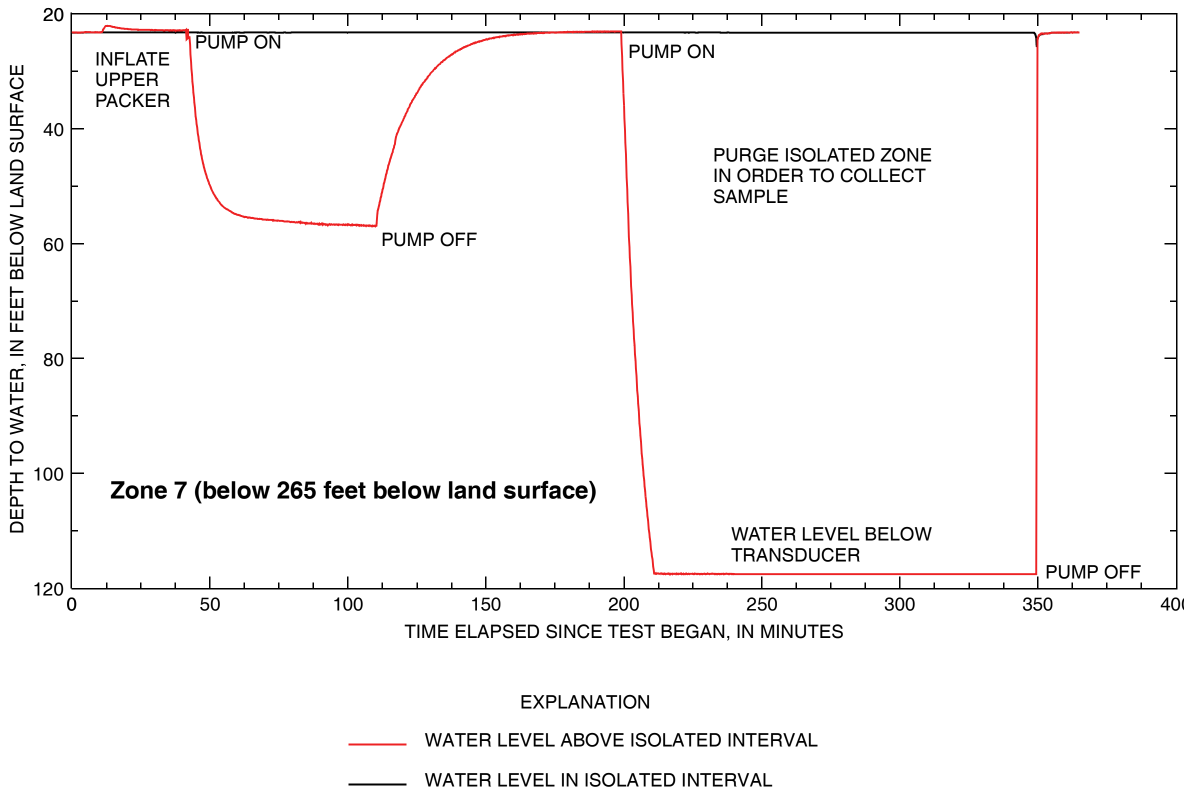


Figure 3-22. Depth to water above isolated interval and in isolated interval during, and after pumping for test of isolated interval zone 7 (below 265 feet below land surface) in well MG-2087 (RI-4D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 29, 2004.

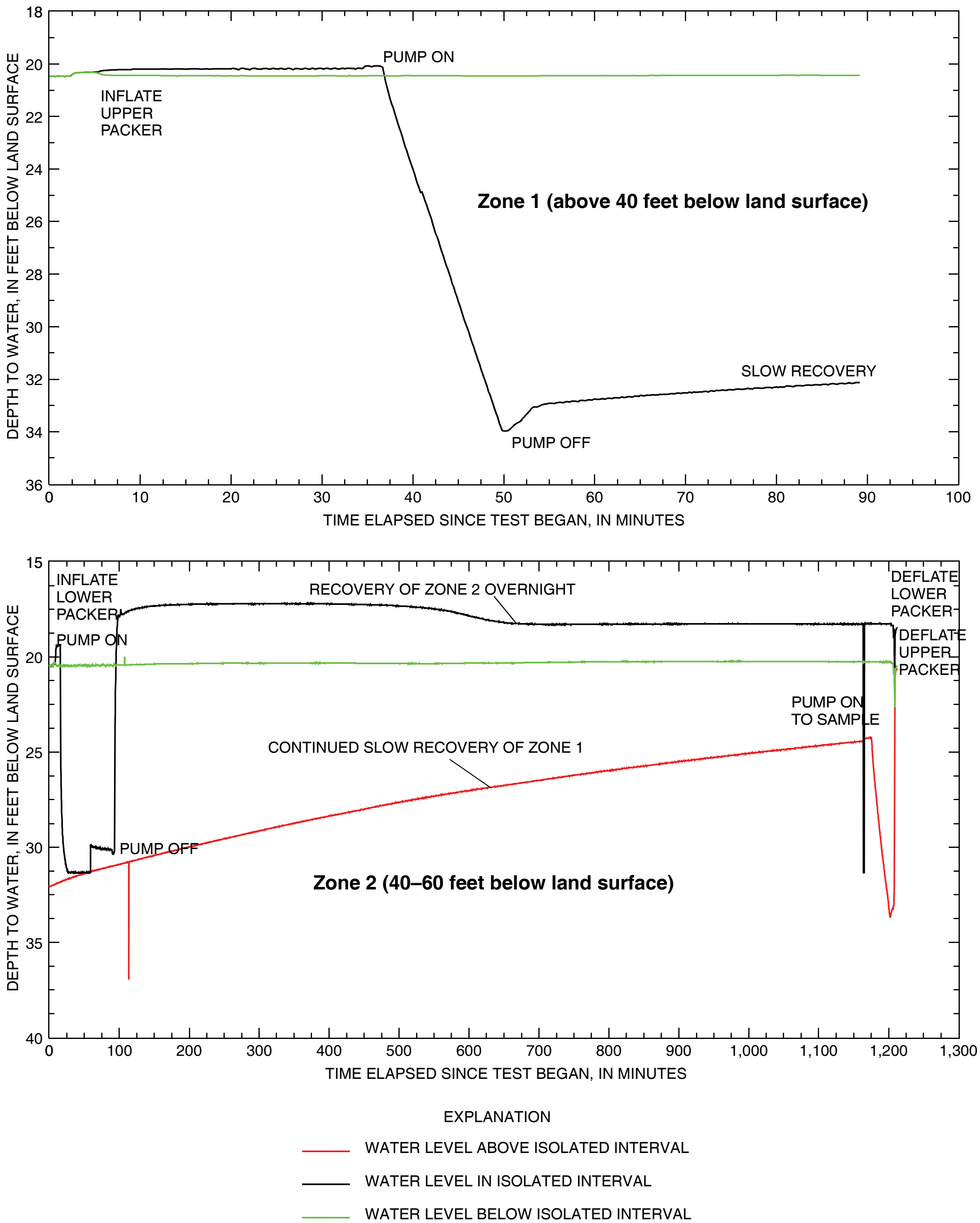


Figure 3-23. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 40 feet below land surface) and zone 2 (40–60 feet below land surface) in well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 17-18, 2004.

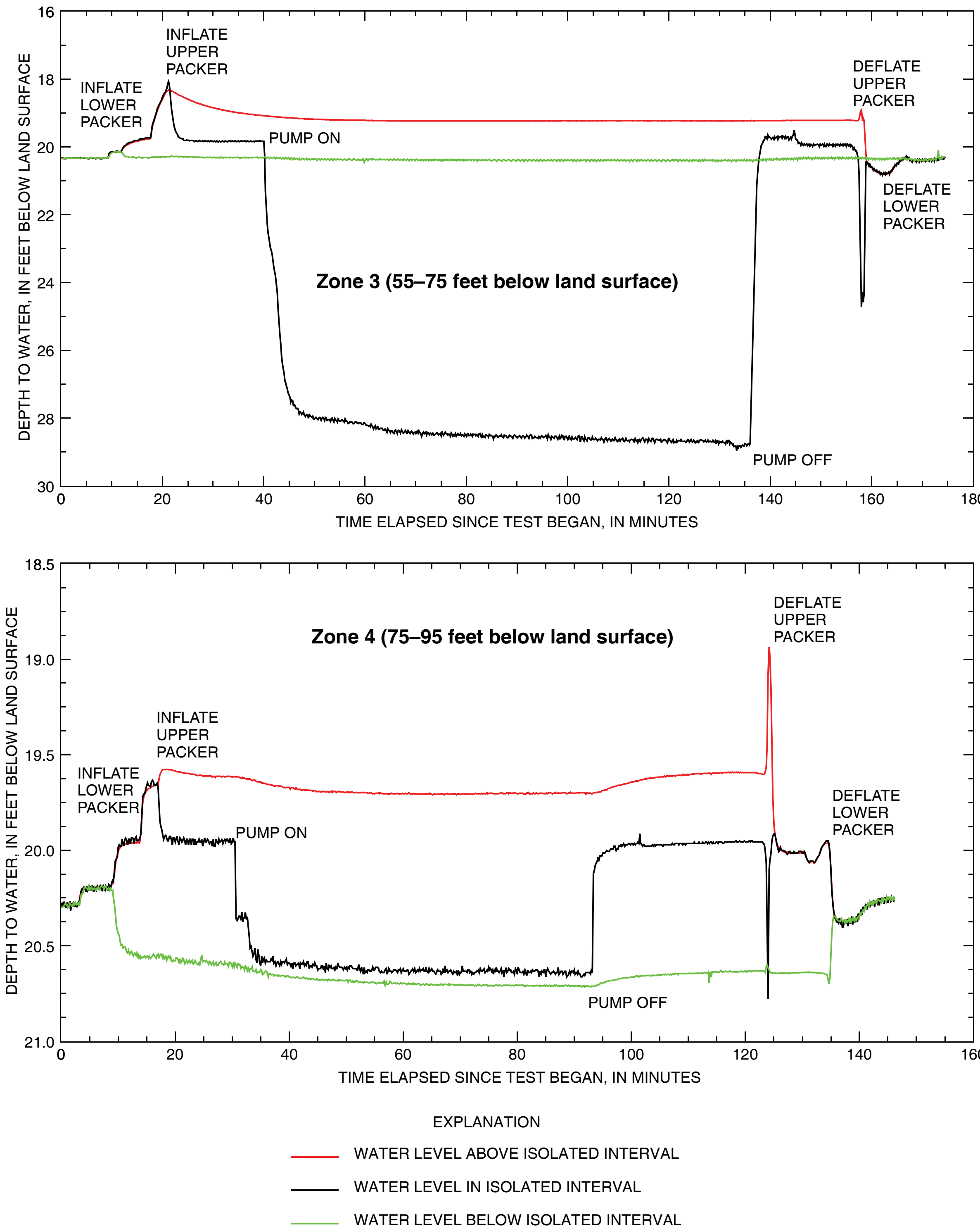


Figure 3-24. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (55–75 feet below land surface) and zone 4 (75–95 feet below land surface) in well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 18, 2004.

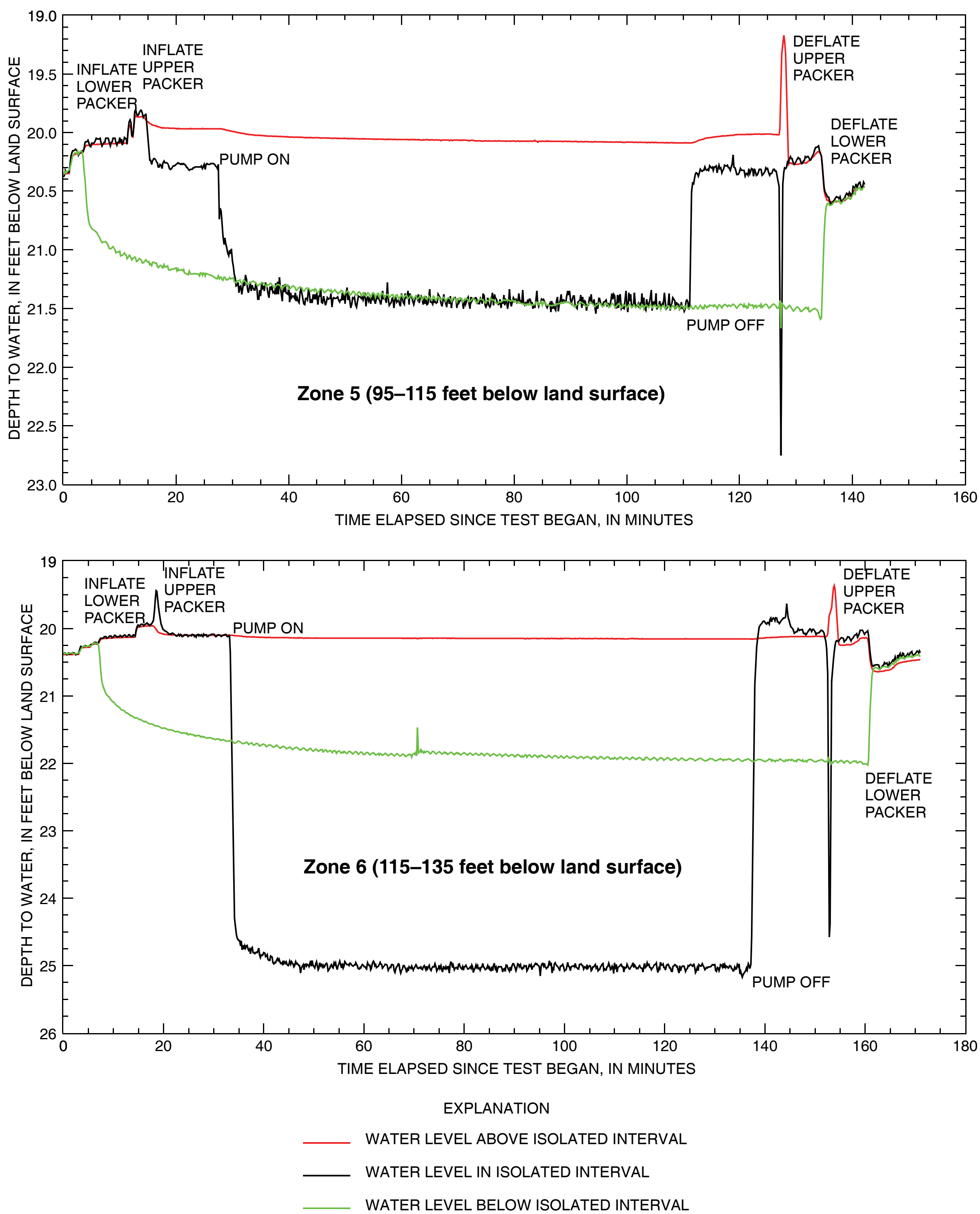


Figure 3-25. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (95–115 feet below land surface) and zone 6 (115–135 feet below land surface) in well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 19, 2004.

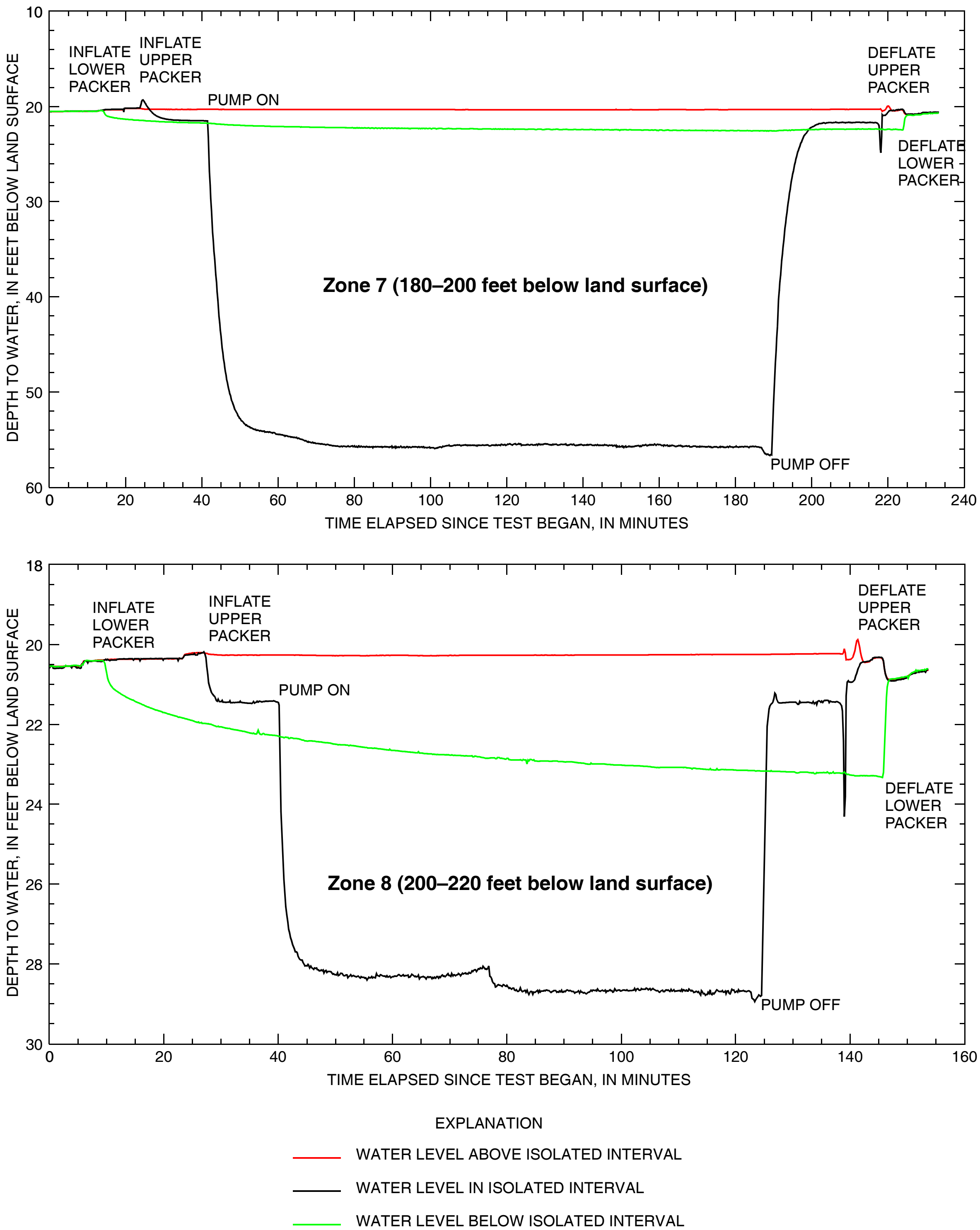


Figure 3-26. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (180–200 feet below land surface) and zone 8 (200–220 feet below land surface) in well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 20, 2004.

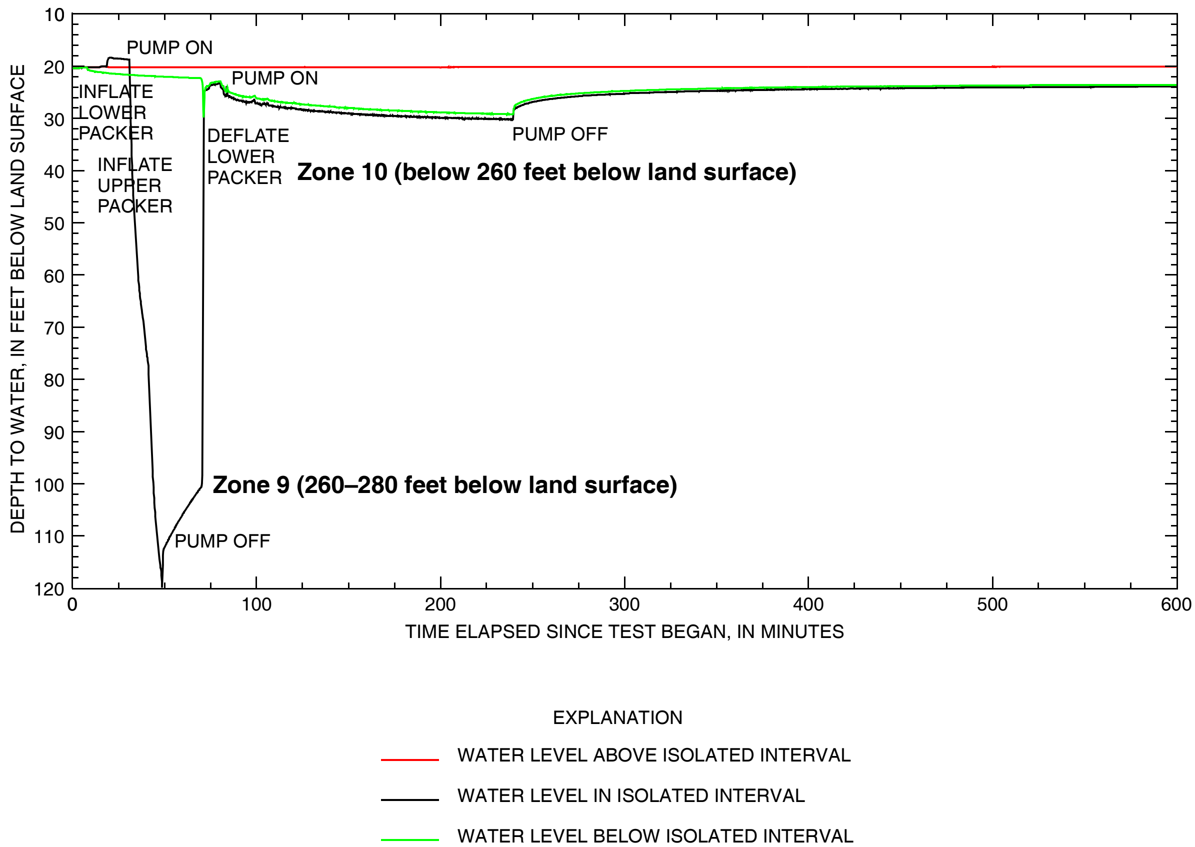


Figure 3-27. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 9 (240–260 feet below land surface) and zone 10 (below 240 feet below land surface) in well MG-2090 (RI-5D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 21, 2004.

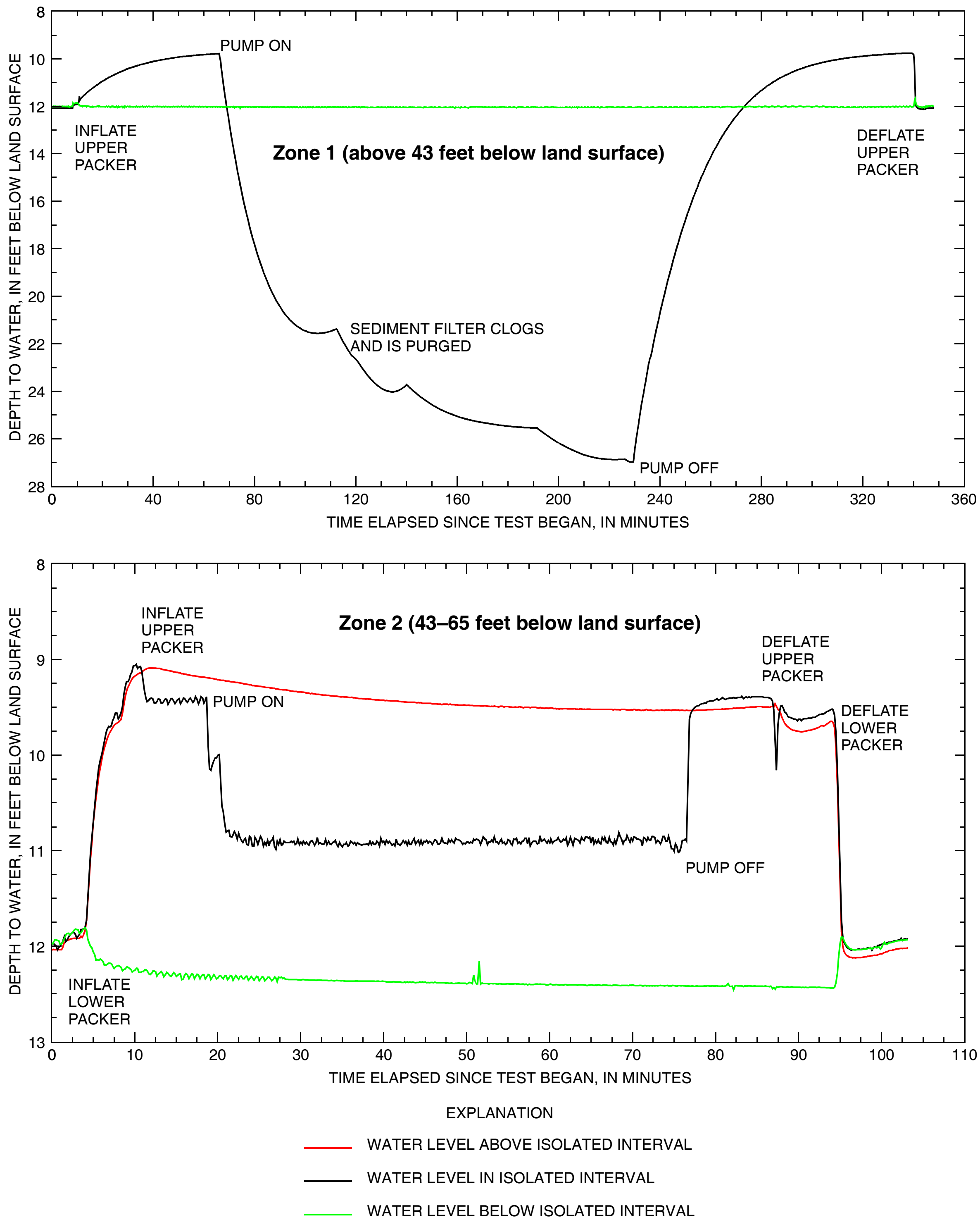


Figure 3-28. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 43 feet below land surface) and zone 2 (43–65 feet below land surface) in well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 24, 2004.

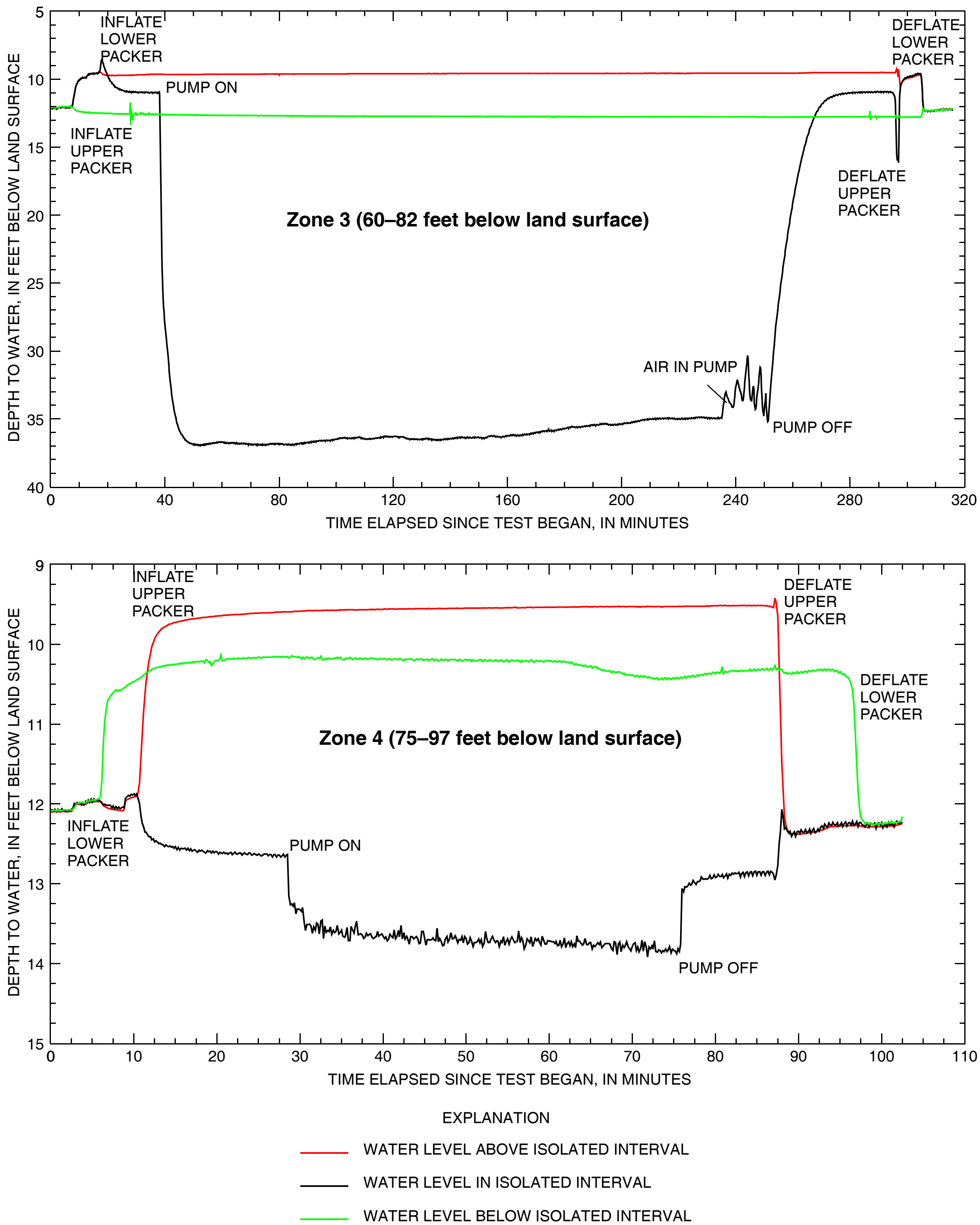
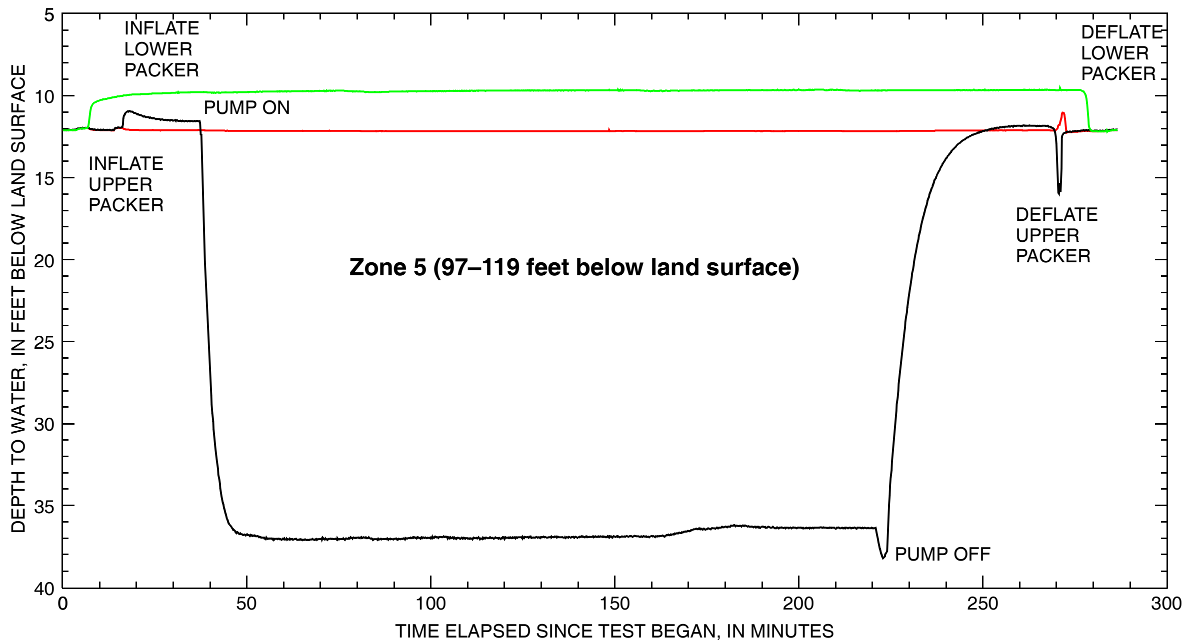


Figure 3-29. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (60–82 feet below land surface) and zone 4 (75–97 feet below land surface) in well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 25, 2004.



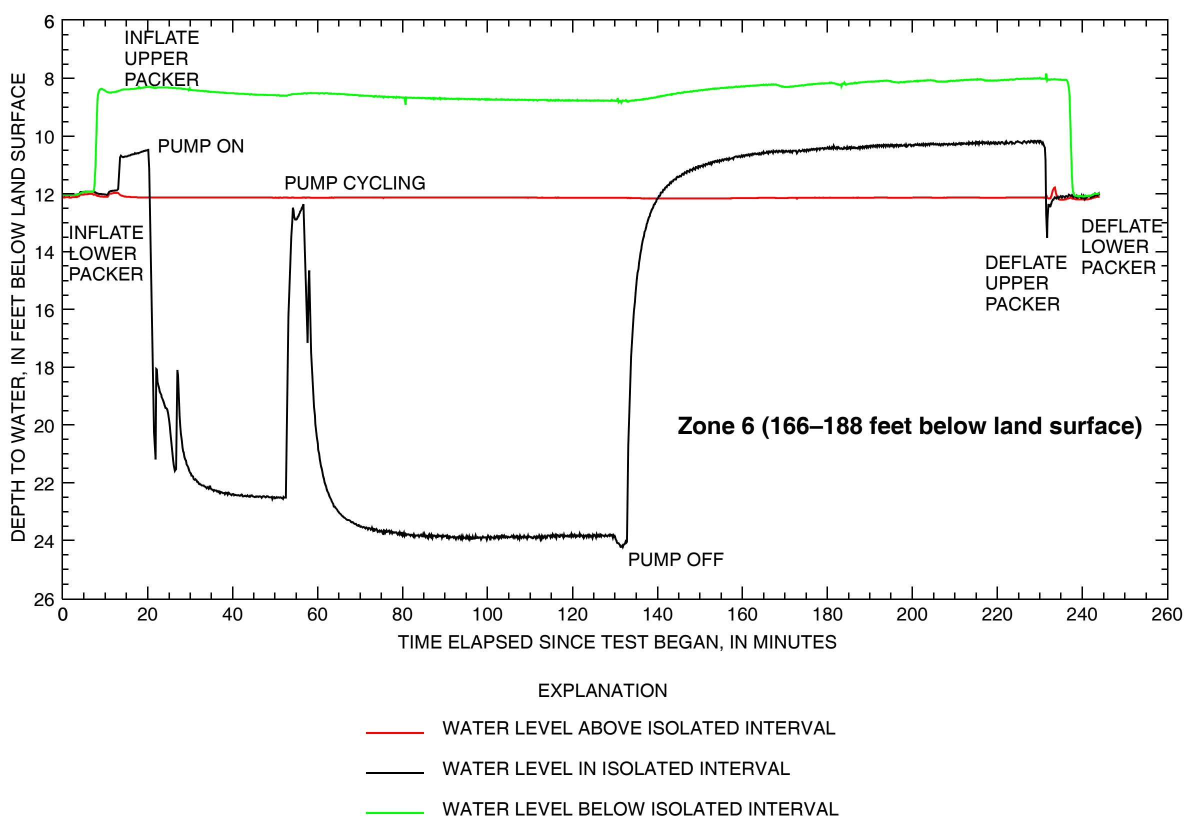


Figure 3-30. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (97–119 feet below land surface) and zone 6 (166–188 feet below land surface) in well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 26, 2004.

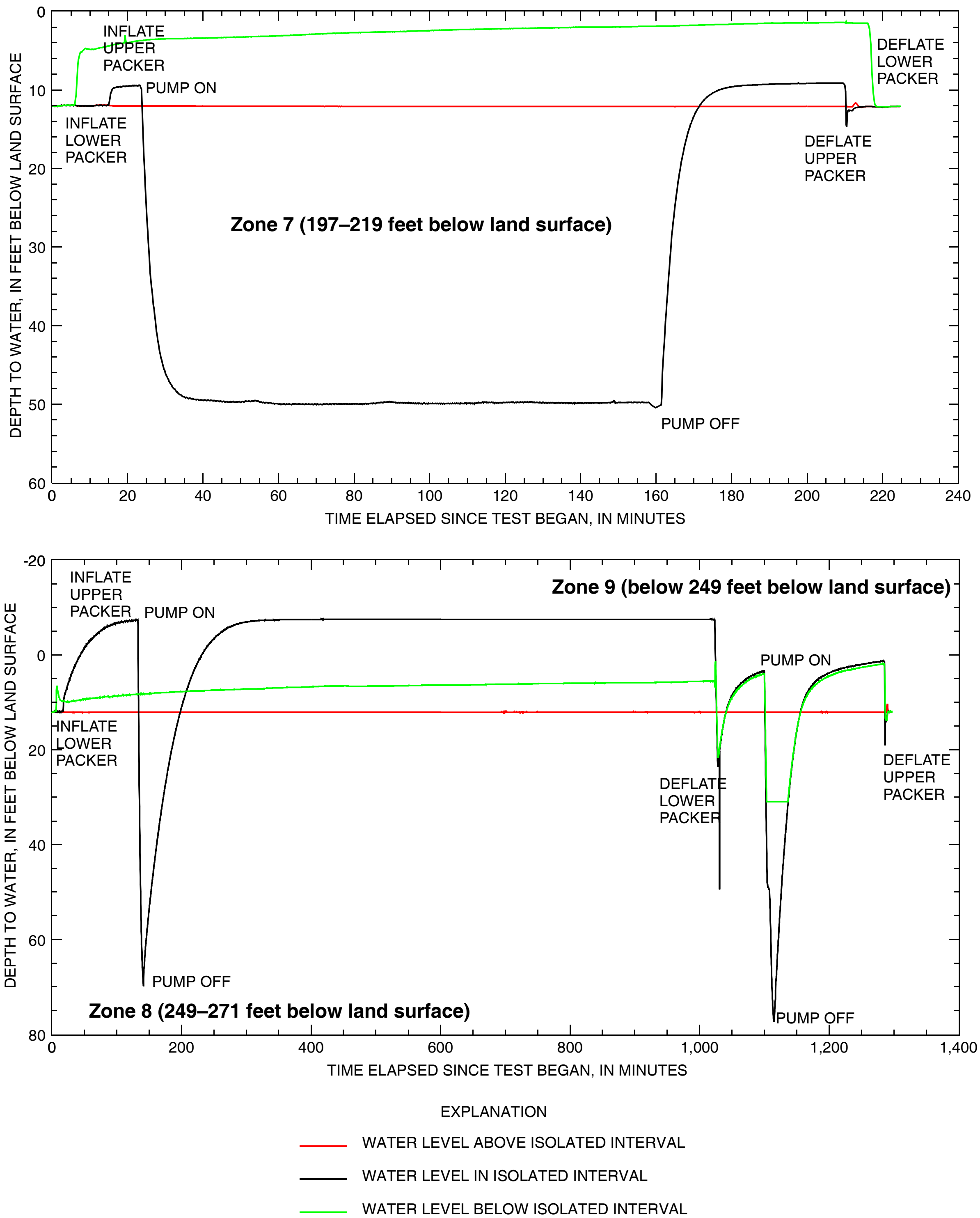


Figure 3-31. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (60–82 feet below land surface) and zone 8 (75–97 feet below land surface) and zone 9 (below 240 feet below land surface) in well MG-2093 (RI-6D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., May 27-28, 2004.

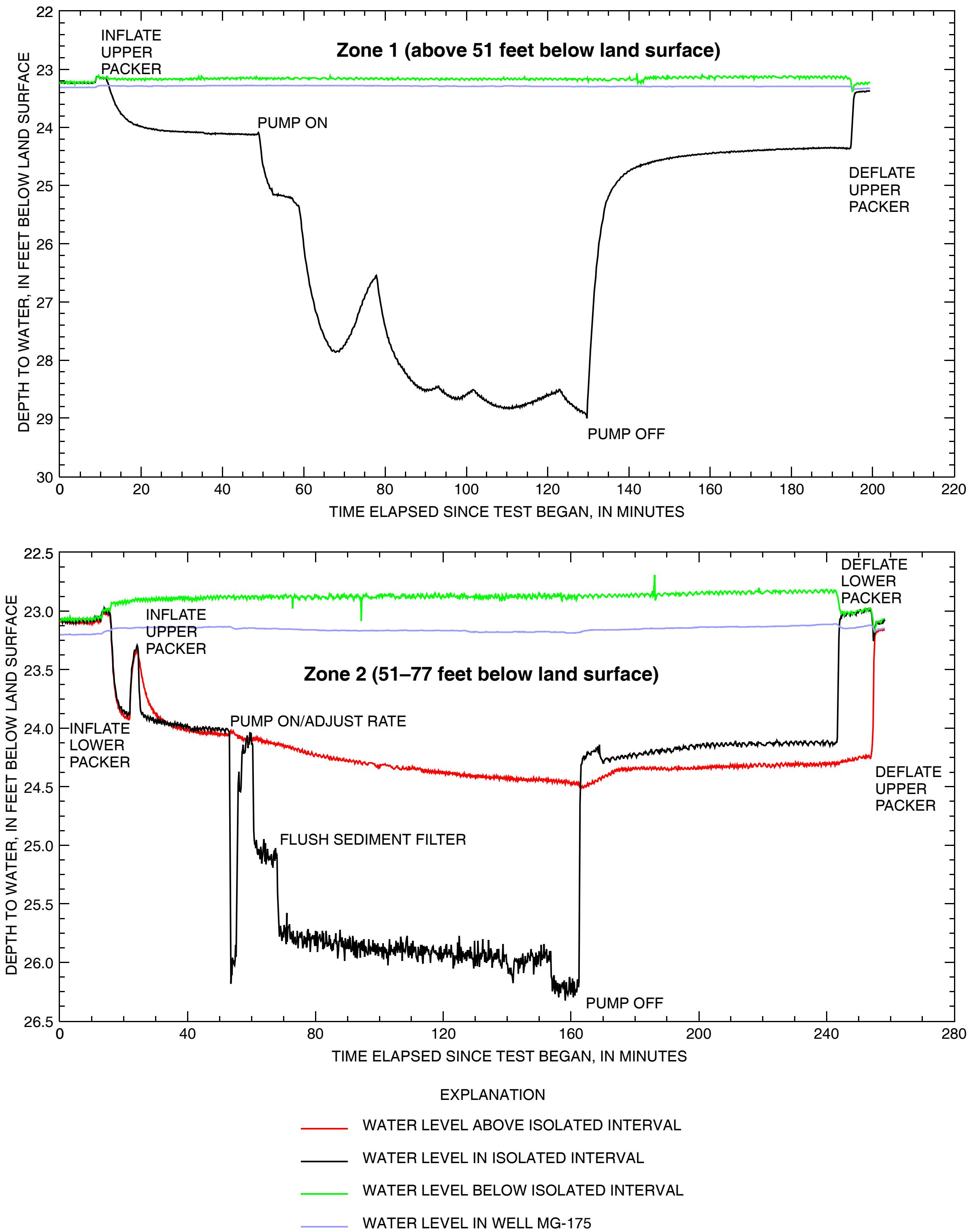


Figure 3-32. Depth to water above isolated interval, in isolated interval, and below isolated interval and in nearby well MG-175 before, during, and after pumping for tests of isolated intervals zone 1 (above 51 feet below land surface) and zone 2 (51–77 feet below land surface) in well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 1-2, 2004.

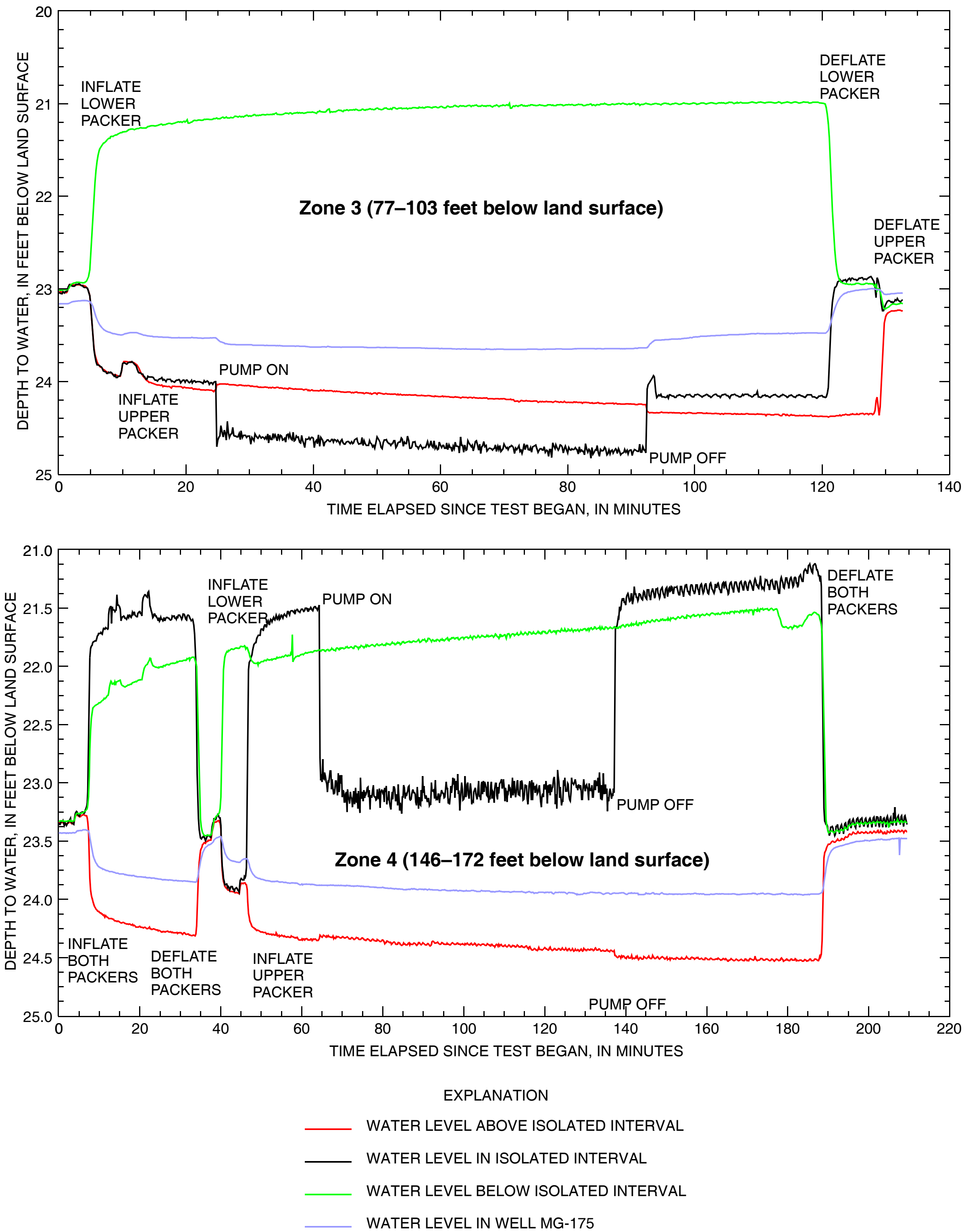


Figure 3-33. Depth to water above isolated interval, in isolated interval, and below isolated interval and in nearby well MG-175 before, during, and after pumping for tests of isolated intervals zone 3 (77–103 feet below land surface) and zone 4 (146–172 feet below land surface) in well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 2-3, 2004.

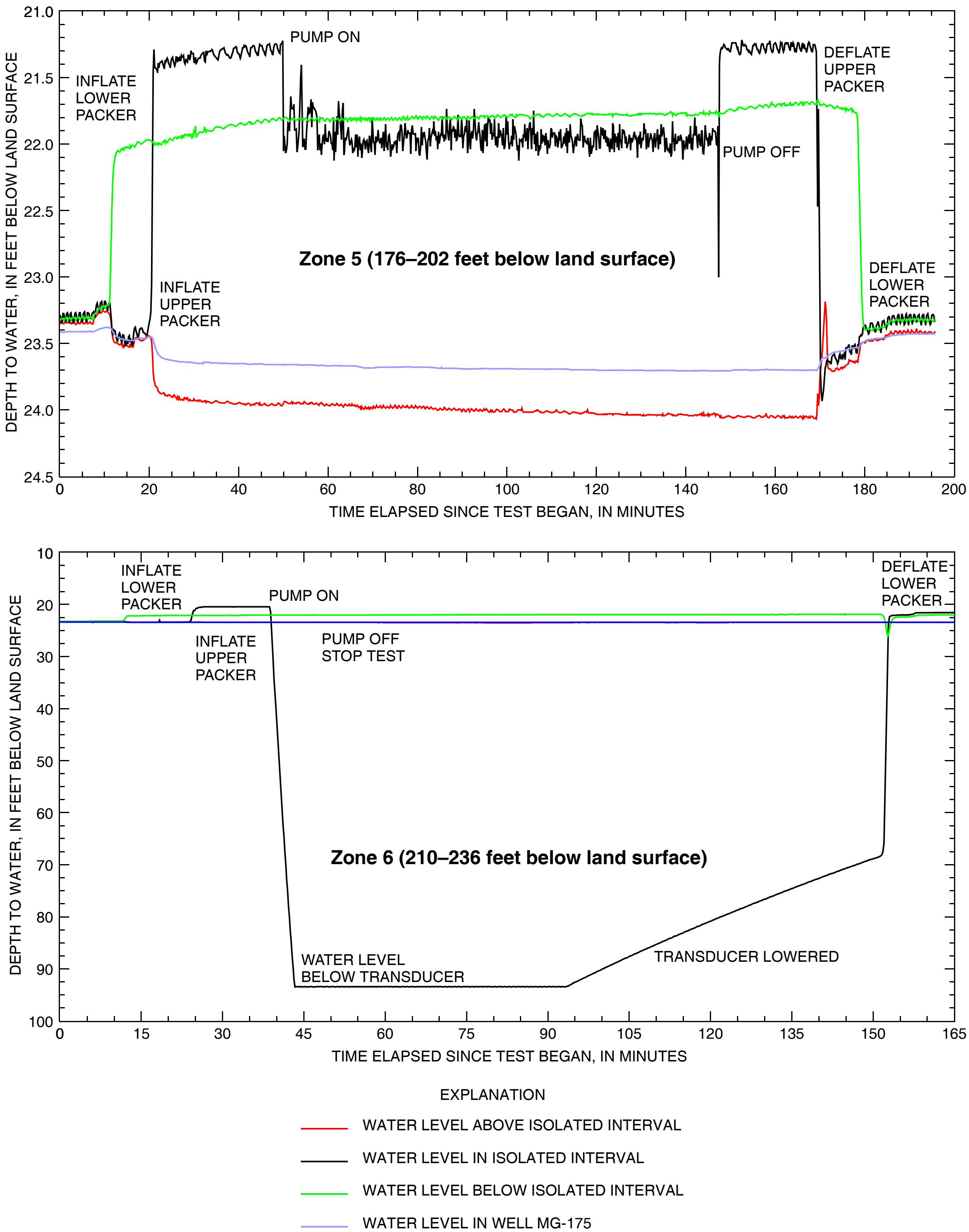


Figure 3-34. Depth to water above isolated interval, in isolated interval, and below isolated interval and in nearby well MG-175 before, during, and after pumping for tests of isolated intervals zone 5 (176–202 feet below land surface) and zone 7 (210–236 feet below land surface) in well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 3-4, 2004. Test of zone 6 (210–236 feet below land surface) was discontinued because of poor yield.

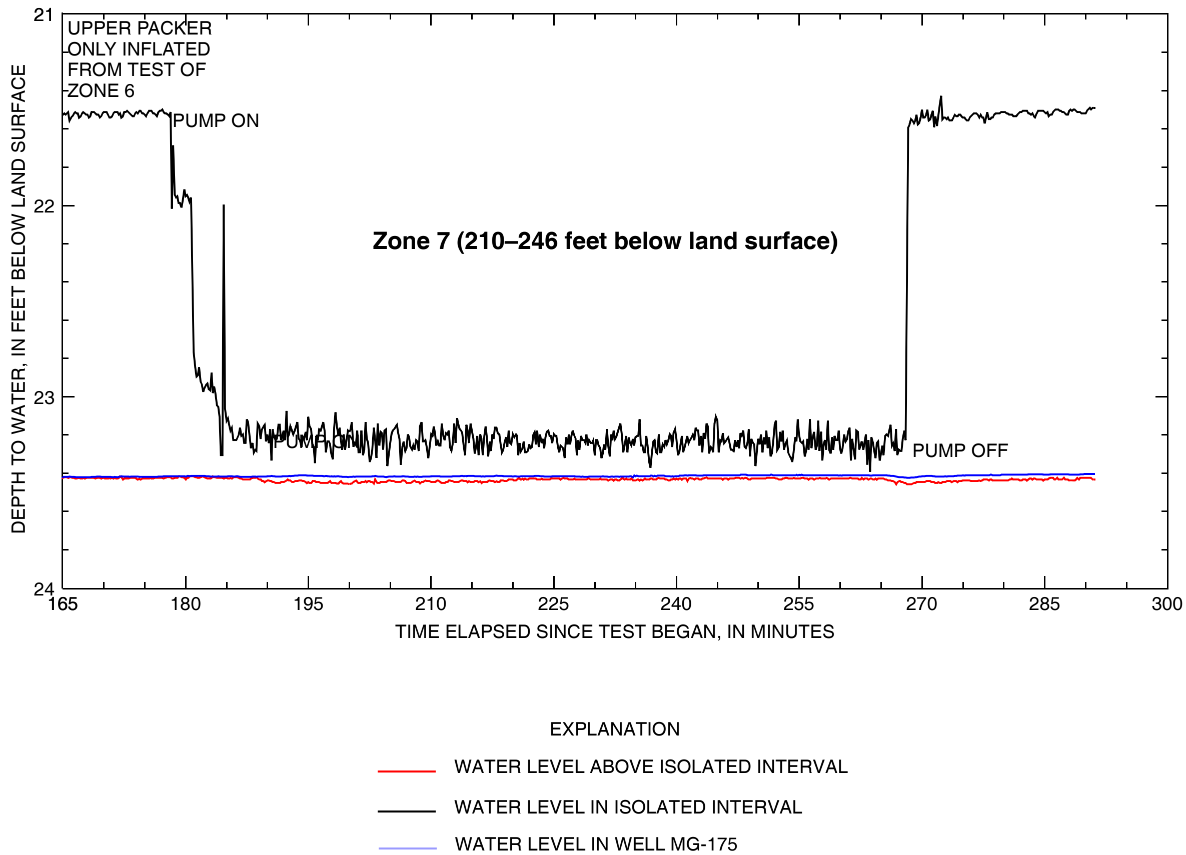
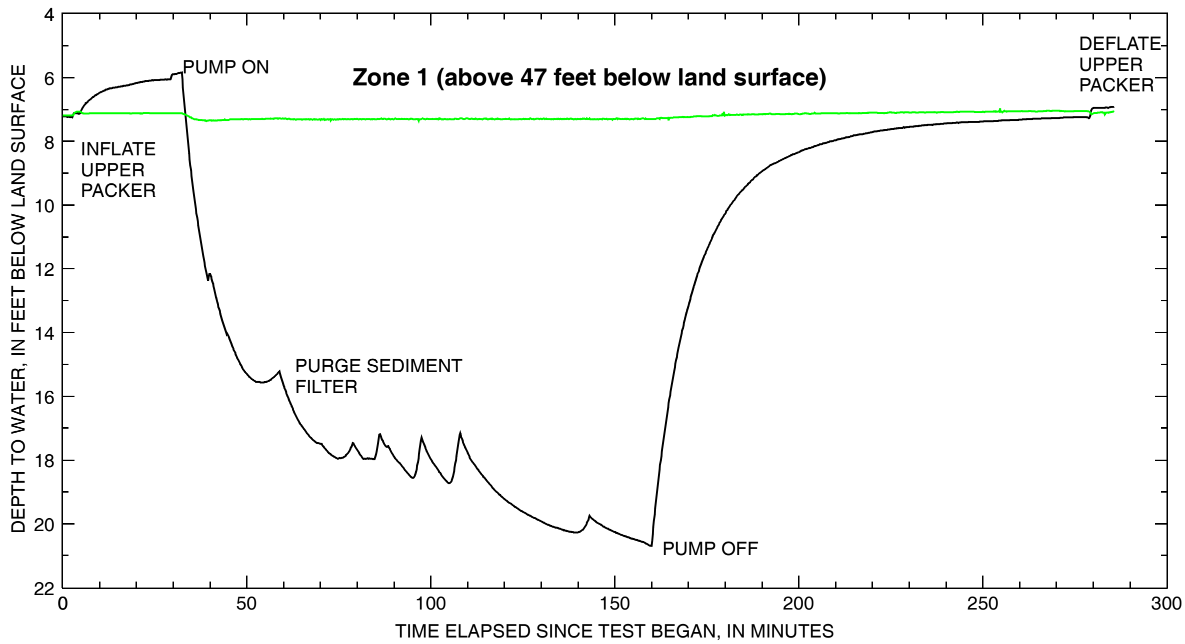


Figure 3-35. Depth to water above isolated interval, in isolated interval, and below isolated interval and in nearby well MG-175 before, during, and after pumping for tests of isolated interval zone 7 (210–246 feet below land surface) in well MG-2095 (RI-7D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 4, 2004. Test of zone 7 occurred after lower packer was deflated in test of zone 6 (210–236 feet below land surface).



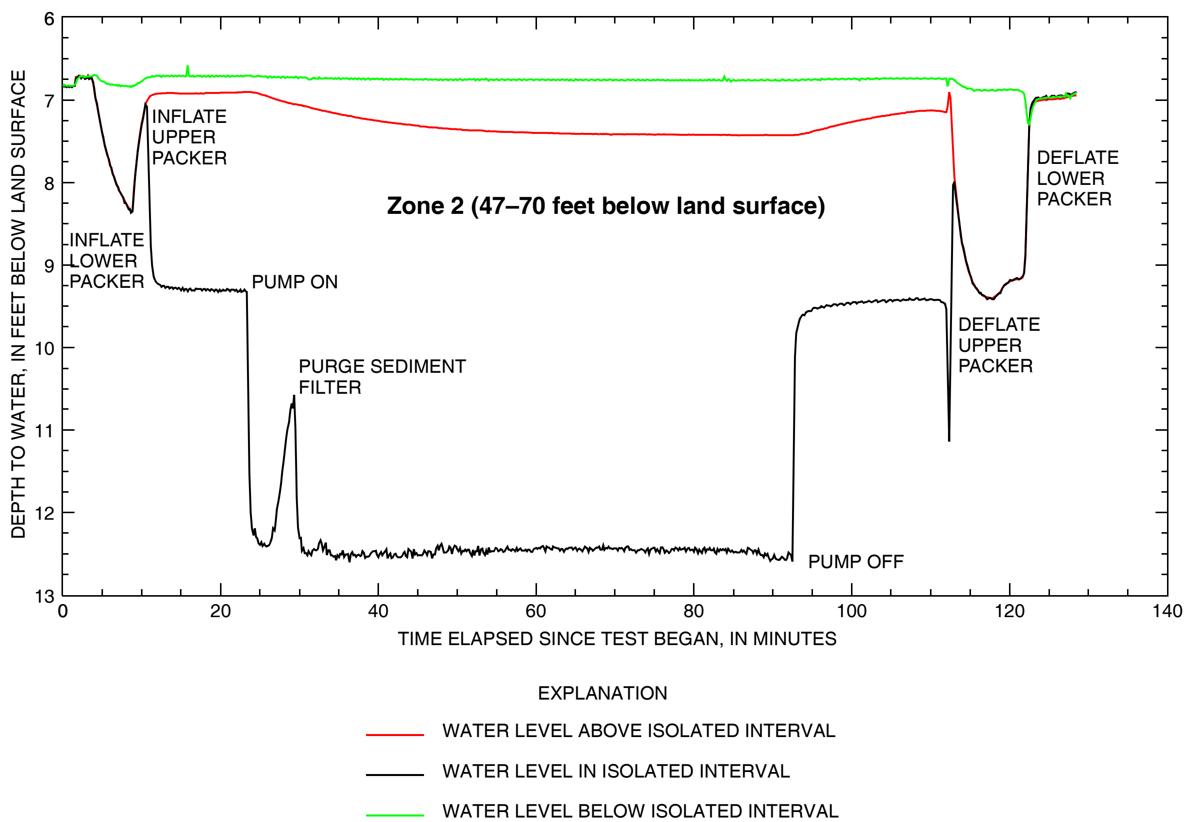


Figure 3-36. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 47 feet below land surface) and zone 2 (47–70 feet below land surface) in well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 2-3, 2004.

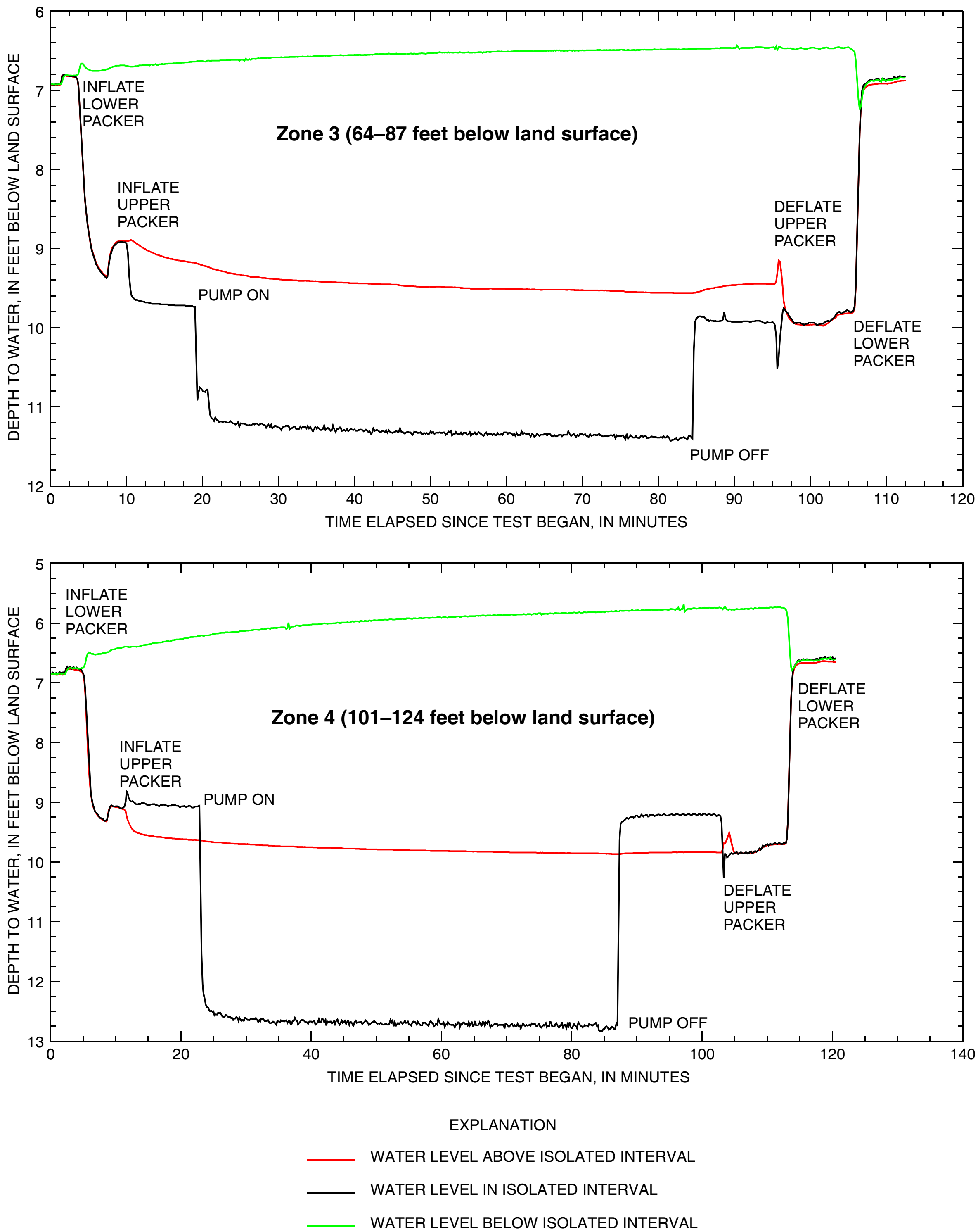


Figure 3-37. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (64–87 feet below land surface) and zone 4 (101–124 feet below land surface) in well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 3, 2004.

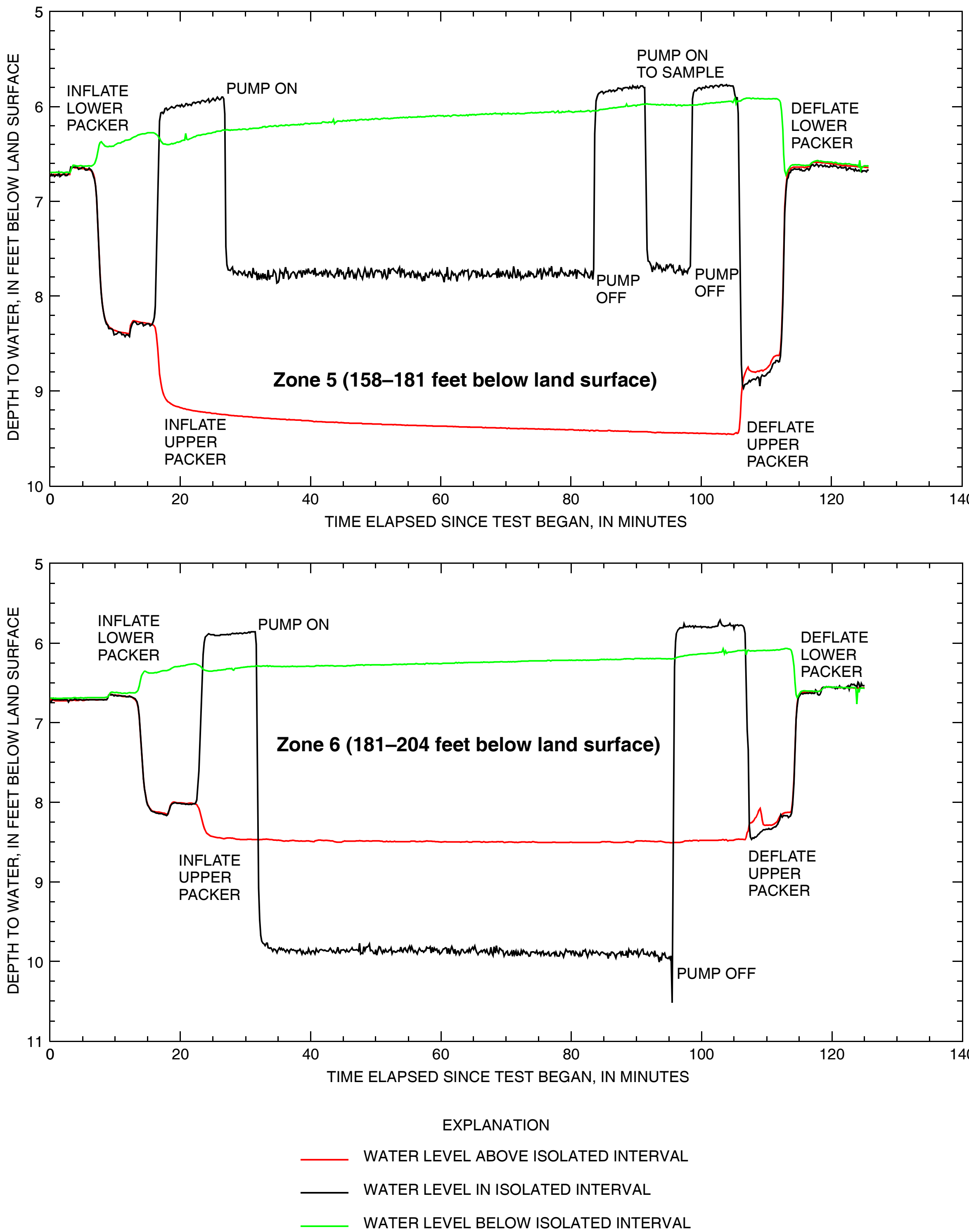


Figure 3-38. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (158–181 feet below land surface) and zone 6 (181–204 feet below land surface) in well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 4, 2004.

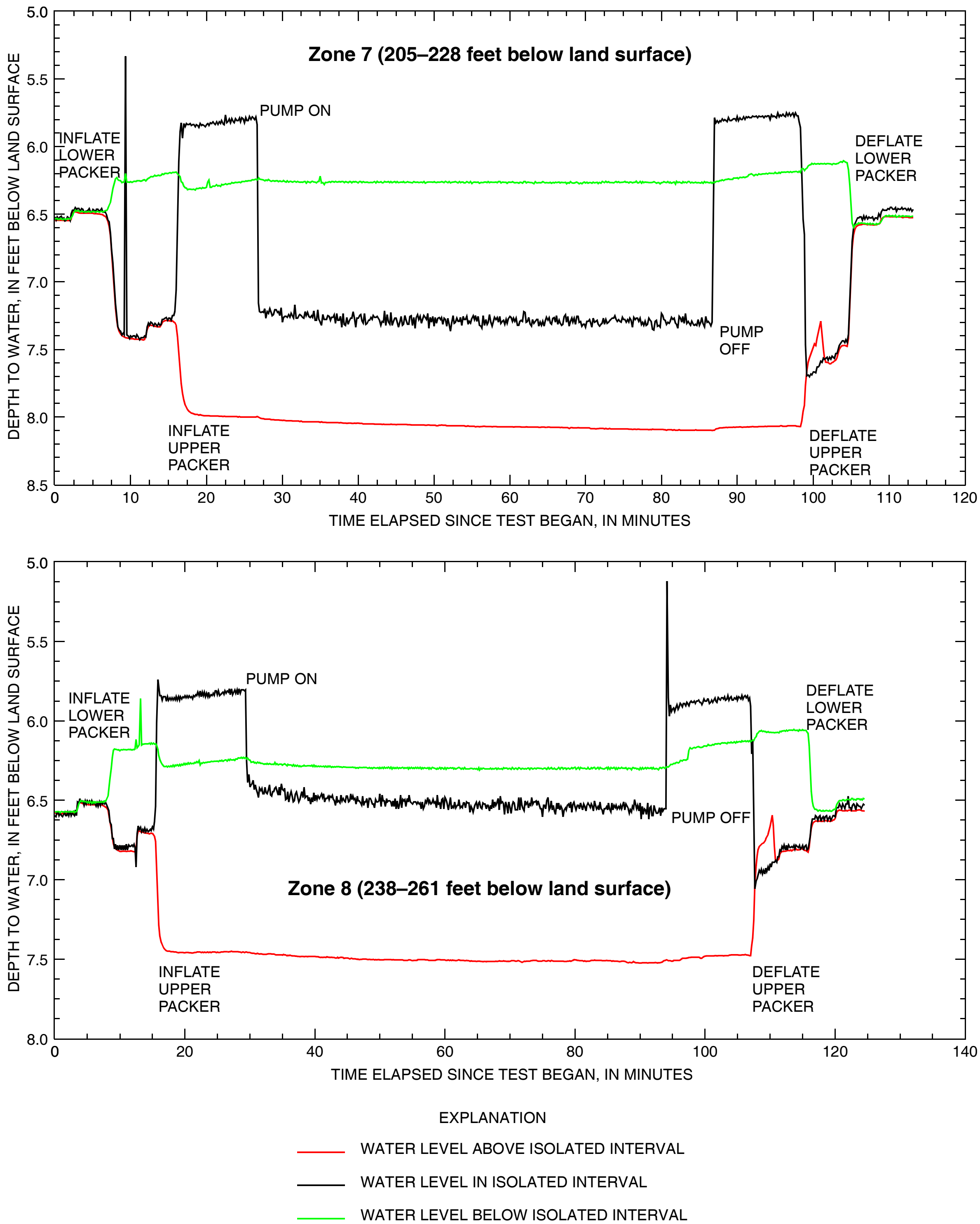


Figure 3-39. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (205–228 feet below land surface) and zone 8 (238–261 feet below land surface) in well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 5, 2004.

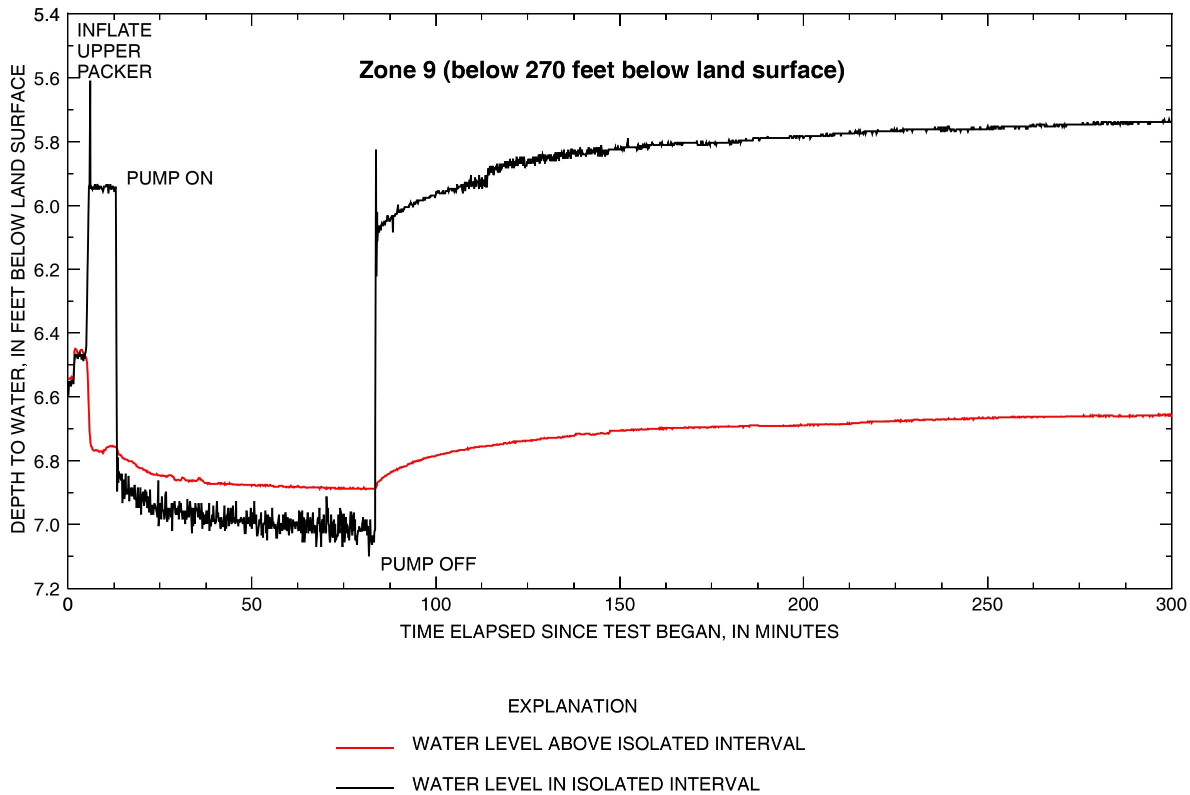


Figure 3-40 Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated interval zone 9 (below 270 feet below land surface) in well MG-2097 (RI-8D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., August 5, 2004.

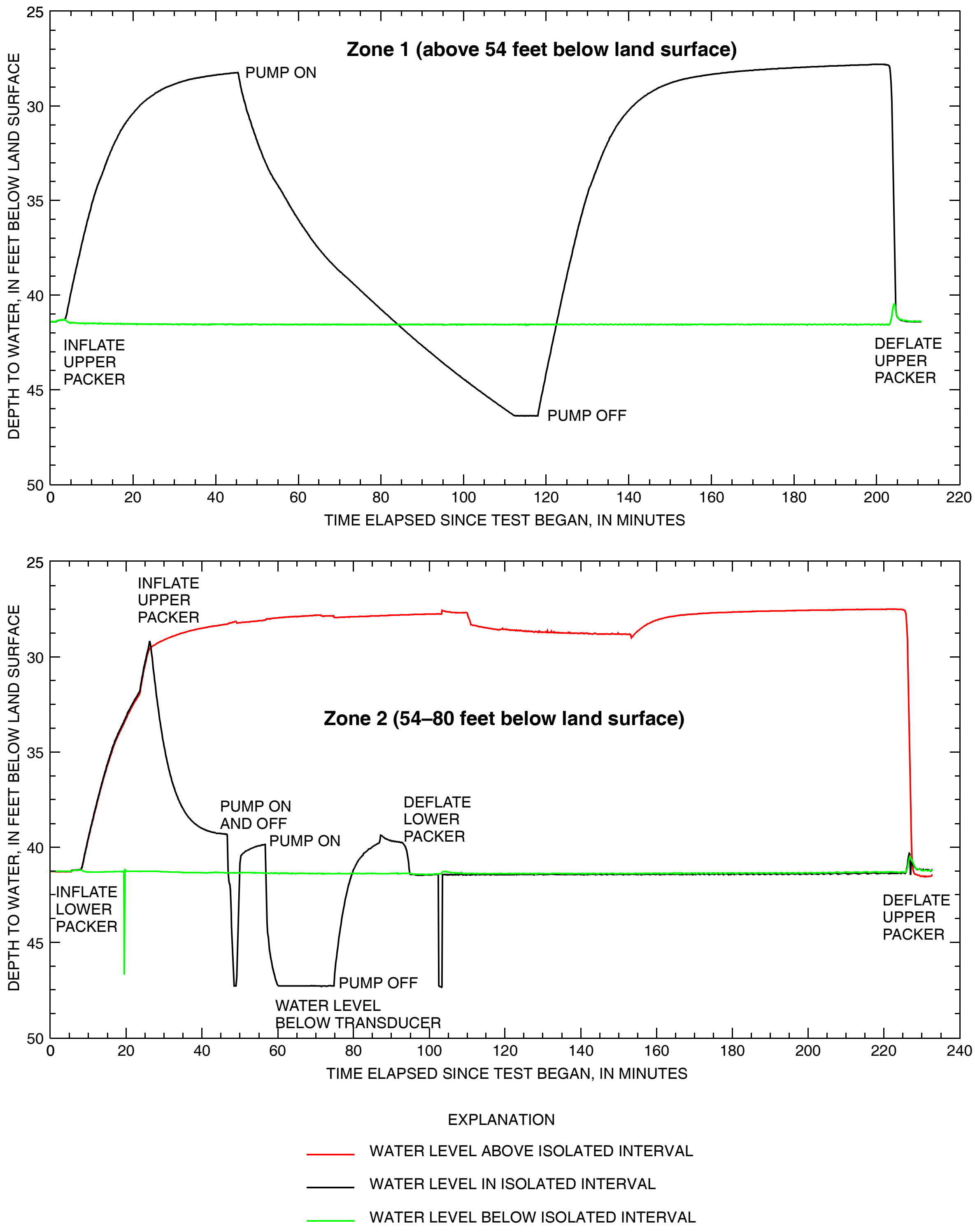


Figure 3-41. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 54 feet below land surface) and zone 2 (54–80 feet below land surface) in well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 26-27, 2004.

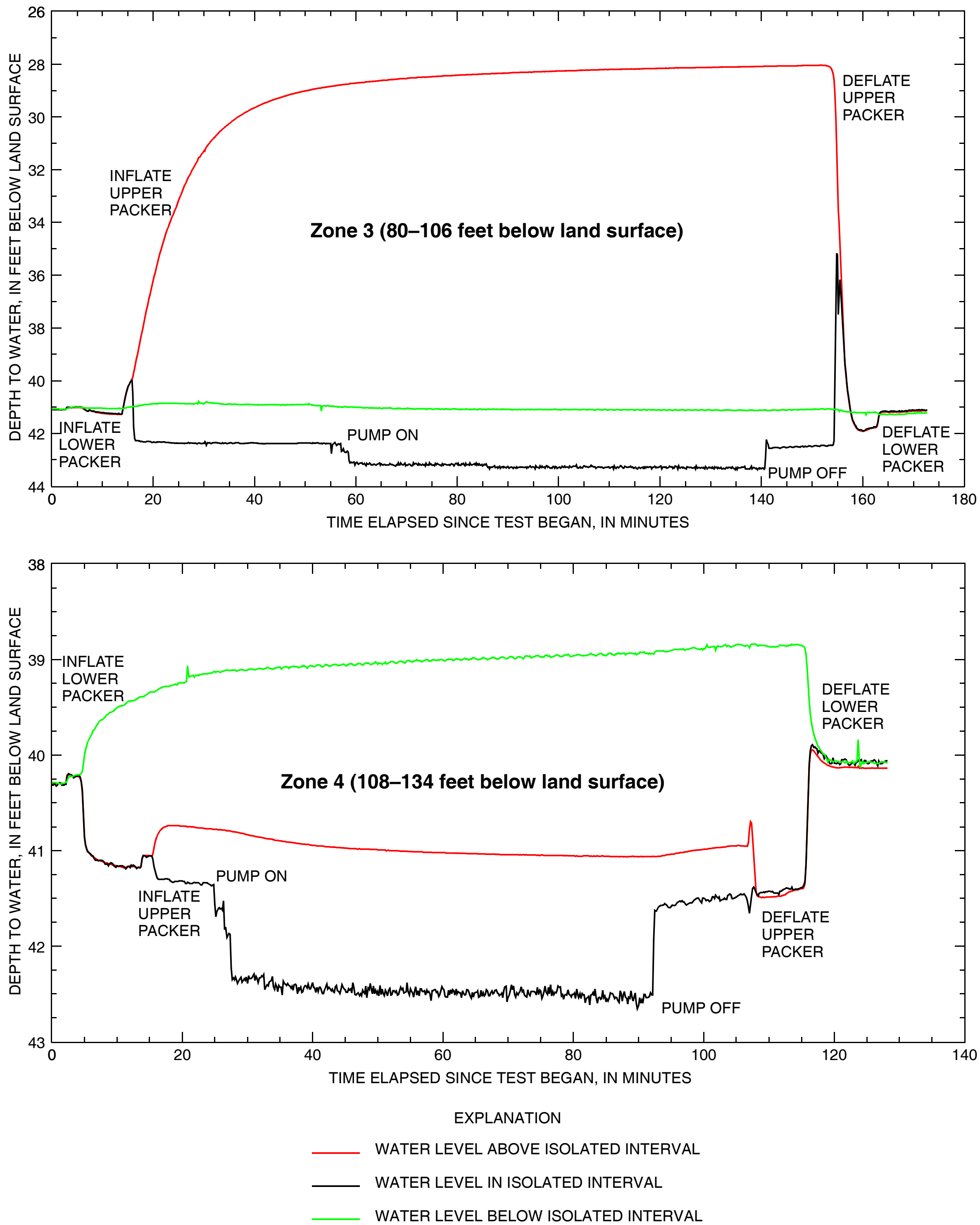


Figure 3-42. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (80–106 feet below land surface) and zone 4 (108–134 feet below land surface) in well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 27, 2004.

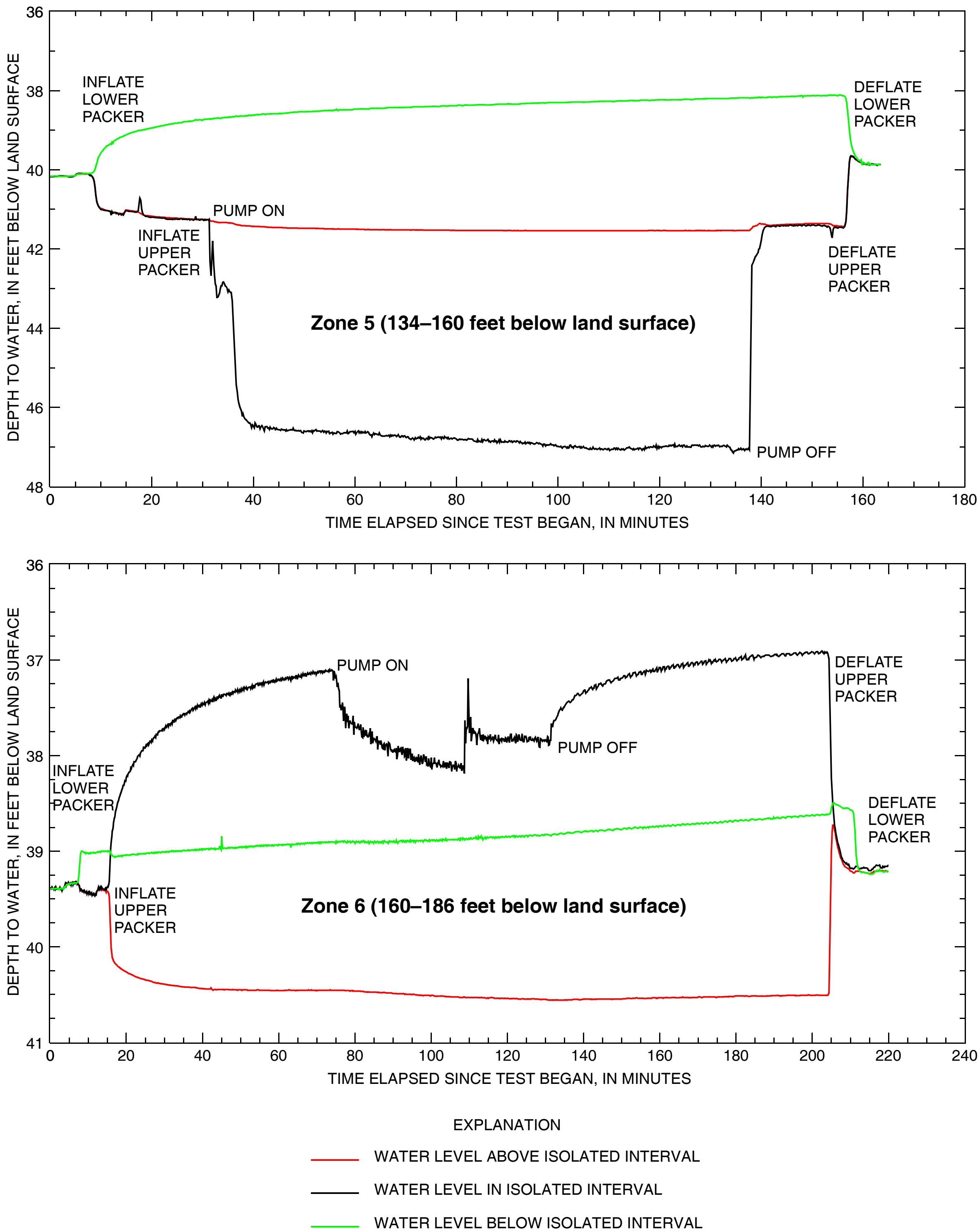
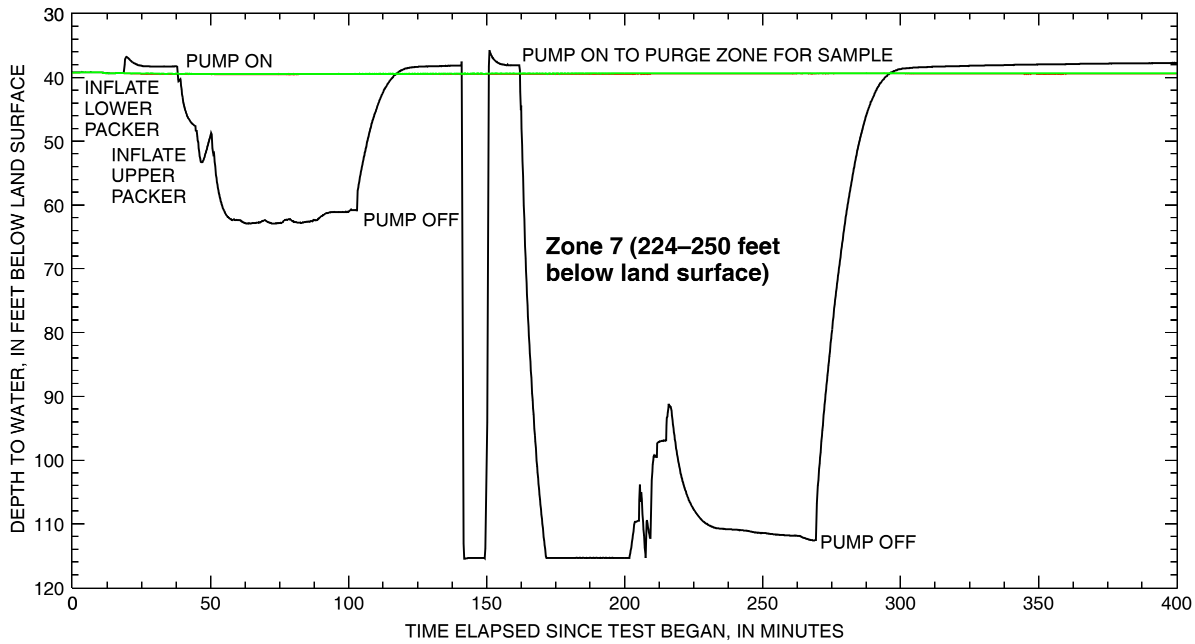


Figure 3-43. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (134–160 feet below land surface) and zone 6 (160–186 feet below land surface) in well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 28-29, 2004.



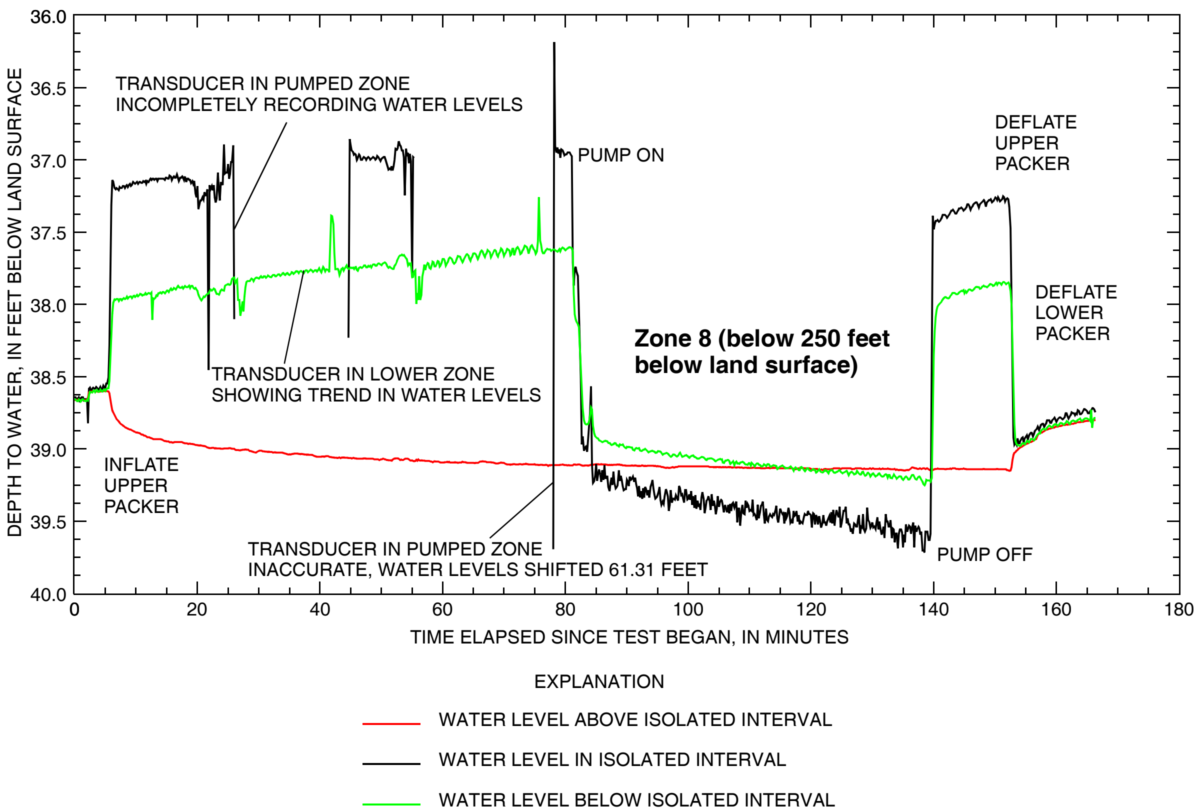


Figure 3-44. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (224–250 feet below land surface) and zone 8 (below 250 feet below land surface) in well MG-2100 (RI-9D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 29-30, 2004.

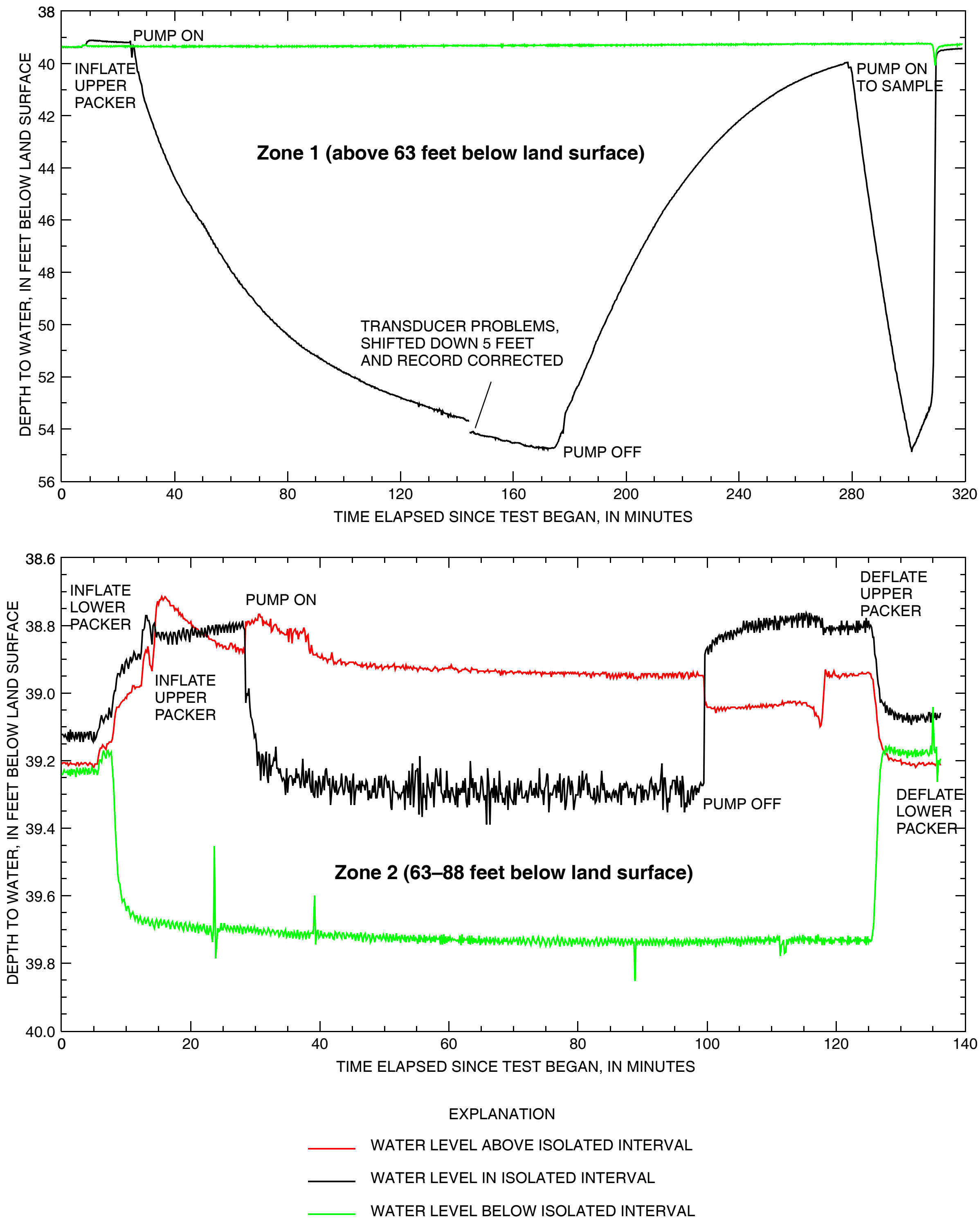


Figure 3-45. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 63 feet below land surface) and zone 2 (63–88 feet below land surface) in well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 23, 2004.

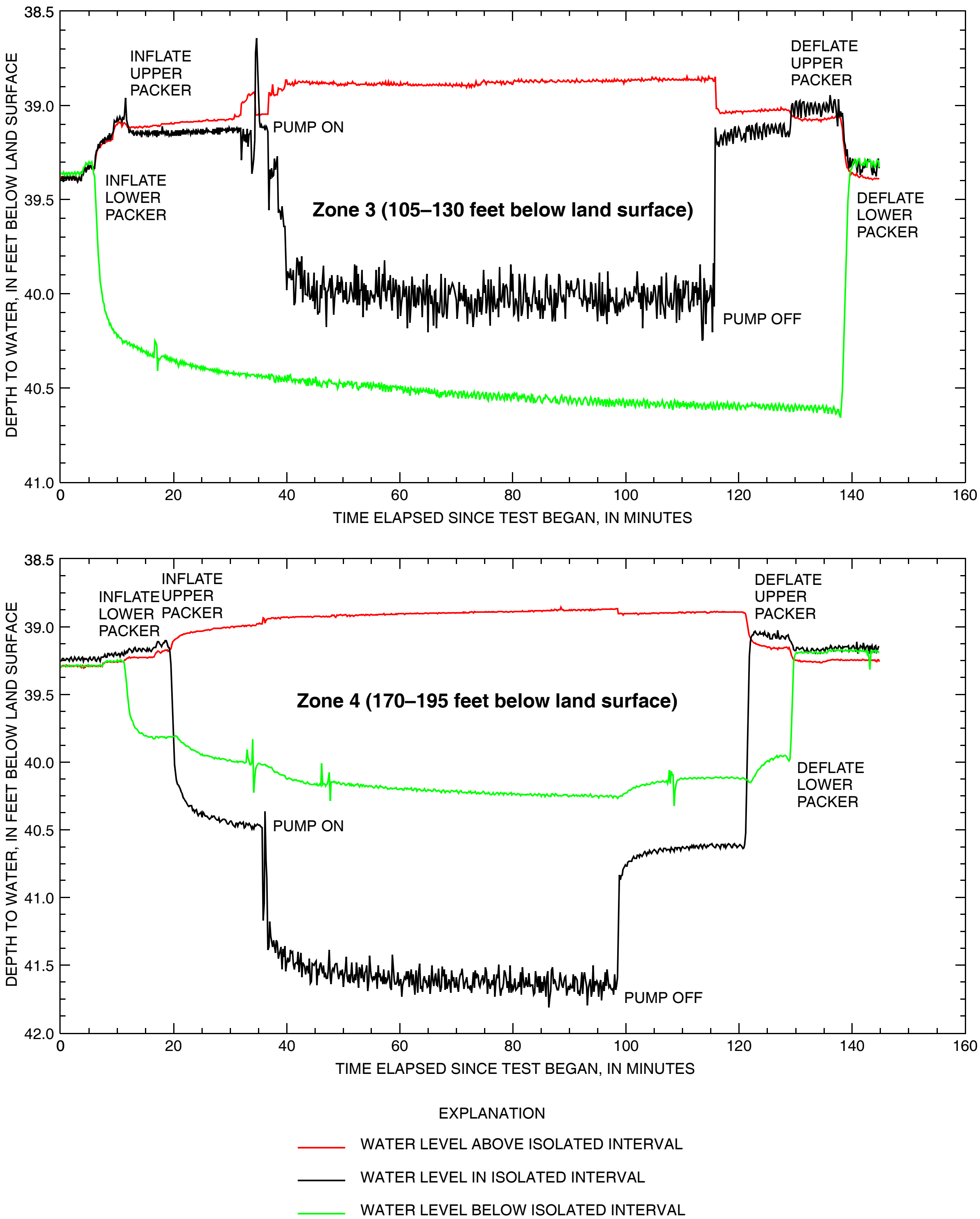


Figure 3-46. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (105–130 feet below land surface) and zone 4 (170–195 feet below land surface) in well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 23-24, 2004.

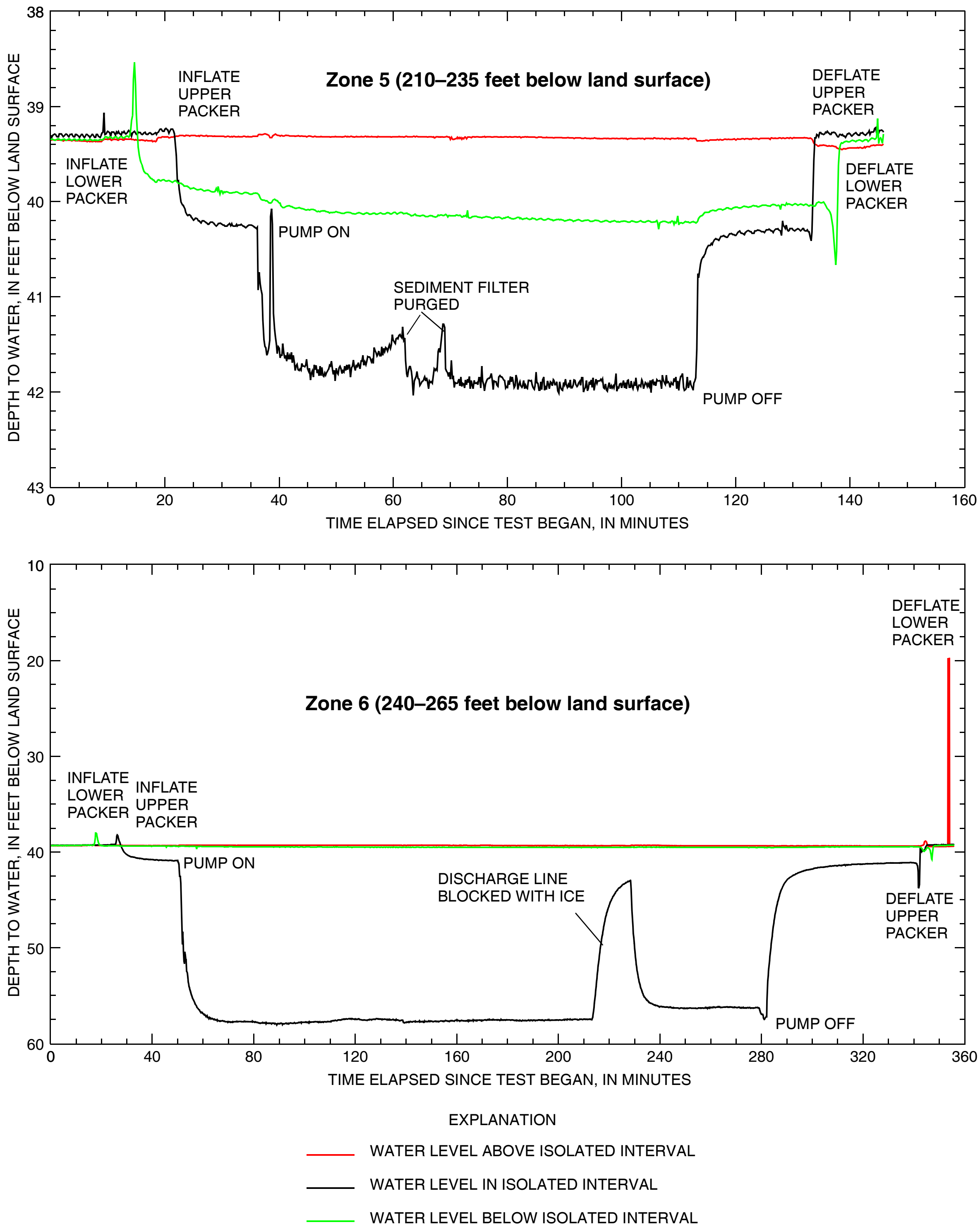


Figure 3-47. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (210–235 feet below land surface) and zone 6 (240–265 feet below land surface) in well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 24-25, 2004.

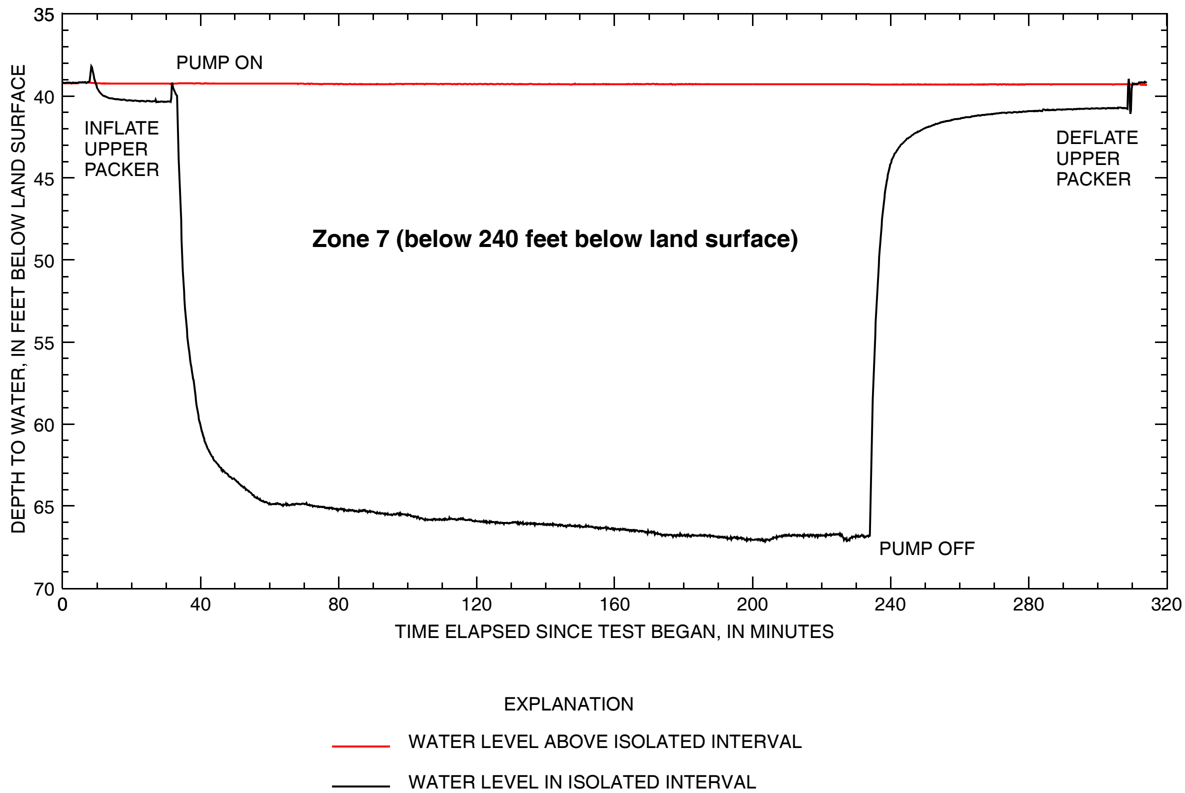
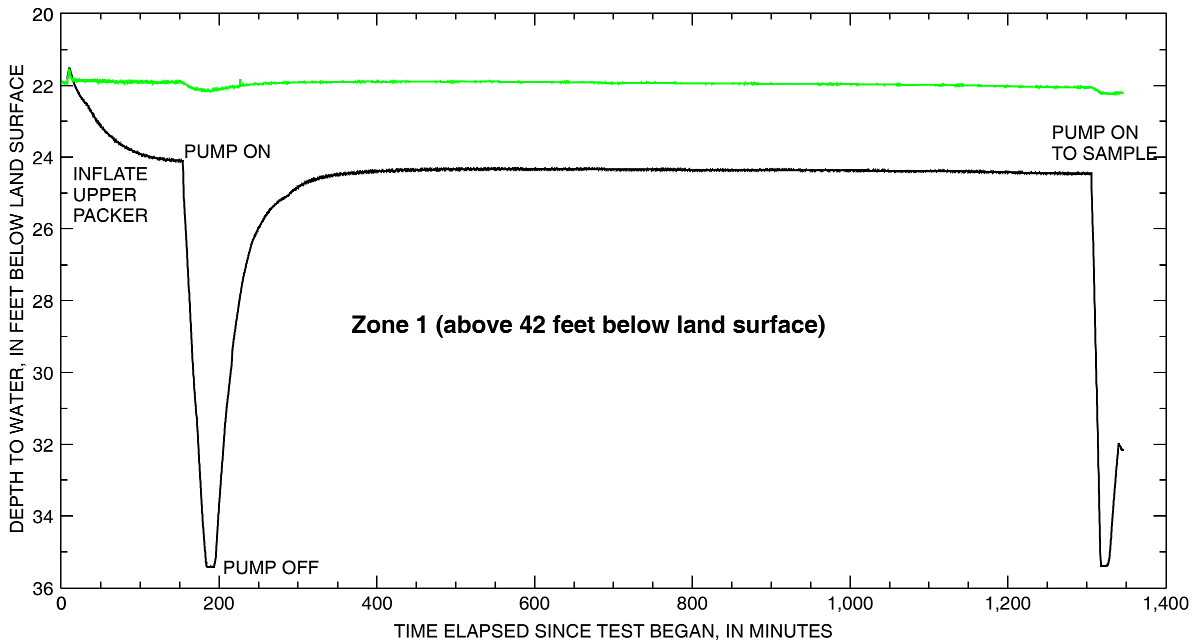
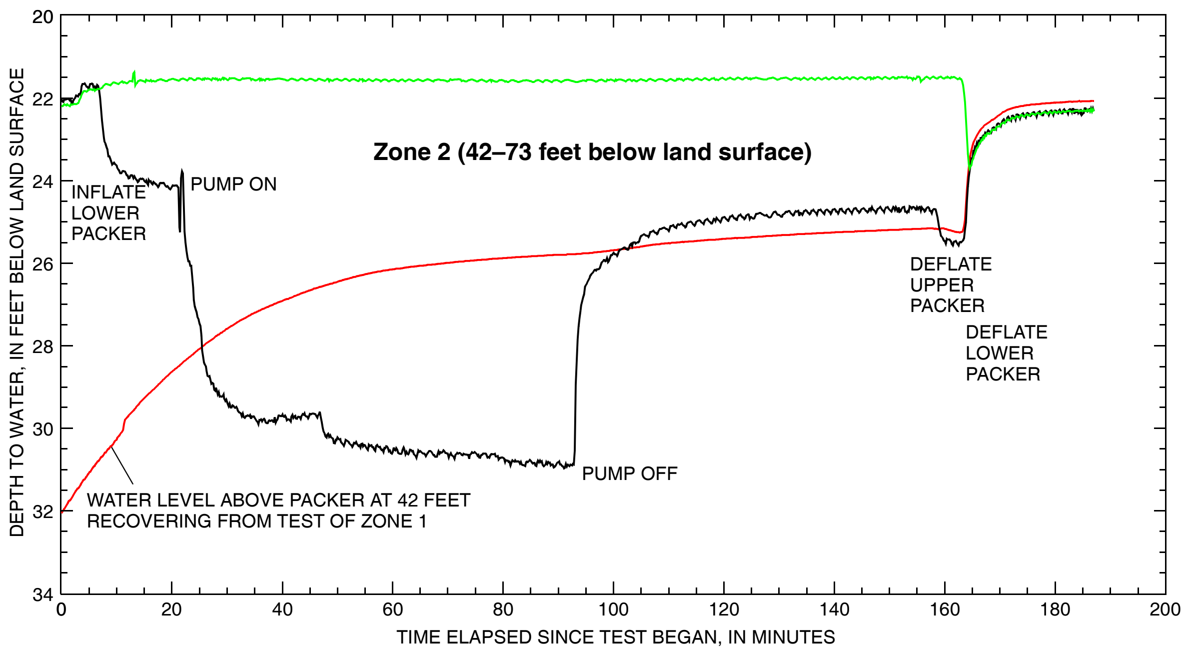


Figure 3-48. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated interval zone 7 (below 240 feet below land surface) in well MG-2119 (RI-10D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., March 25, 2004.





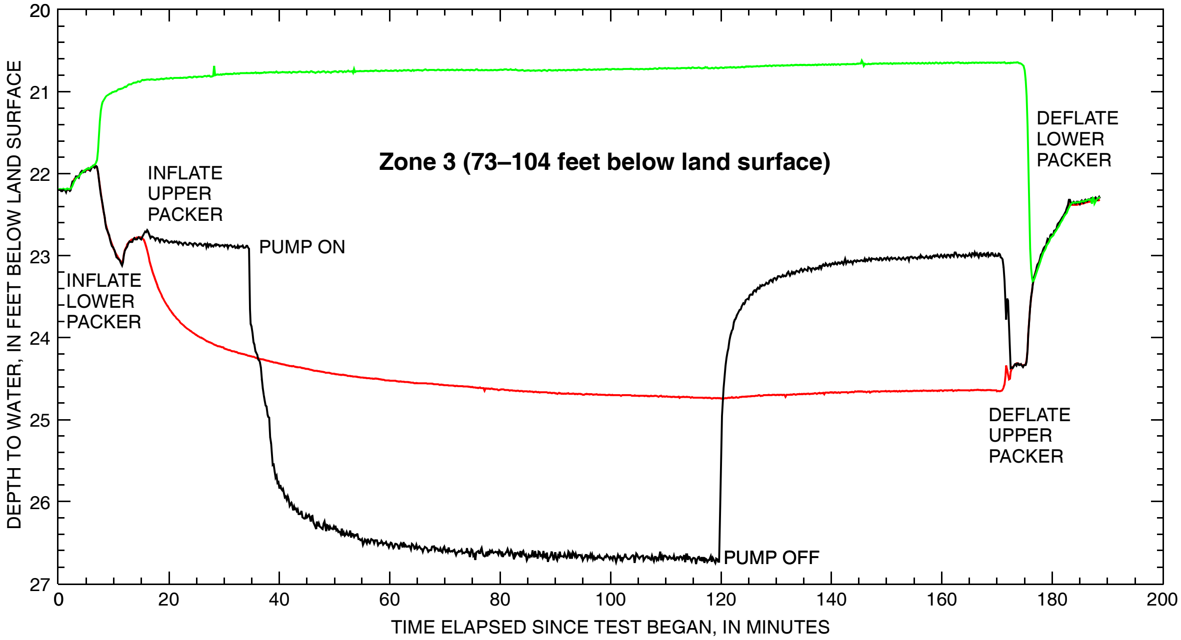
EXPLANATION

WATER LEVEL ABOVE ISOLATED INTERVAL

WATER LEVEL IN ISOLATED INTERVAL

WATER LEVEL BELOW ISOLATED INTERVAL

Fiugre 3-49. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 42 feet below land surface) and zone 2 (42–73 feet below land surface) in well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 8-9, 2004.



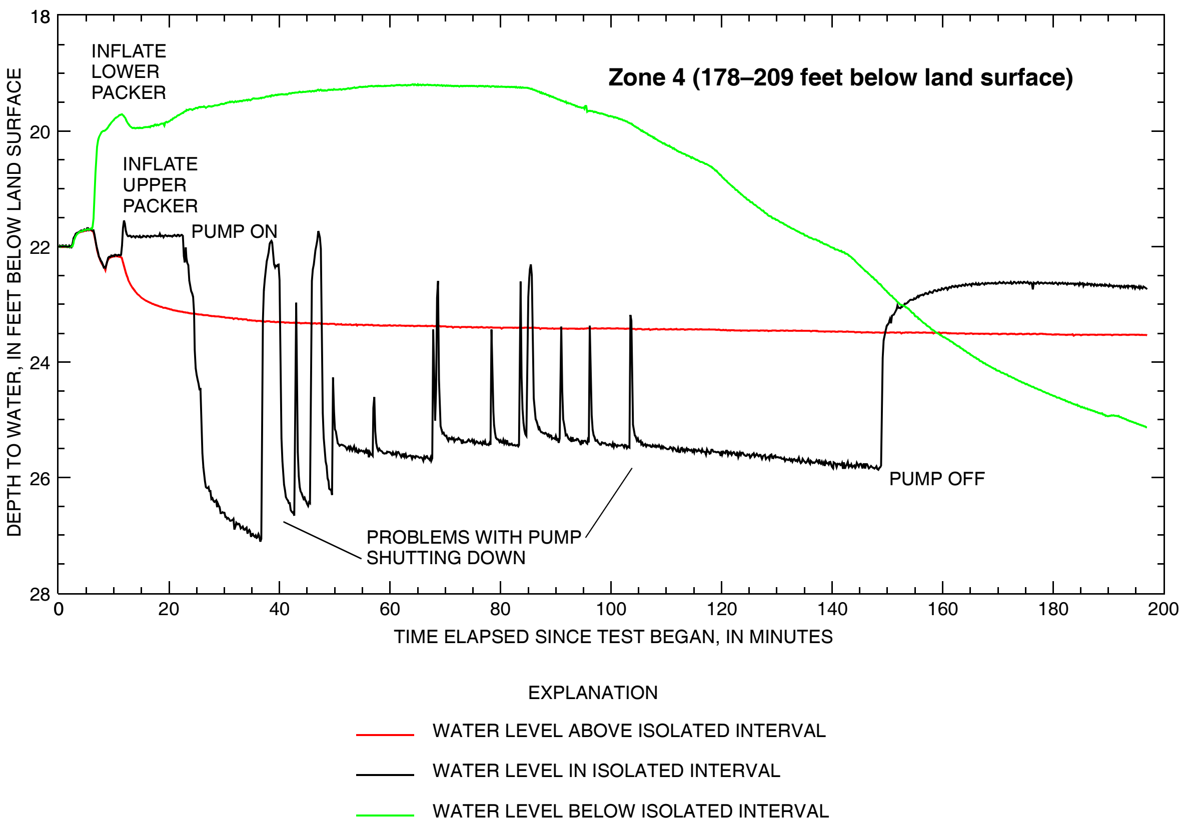


Figure 3-50. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (73–104 feet below land surface) and zone 4 (178–209 feet below land surface) in well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 9 and 13, 2004.

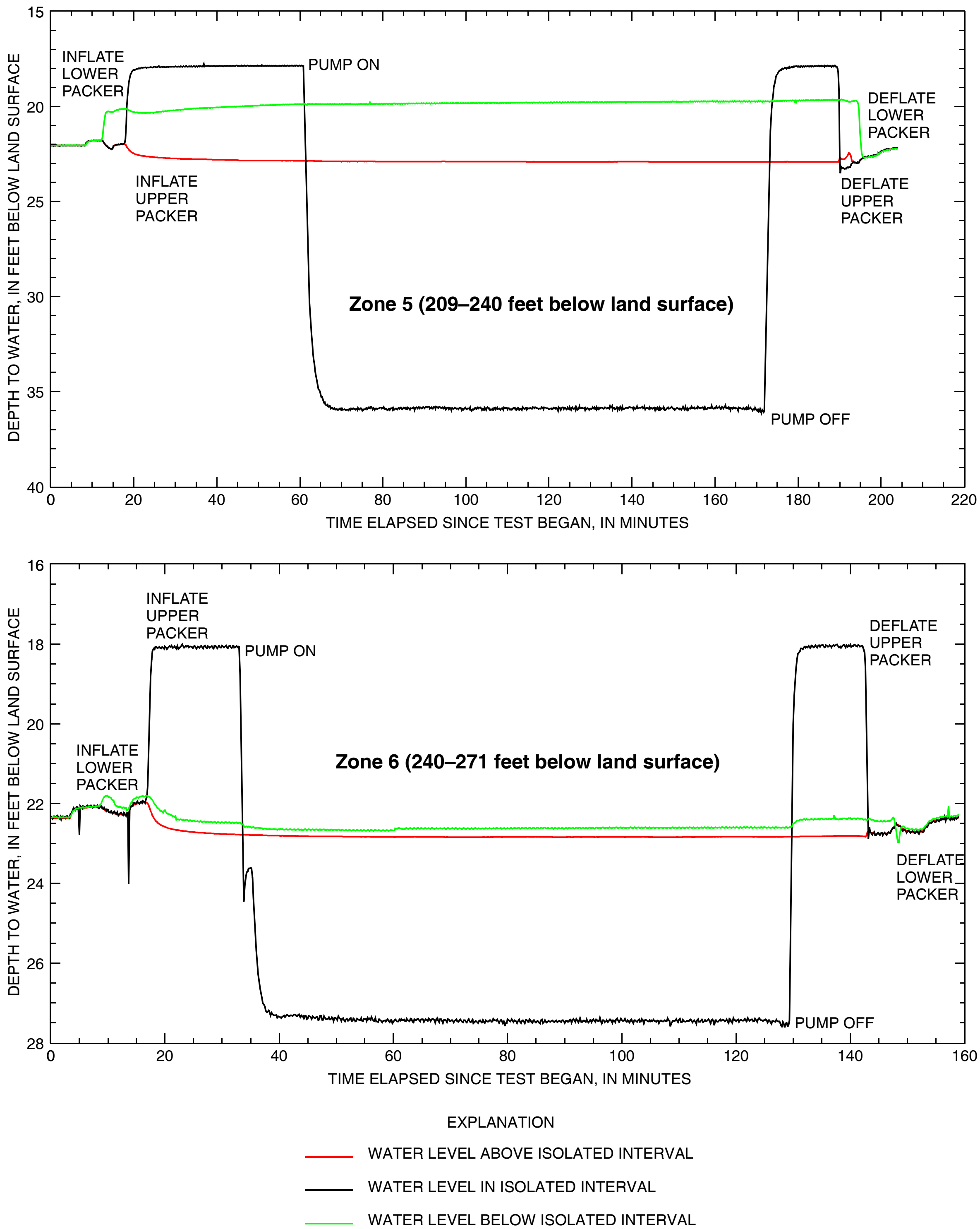


Figure 3-51. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (209–240 feet below land surface) and zone 6 (240–271 feet below land surface) in well MG-2122 (RI-11D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., July 12, 2004.

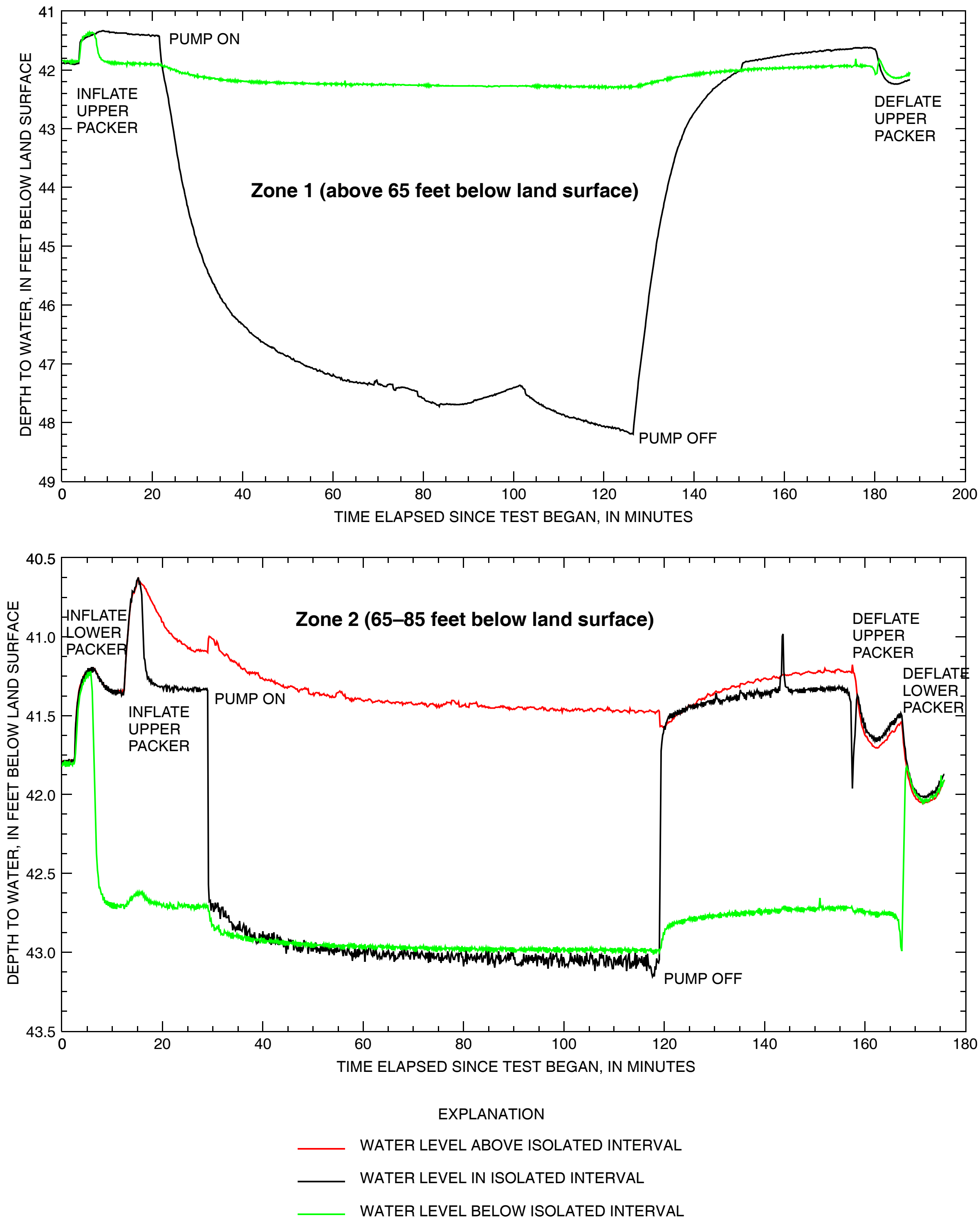


Figure 3-52. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 42 feet below land surface) and zone 2 (42–73 feet below land surface) in well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 6, 2004.

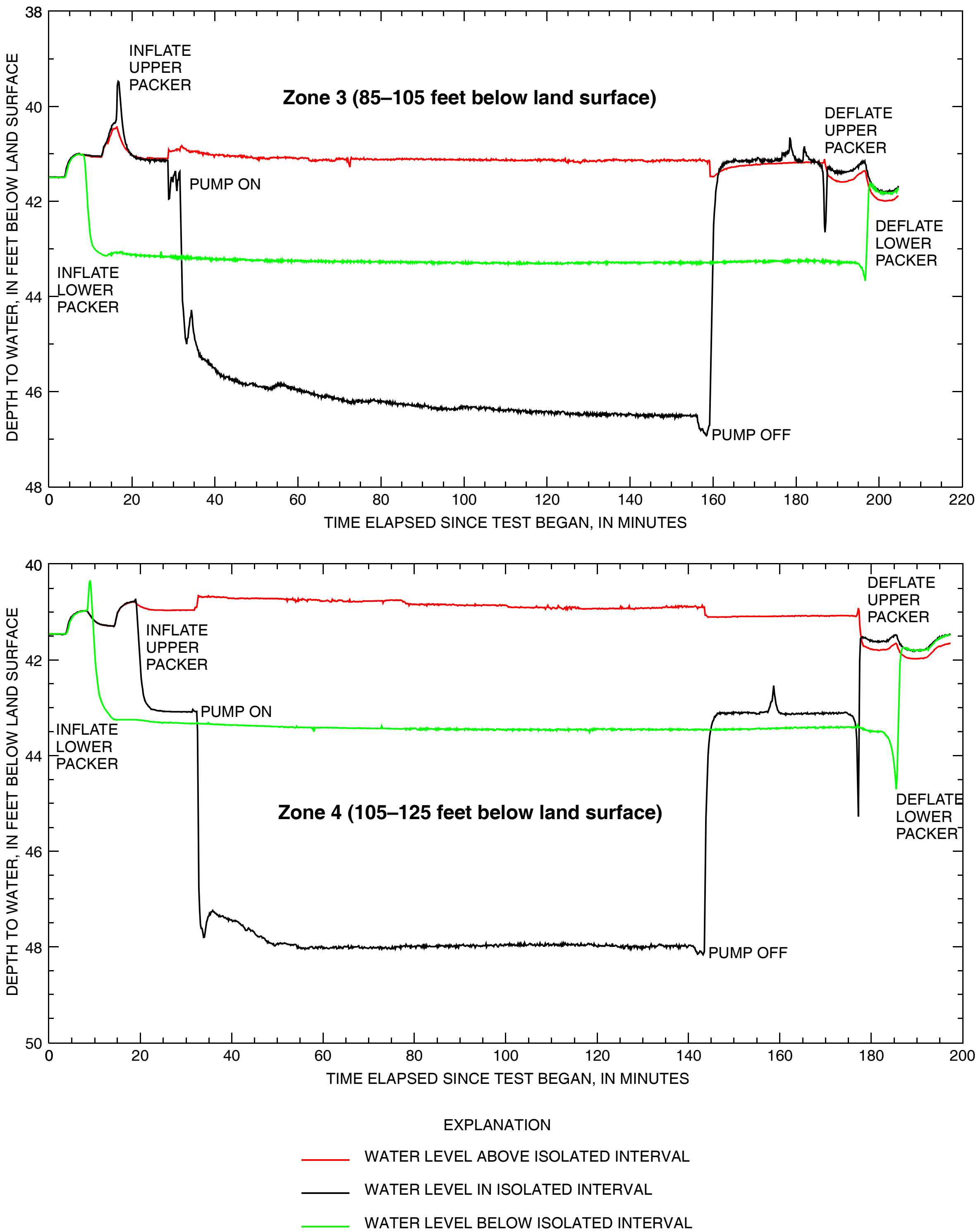


Figure 3-53. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (85–105 feet below land surface) and zone 4 (105–125 feet below land surface) in well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 7, 2004.

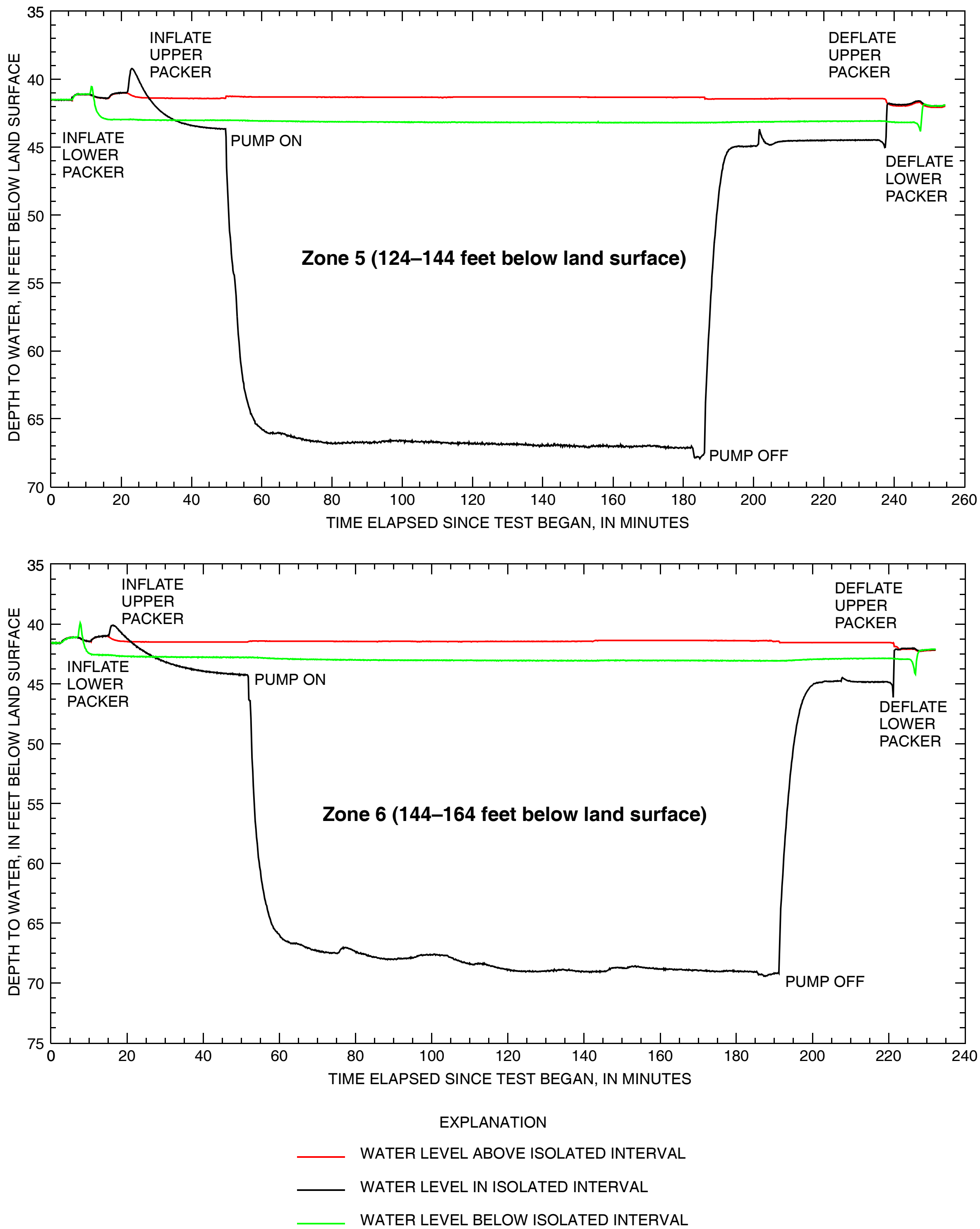


Figure 3-54. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (124–144 feet below land surface) and zone 6 (144–164 feet below land surface) in well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 8, 2004.

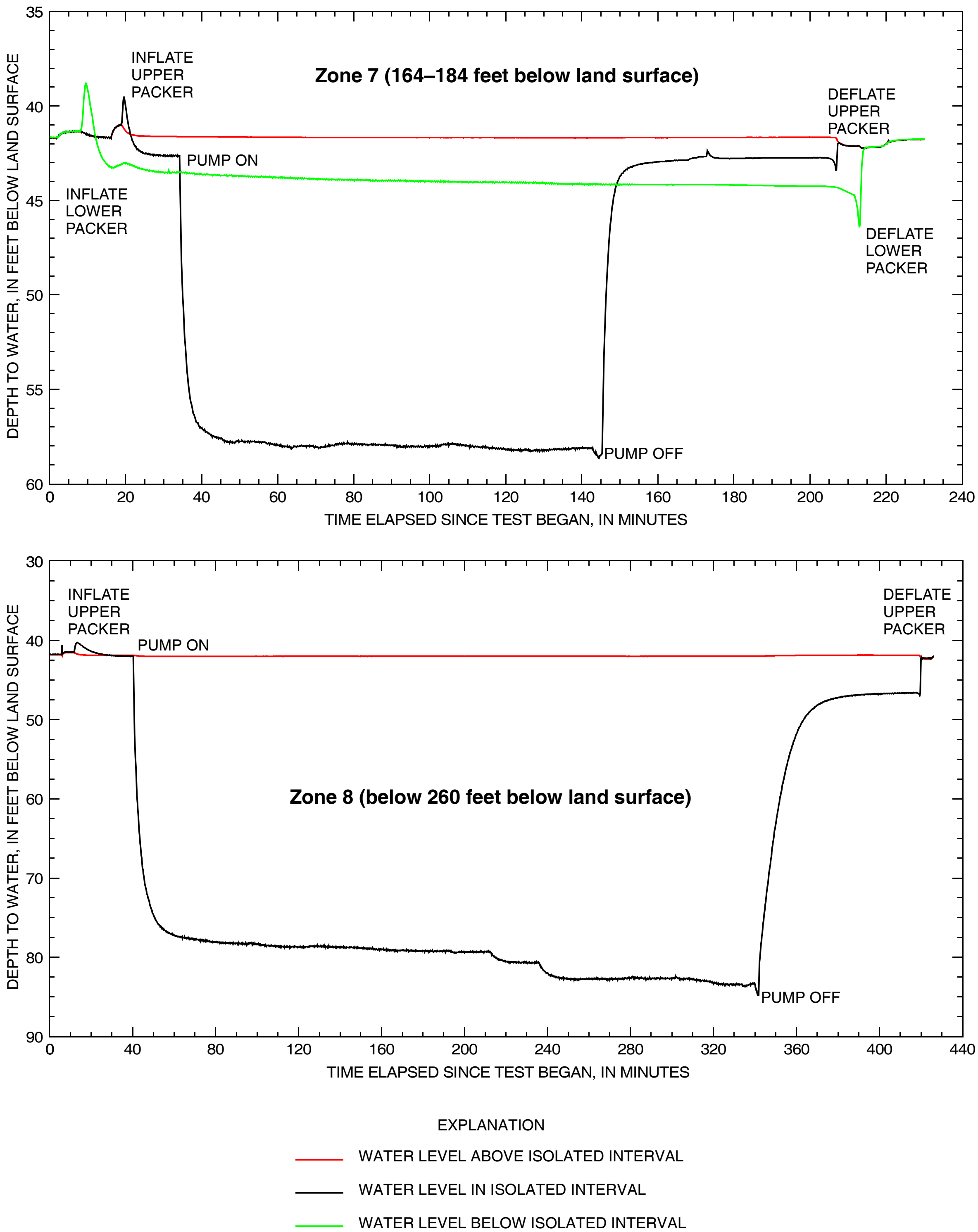


Figure 3-55. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 7 (164–184 feet below land surface) and zone 8 (below 260 feet below land surface) in well MG-2125 (RI-12D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., April 9 and 12, 2004.

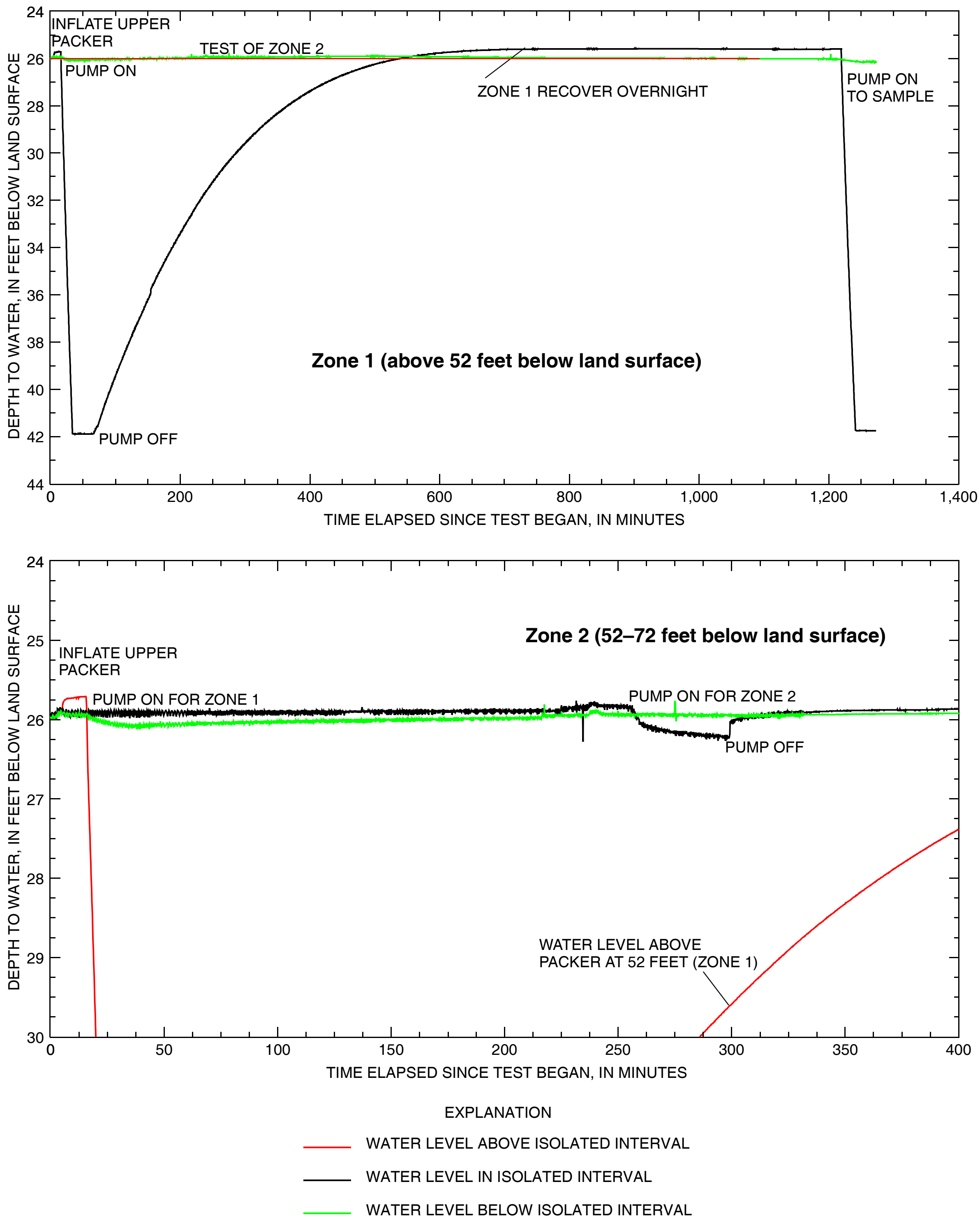


Figure 3-56. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 42 feet below land surface) and zone 2 (42–73 feet below land surface) in well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 7-8, 2004. Test of zone 2 occurred while water levels in zone 1 were recovering.

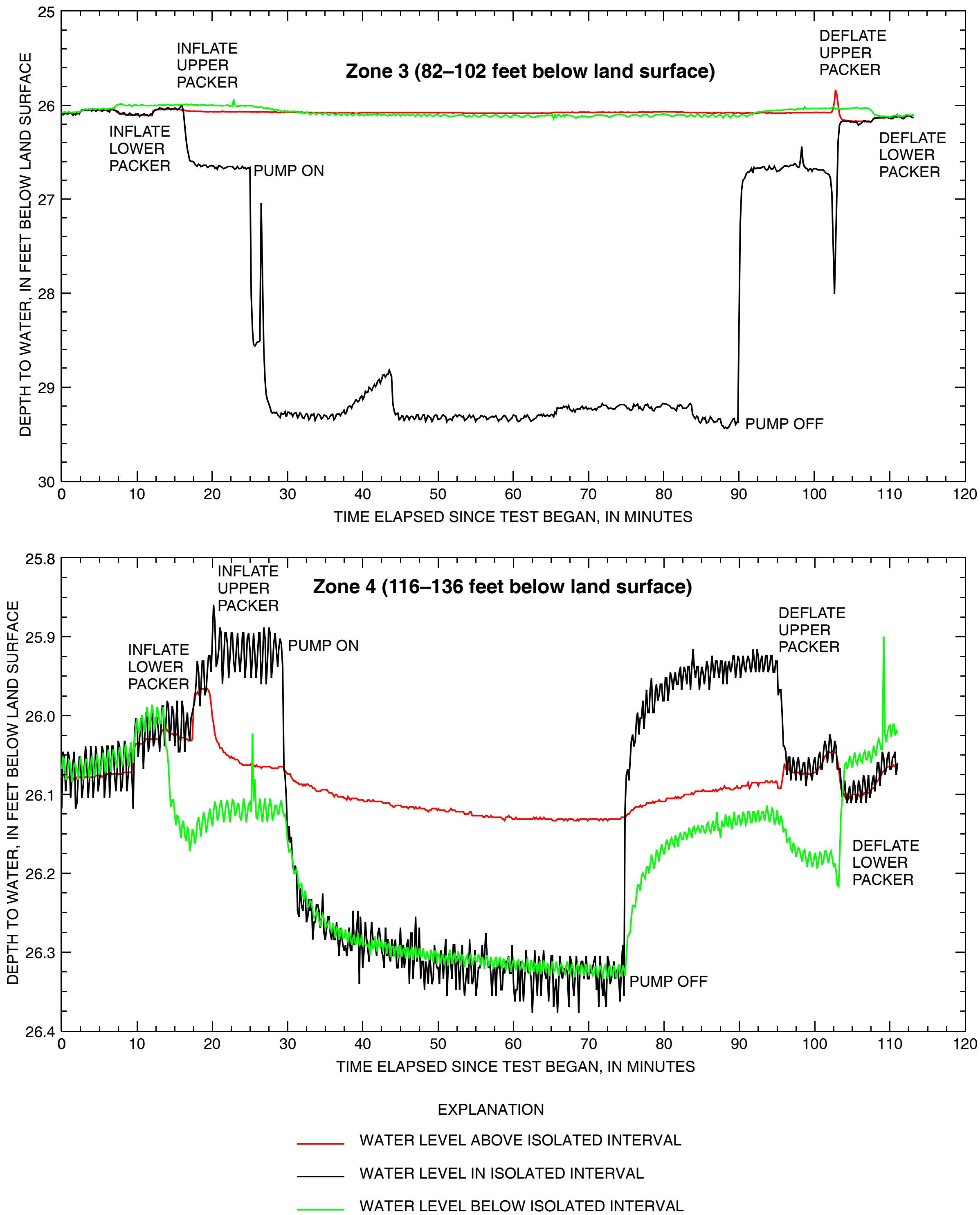


Figure 3-57. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (82–102 feet below land surface) and zone 4 (116–136 feet below land surface) in well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 8, 2004.

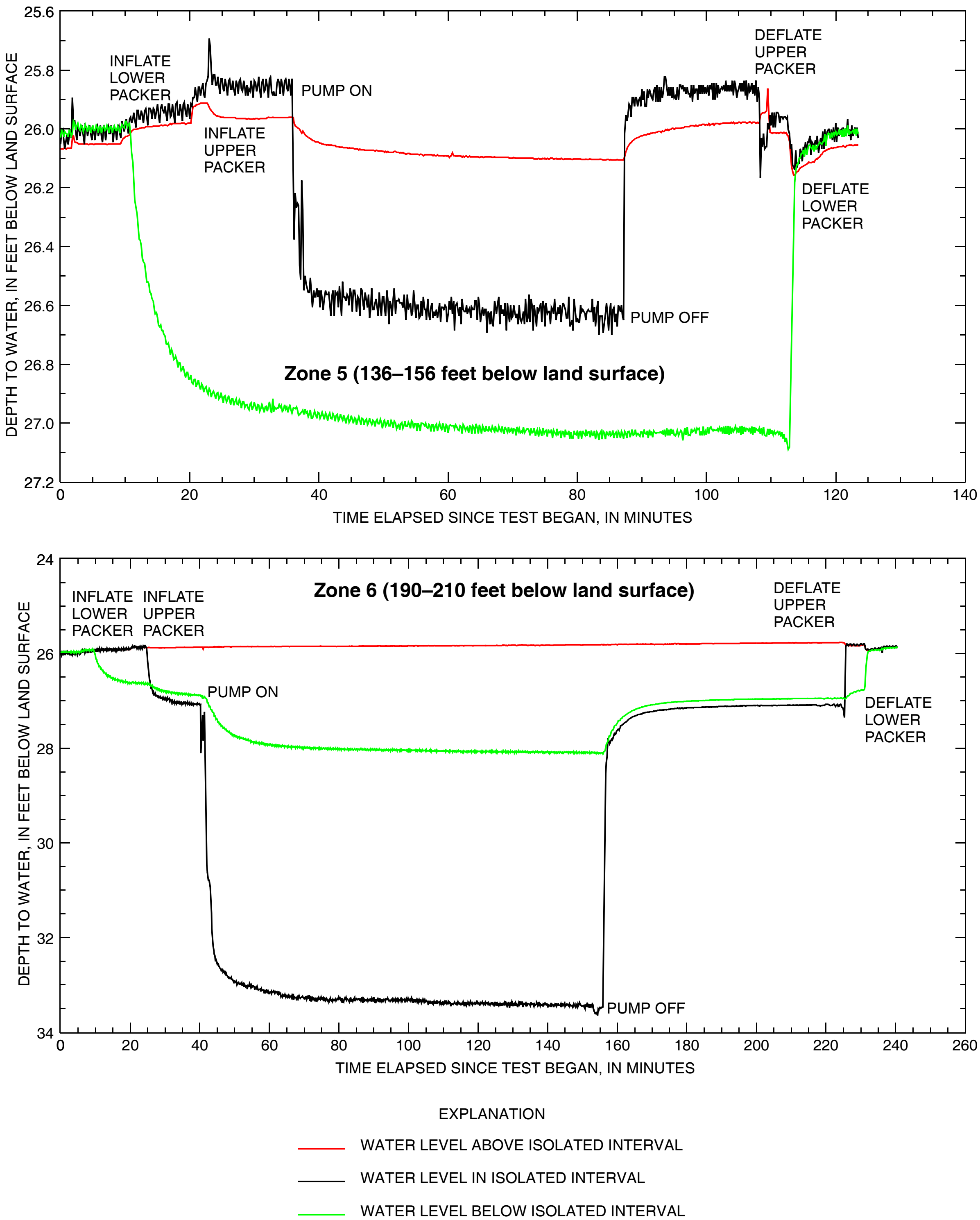


Figure 3-58. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (136–156 feet below land surface) and zone 6 (190–210 feet below land surface) in well MG-2126 (RI-13D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 8-9, 2004.

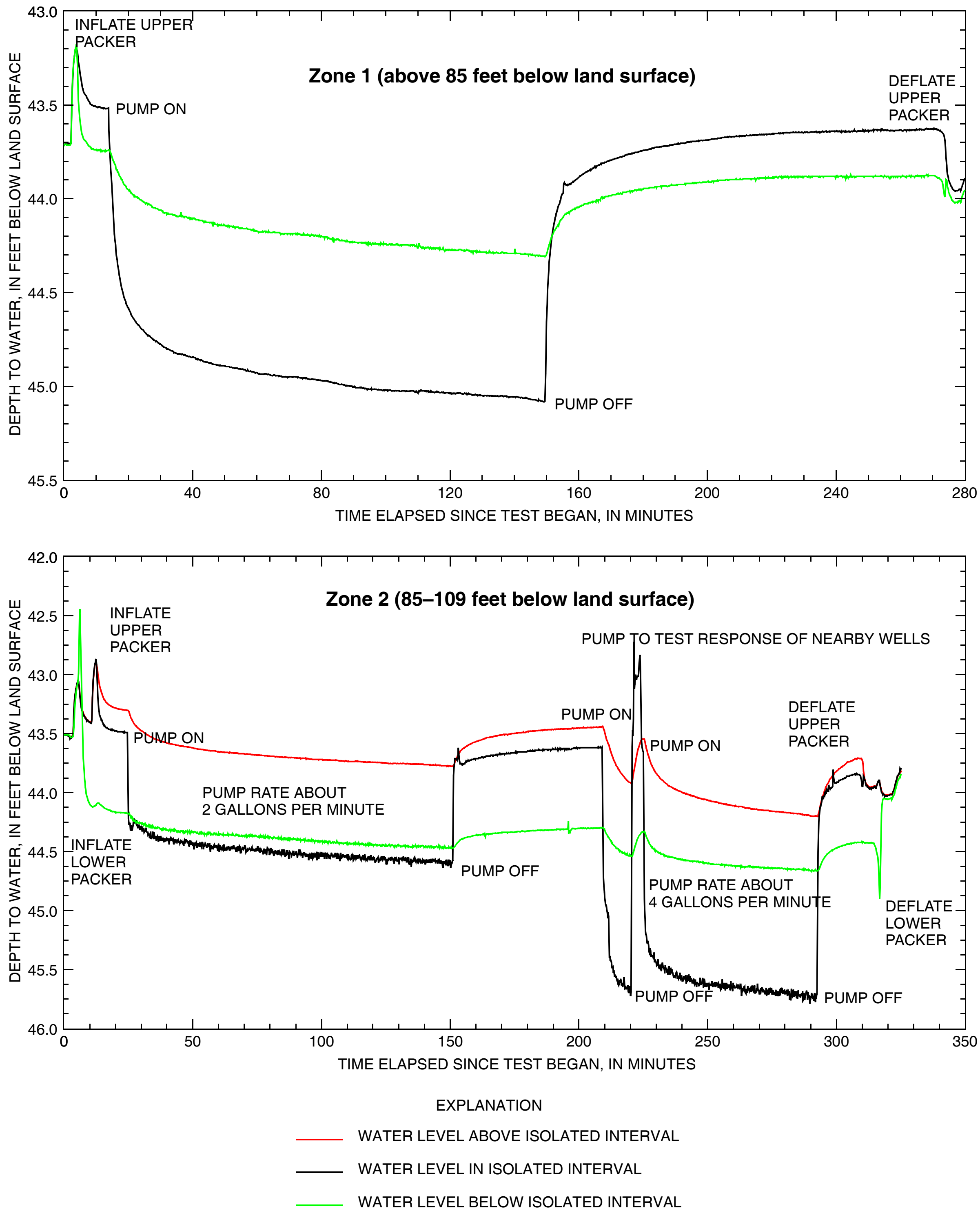


Figure 3-59. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 85 feet below land surface) and zone 2 (85–109 feet below land surface) in well MG-2129 (RI-14D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 15-16, 2005. Test of zone 2 occurred while water levels in zone 1 were recovering.

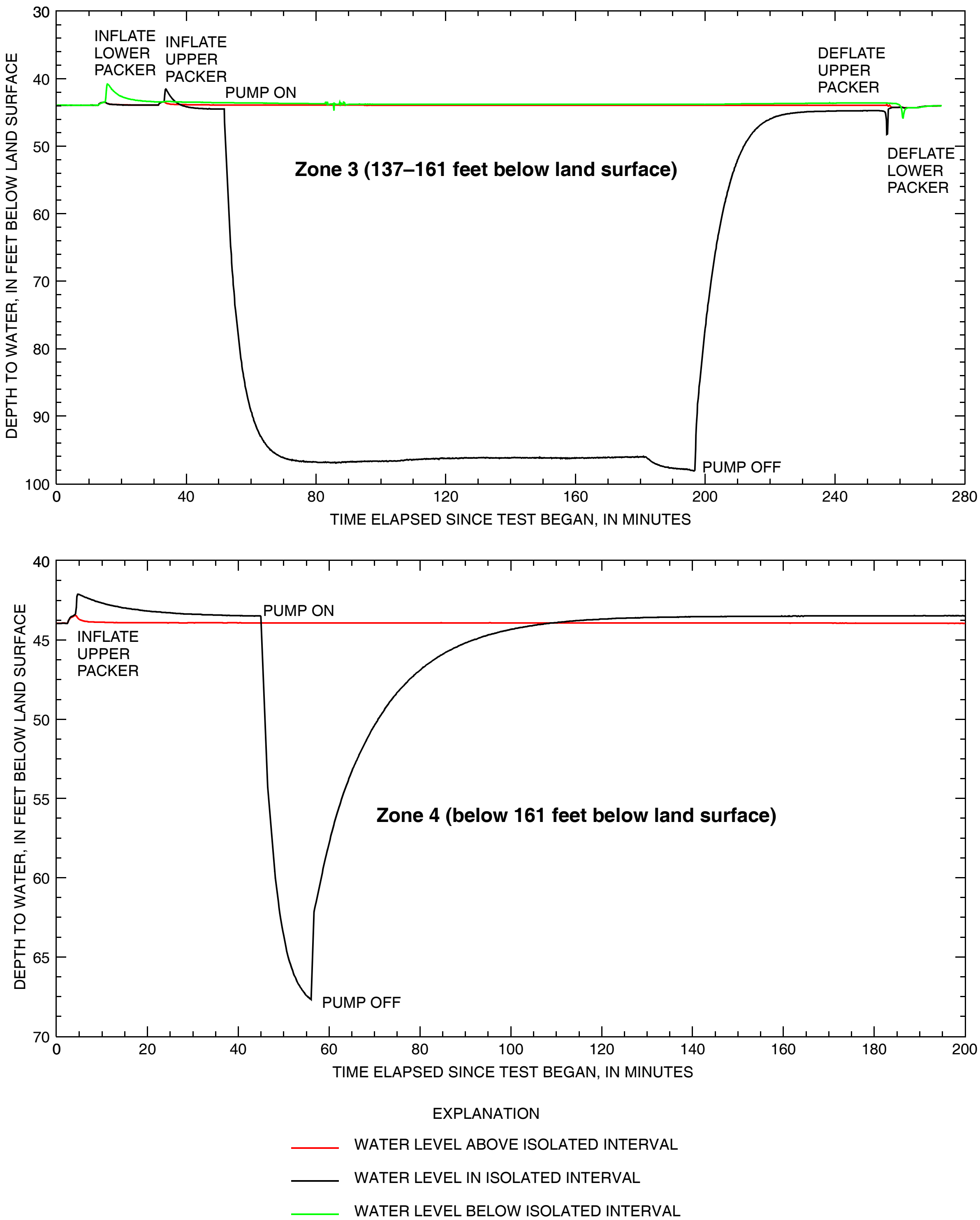


Figure 3-60. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (137–161 feet below land surface) and zone 4 (below 161 feet below land surface) in well MG-2129 (RI-14D), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 17, 2005.

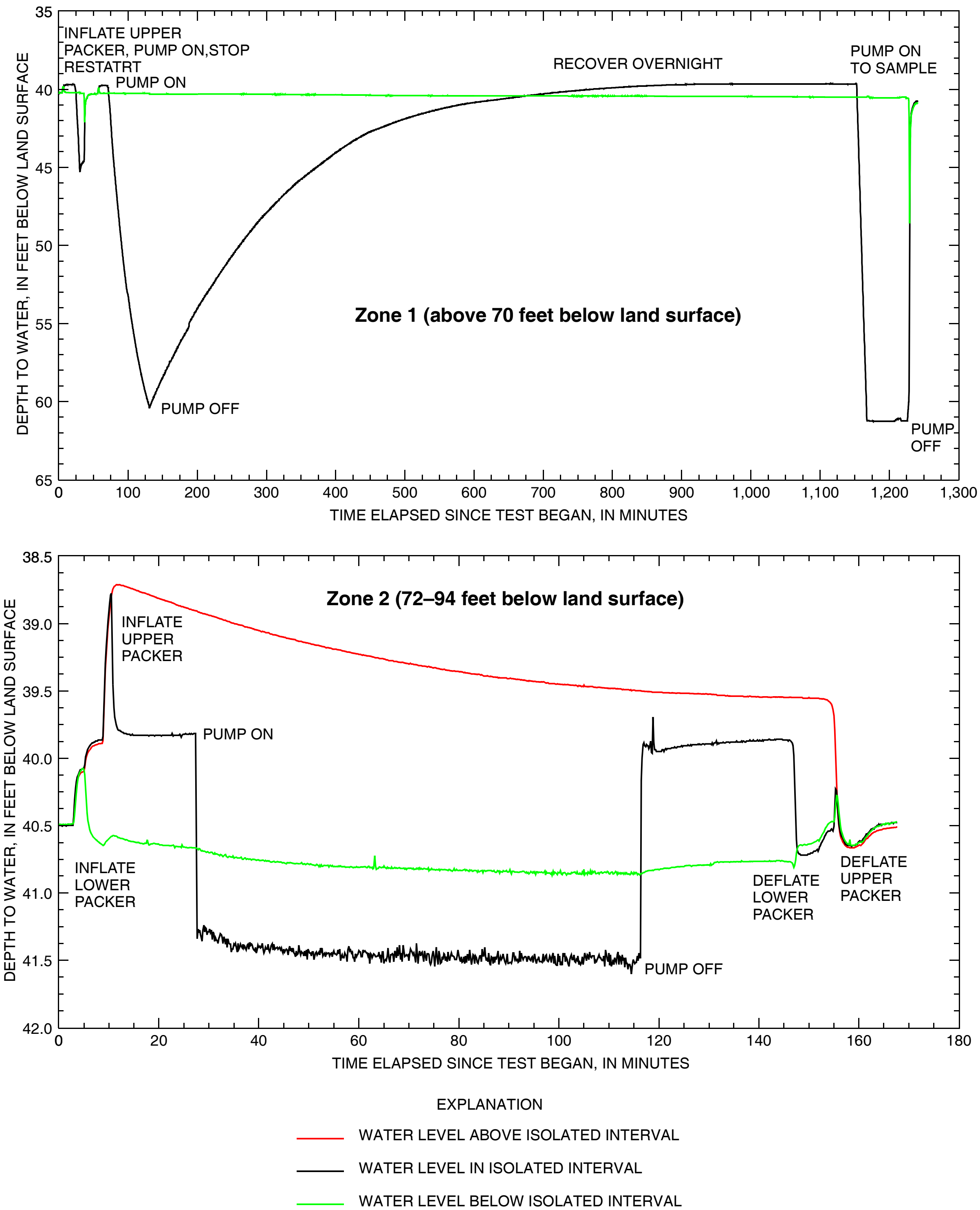


Figure 3-61. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 1 (above 70 feet below land surface) and zone 2 (72–94 feet below land surface) in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 8-9, 2005. Test of zone 2 occurred while water levels in zone 1 were recovering.

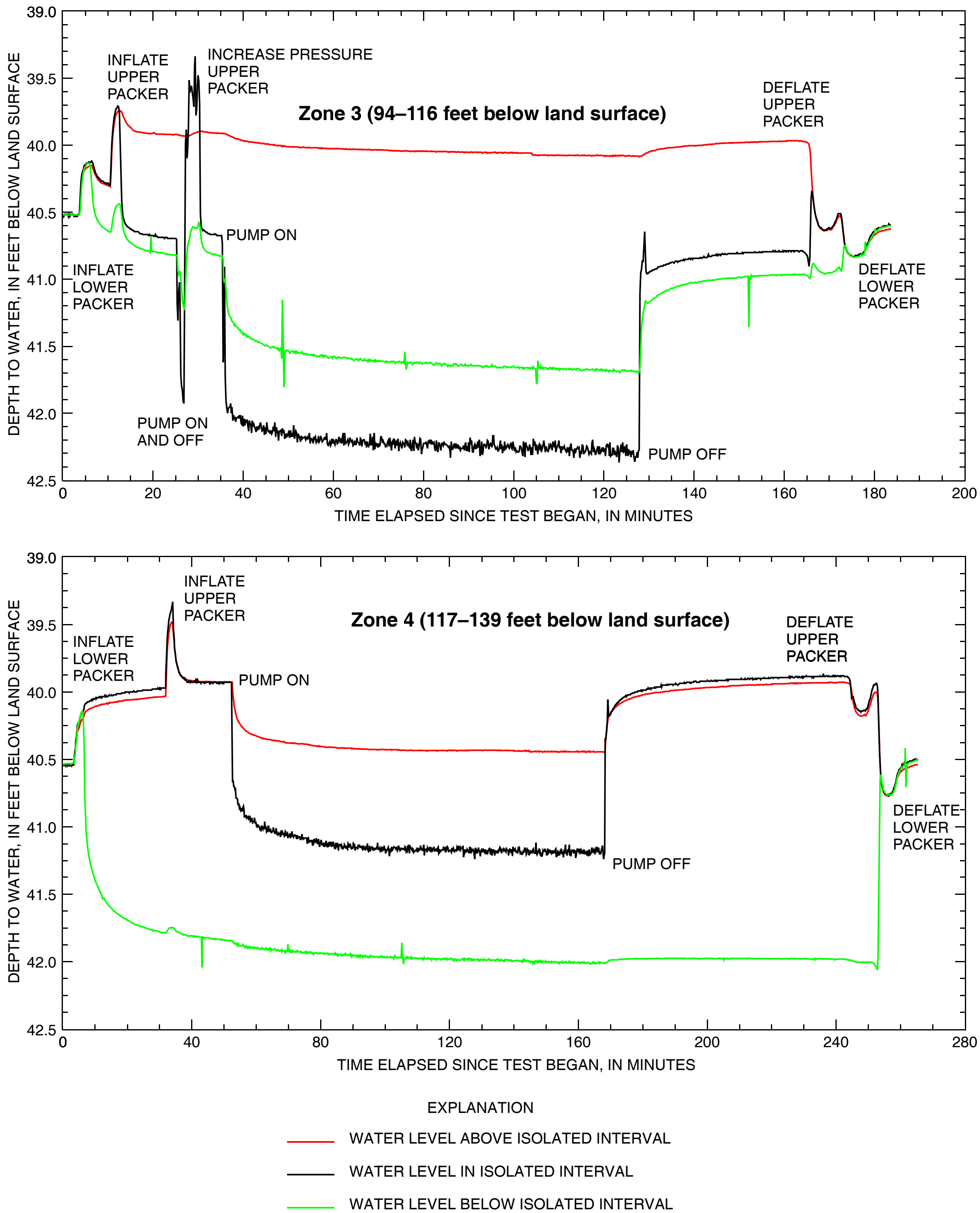


Figure 3-62. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 3 (94–116 feet below land surface) and zone 4 (117–139 feet below land surface) in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 9-10, 2005.

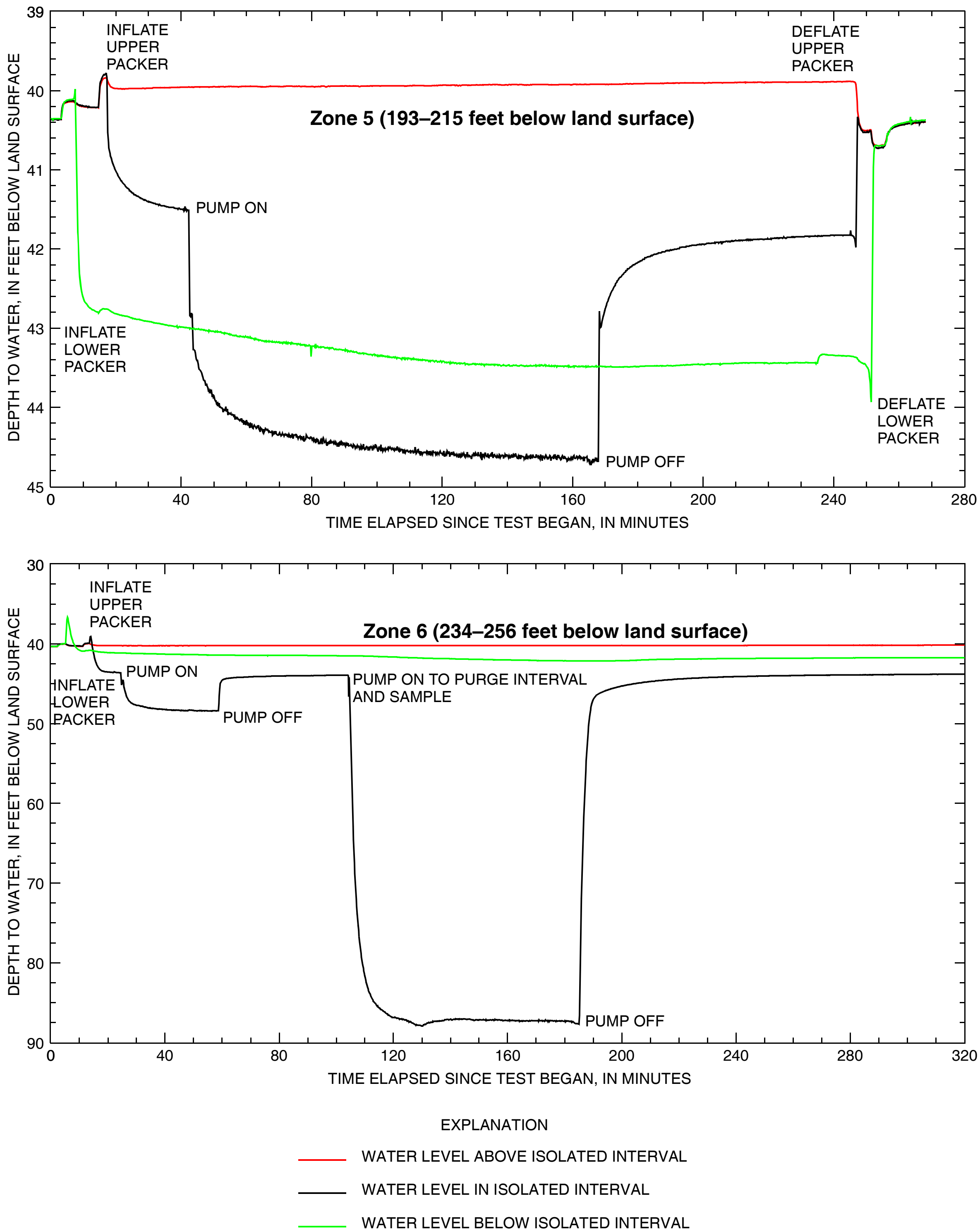


Figure 3-63. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated intervals zone 5 (193–215 feet below land surface) and zone 6 (234–256 feet below land surface) in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 10 and 13, 2005.

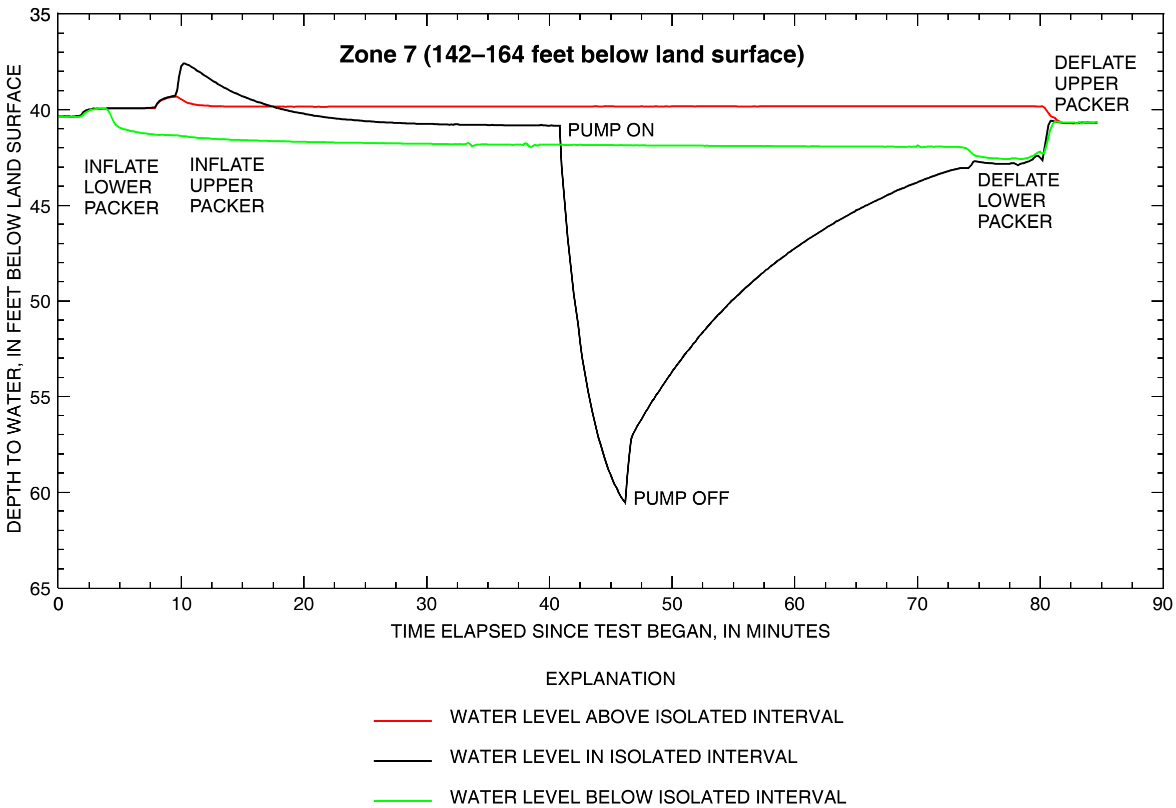


Figure 3-64. Depth to water above isolated interval, in isolated interval, and below isolated interval before, during, and after pumping for tests of isolated interval zone 7 (142–164 feet below land surface) in well MG-2131 (RI-15DD), North Penn Area 7, Upper Gwynedd Township, Montgomery County, Pa., June 15, 2005.

USGS

Senior and others— **Geophysical Logs, Aquifer Tests, and Water Levels in Wells, North Penn Area 7 Superfund Site, 2002-2006**—Scientific Investigations Report 2008–5154