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

Evaluation of Borehole Geophysical Logs and Hydraulic Tests, Phase III, at AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania

by Ronald A. Sloto

Water-Resources Investigations Report 01-4004

Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY

New Cumberland, Pennsylvania
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information
write to:

District Chief
U.S. Geological Survey
215 Limekiln Road
New Cumberland, Pennsylvania 17070-2424

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, Colorado 80225-0286

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS—Continued

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	LENGTH	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	0.4047	hectare
	VOLUME	
gallon (gal)	3.785	liter
	FLOW	
gallon per minute (gal / min)	0.06309	liter per second
	SPECIFIC CAPACITY	
gallon per minute per foot [(gal / min) / ft]	0.2070	liter per second per meter

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS AND HYDRAULIC TESTS, PHASE III, AT AIW FRANK/MID-COUNTY MUSTANG SUPERFUND SITE, CHESTER COUNTY, PENNSYLVANIA

By Ronald A. Sloto

ABSTRACT

Borehole geophysical logs, heatpulse-flowmeter measurements, and aquifer-isolation tests were used to characterize the ground-water-flow system at the AIW Frank/Mid-County Mustang Superfund Site. The site is underlain by fractured carbonate rocks. Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs were run in six wells, and an acoustic borehole televiewer and borehole deviation log was run in one well. The direction and rate of borehole-fluid movement was measured with a high-resolution heatpulse flowmeter for both nonpumping and pumping conditions in four wells. The heatpulse-flowmeter measurements showed flow within the borehole during nonpumping conditions in three of the four wells tested. Flow rates up to 1.4 gallons per minute were measured. Flow was upward in one well and both upward and downward in two wells. Aquifer-isolation (packer) tests were conducted in four wells to determine depth-discrete specific capacity values, to obtain depth-discrete water samples, and to determine the effect of pumping an individual fracture or fracture zone in one well on water levels in nearby wells. Water-level data collected during aquifer-isolation tests were consistent with and confirmed interpretations of borehole geophysical logs and heatpulse-flowmeter measurements. Seven of the 13 fractures identified as water-producing or water-receiving zones by borehole geophysical methods produced water at a rate equal to or greater than 7.5 gallons per minute when isolated and pumped. The specific capacities of isolated fractures range over three orders of magnitude, from 0.005 to 7.1 gallons per minute per foot. Vertical distribution of specific capacity between land surface and 298 feet below land surface is not related to depth. The four highest specific capacities, in descending order, are at depths of 174-198, 90-92, 118-119, and 34-37 feet below land surface.

INTRODUCTION

The AIW Frank / Mid County Mustang Superfund Site is in West Whiteland Township, Chester County, Pa., on U.S. Route 30 (fig. 1). The 15-acre site consists of two adjoining properties. The AIW Frank Property is at 717 East Lincoln Highway (Route 30) and the Mid-County Mustang property (currently Rex Carle Automotive) is at 891 East Lincoln Highway (Halliburton NUS, 1991).

The AIW Frank Corporation occupied a small facility used to manufacture styrofoam products and commercial refrigeration units. The site is no longer active. The AIW Frank Corporation first leased the property in 1962 and purchased the property in 1975. AIW Frank operated the facility as a styrofoam products manufacturing plant from 1962 until declaring bankruptcy in 1981. AIW Frank reportedly used trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) to clean equipment. After bankruptcy, the site was bought and operated by Continental Refrigerator Corporation (CRC). From 1983 to about 1988, CRC manufactured refrigerators, freezers, and warming cabinets for the food-service industry. The front building (no longer existing) was used for manufacturing by AIW Frank and as an office by CRC. The rear building was used for warehousing by AIW Frank and for manufacturing by CRC. Solvents may have been used by CRC to clean metal components of the refrigeration units (Halliburton NUS, 1991).

The U.S. Environmental Protection Agency (USEPA) requested the U.S. Geological Survey (USGS) provide technical assistance to the hydrological investigation being conducted at the AIW Frank / Mid-County Mustang Superfund Site. The USGS conducted borehole geophysical logging, aquifer tests, and aquifer-isolation tests as part of that investigation.

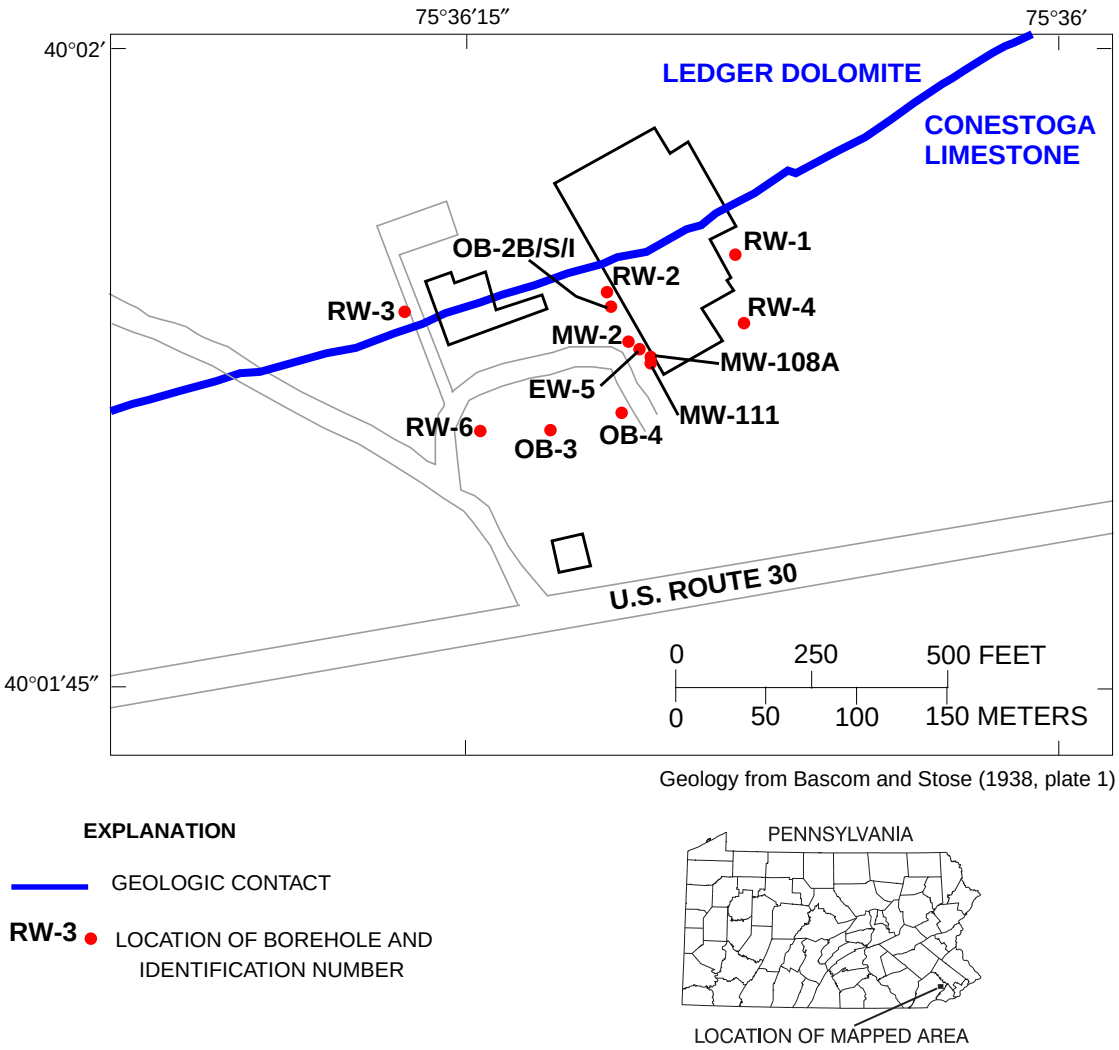


Figure 1. Location of the boreholes where geophysical logging and aquifer-isolation tests were conducted, AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Purpose and Scope

This report provides an interpretation of borehole geophysical logs and heatpulse-flowmeter measurements for six boreholes and provides drawdowns and specific capacities for isolated fracture zones in four boreholes. The USGS collected the data presented here between May 1999 and May 2000 and prepared this report as part of the environmental hydrogeological investigations conducted at the AIW Frank / Mid County Mustang Superfund Site in cooperation with the USEPA. A cross-reference between USGS borehole-identification numbers and site borehole-identification numbers are given in table 1.

Hydrogeological Setting and Physiography

The AIW Frank / Mid-County Mustang Superfund Site is in the Piedmont Physiographic Province and is underlain by the Ordovician-age Conestoga Limestone and Cambrian-age Ledger Dolomite (fig. 1). The Ledger Dolomite is a white to light gray, massive to thick-bedded, granular, rather pure dolomite with a high magnesium content. The dolomite is interbedded with some siliceous beds and laminated limestone. The Ledger contains a few beds of marble with a high calcium content (Sloto, 1994). The map of Bascom and Stose (1938, plate 1) shows that the Ledger strikes N. 74° E. with a near vertical dip to the west of the site and strikes N. 68° E. with a dip of 60° to the southeast

Table 1. *Boreholes logged at the AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[--, no data; L, logged depth]

U.S. Geological Survey borehole-identification number	Site borehole-identification number	Length of casing below land surface (feet)	Casing diameter (inches)	Depth logged or drilled (feet below land surface)	Depth to water (feet below land surface)	Date measured
CH-5040	EW-5	63	9	298 L	23.56	6-30-1999
CH-5804	RW-1	40	8.5	297 L	--	--
CH-5805	RW-2	30	8.5	184 L	21.40	3-14-2000
CH-5806	RW-3	72	8.5	197 L	23.83	5-9-2000
CH-5807	RW-4	18	8.5	298 L	--	--
CH-5808	RW-6	67	8.5	248 L	11.45	5-1-2000
CH-5981	OB2-S	--	2	58	25.85	6-29-1999
CH-5982	OB2-I	--	2	86	25.72	6-29-1999
CH-5983	OB-3	--	--	--	8.47	5-1-2000
CH-5984	OB-4	--	--	--	10.79	5-1-2000
CH-5447	OB-5	21.5	6	38 L	--	--
CH-5985	MW-2	23	2	44	22.27	6-29-1999
CH-4160	MW-108A	64	6.5	192 L	22.62	6-29-1999
CH-5670	MW-111	72	2	116	22.16	6-29-1999

to the east of the site. In previous work at the site, Conger and others (2000) used borehole television surveys to measure bedding planes at the site striking east-west and dipping 76° S. The Ledger is 660 to 1,000 ft thick.

The Conestoga Limestone is a blue-gray, thin-bedded, argillaceous limestone with intervals of a purer, granular limestone. Mica coats most of the bedding and cleavage planes. The impure part of the Conestoga has thin-bedded alterations of dark gray, clayey, silty, slaty, micaceous layers and medium gray, argillaceous limestone that imparts a characteristic banded appearance to the rock. Some of the basal beds are a coarse limestone conglomerate containing large pebbles and irregular masses of coarse white marble in a gray limestone (Sloto, 1994). The map of Bascom and Stose (1938, plate 1) shows that the Conestoga strikes N. 74°E. with a dip of 85° to the southeast to the southeast of the site.The Conestoga Limestone is 500 to 800 ft thick (Sloto, 1994). The Ledger and Conestoga are in fault contact.

Ground water in carbonate rocks flows through a network of secondary openings enlarged by solution. Some fractures enlarged by solution are several feet wide; however, most are only a fraction of an inch wide, but they may be capable of transmitting large quantities of water. Solution is the primary weathering process in carbonate rock. Permeability is predominately the result of solution-enlarged fractures. Where solution has been active, permeability may be high; elsewhere, the same unit may be nearly impermeable. Solution generally is most active above and within the zone of water-table fluctuation where water movement is relatively rapid and recharge water is acidic. Below the zone of water-table fluctuation, water movement is slower, and acidic water from recharge is neutralized. Clay and other unconsolidated material sometimes move downward from the surface, plugging openings. This plugging results in decreased well yields and turbid ground-water discharge from some wells. The depth of weathering in carbonate rocks is highly variable. Deeply weathered zones can be found adjacent to outcrops. The carbonate rocks in Chester County commonly exhibit pinnacle weathering. Pinnacle weathering is caused by solution along bedding planes and fractures in dipping strata. As solution enlargement moves downward in the formation, the solid rock between the weathered areas is left as pinnacles (Sloto, 1994).

Acknowledgments

Borehole geophysical logging was done by Randall Conger, Kim Moyer, and Philip Bird of the Pennsylvania District. Kevin Grazul, Abdul Mohammad, and Leif Olson of the USGS Pennsylvania District and Robert Rosman, Nicholas Smith, and Timothy Oden of the USGS New Jersey District performed the aquifer-isolation (packer) tests. Their assistance is greatly appreciated.

METHODS OF INVESTIGATION

Borehole Geophysical Methods

Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs were collected in six wells. An acoustic borehole televiewer and borehole deviation log were collected in well RW-2. The logs were used to locate water-bearing fractures, determine probable zones of vertical borehole-fluid movement, and determine the depth to set packers.

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

Natural-gamma logs, also called gamma-ray logs, record the natural-gamma radiation emitted from rocks penetrated by the borehole. Gamma radiation can be measured through casing, but the gamma response is dampened. Uranium-238, thorium-232, and the progeny of their decay series and potassium-40 are the most common emitters of natural-gamma radiation.

Single-point-resistance logs record the electrical resistance between the borehole and an electrical ground at land surface. In general, resistance increases with grain size and decreases with borehole diameter, density of water-bearing fractures, and increasing dissolved-solids concentration of borehole fluid (Keys, 1990). A fluid-filled borehole is required for single-point-resistance logs, and they are collected only for the saturated part of the formation below the casing. Single-point-resistance logs sometimes help to identify the location of water-bearing zones because a fluid-filled fracture is less resistive than solid rock.

Fluid-temperature logs provide a continuous record of the temperature of the fluid in the borehole. Fluid-temperature logs were used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones usually were identified by sharp changes in fluid temperature, and intervals of vertical borehole flow were identified by little or no temperature gradient.

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

The acoustic borehole televiewer log is a magnetically oriented, 360°, photograph-like image of the acoustic reflectivity of the borehole wall. The acoustic televiewer is an ultrasonic imaging tool operating at a frequency of about 1 megahertz that scans the borehole wall with an acoustic beam generated by a rapidly pulsed piezoelectric source rotating at about three revolutions per second as the tool is moved up the borehole. Digital images from the televiewer are recorded by the computer collecting logging data. A smooth and hard borehole wall produces a uniform pattern of reflectivity. The intersection of a fracture with the borehole wall scatters the acoustic waves, producing a dark, linear feature on the image. Because the image is magnetically oriented, the azimuth of the fracture can be determined. Azimuth is the direction of maximum dip of a fracture from 0 to 360 degrees; an azimuth of 90° would mean a fracture is dipping to the east.

Borehole deviation logs, also called dipmeter logs, record the deviation of a borehole from true vertical. Deviation of boreholes from the vertical is common, and deviation logs are used to calculate true vertical depth of features of interest and to correct the strike and dip of fractures or bedding obtained from acoustic televiewer logs.

Measurement of Vertical Borehole Flow

The direction and rate of borehole-fluid movement were measured with a high-resolution heatpulse flowmeter. The heatpulse flowmeter operates by diverting nearly all flow to the center of the tool where a heating grid slightly heats a thin zone of water. If vertical borehole flow is occurring, the water moves up or down the borehole to one of two sensitive thermistors (heat sensors). When a peak temperature is recorded by one of the thermistors, a measurement of direction and rate is calculated by the computer collecting the logging data. The range of flow measurement is about 0.01-1.5 gal/min in a 2- to 12-in.-diameter borehole. Heatpulse-flowmeter measurements may be influenced by poor seal integrity between the borehole and the flowmeter or contributions of water from storage within the borehole during pumping. If the seal between the borehole and the heatpulse flowmeter is not complete, some water can bypass the flowmeter, resulting in flow measurements that are less than the actual rate. The quantity of water bypassing the tool is

a function of borehole size and shape and degree of fracturing. Although the heatpulse flowmeter is a calibrated tool, the data primarily are used as a relative indicator of fluid-producing zones.

Borehole flow was measured under both nonpumping and pumping conditions. Under nonpumping conditions, the natural flow in the borehole is measured. Under pumping conditions, flow is induced in the borehole by pumping, and flow at various depths is measured. To induce flow, a submersible pump is set in the casing, and the well is pumped at a low rate, generally about 1 gal/min. To eliminate the effects of borehole storage, the well is pumped until drawdown stabilizes. After stabilization of drawdown, all of the water being pumped is from the aquifer. A series of measurements under pumping conditions is then made.

Aquifer-Isolation Tests

Aquifer-isolation tests, commonly known as packer tests, were conducted in four wells. Aquifer-isolation tests use straddle packers to isolate a discrete fracture or fracture zone in the aquifer. Because ground water in the Elbrook Formation and Ledger Dolomite moves through discrete fractures, the hydraulic characteristics and chemical quality of water in each fracture can differ. These differences were characterized by isolating discrete fractures or fracture zones using a straddle-packer assembly to determine depth-discrete specific capacity values, to obtain depth-discrete water samples, and to determine the effect of pumping an isolated fracture or fracture zone on water levels in nearby wells.

The packer assembly consisted of two inflatable rubber bladders (packers) about 4 ft long set on 2-in.-diameter lift pipe with a pump set between the packers. The distance from the center of the upper packer to the center of the lower packer varied from well to well. Packer settings given in this report are from the center of the top packer to the center of the bottom packer, and the isolated zone is considered to be from the center of the top packer to the center of the bottom packer. The lowermost interval generally was tested first; isolated intervals are numbered in order from the bottom to the top of the well.

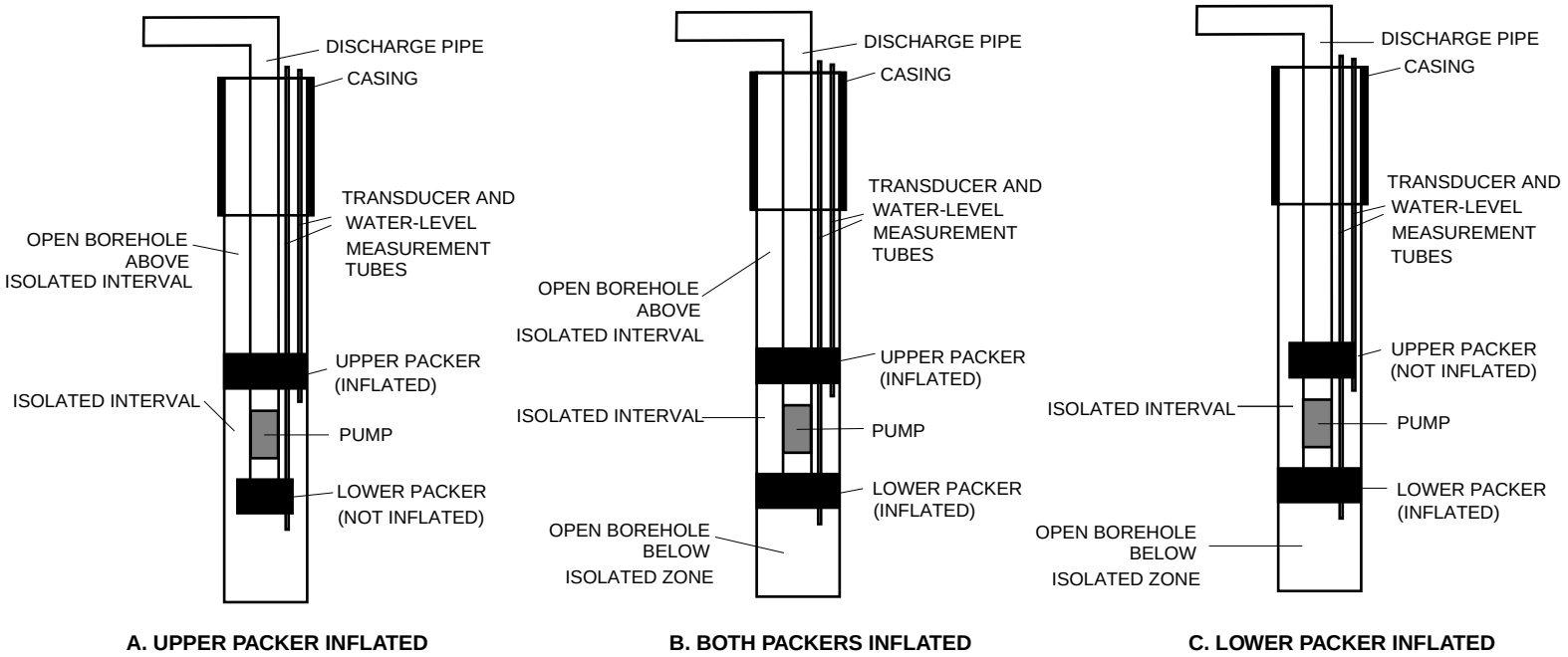
On the basis of the borehole geophysical logs and heatpulse-flowmeter measurements, several intervals in each well were selected for aquifer-isolation tests. The packer assembly was lowered to the selected depth in the borehole, and the packers were inflated against the borehole wall, isolating the selected interval. Exact depths to set packers were based on the location of smooth sections of borehole wall determined from the caliper logs. For the test of the lowermost isolated interval, generally only the upper packer was inflated (fig. 2A). For the test of the uppermost isolated interval, generally only the lower packer was inflated (fig. 2C). For the test of the other intervals, both packers were inflated (fig. 2B). Inflation of both packers created three intervals—an upper interval above the upper packer, the isolated interval between the packers, and a lower interval below the lower packer. Pressure in the packers was monitored so that the packers always remained at maximum inflation.

In order to evaluate the effects of pumping and fracture interconnection, water levels in the upper, lower, and isolated intervals were measured by calibrated pressure transducers and recorded by a digital data logger. The transducers in the pumped well were set in measurement tubes open to the intervals being monitored. Trandsucers also were set in nearby observation wells. Water levels were initially determined by electric measuring tapes. Land surface datum is used as a reference for all water-level measurements in this report.

Calibrated, in-line flowmeters were used to measure discharge. For some tested intervals, sediment in the discharge water clogged the flowmeter, and periodic volumetric measurements were made to estimate discharge.

After the packers were inflated, water levels in each interval were allowed to stabilize. After water levels stabilized, the aquifer-isolation test was run. During the tests, water levels were recorded above, below, and in the isolated interval. After the pump was shut off, water levels were allowed to recover for approximately 30 minutes before packer deflation to collect recovery water-level data.

The specific capacity of each isolated interval was determined by dividing the time-weighted average pumping rate by the drawdown. Specific capacities in this report should be considered estimates because of the variable pumping rate and because the wells were not pumped long enough to allow for stabilization of drawdown. Specific capacity is affected by the pumping rate and the length of the pumping period. In general, a higher pumping rate and/or a longer pumping duration will result in a lower specific capacity.



NOT TO SCALE

Figure 2. Generalized sketch of straddle-packer assembly and pump in borehole.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS AND AQUIFER-ISOLATION TESTS

Well EW-5 (CH-5040)

Interpretation of Borehole Geophysical Logs

A suite of borehole geophysical logs (fig. 3) was collected in well EW-5 by the USGS. The caliper log shows the well is 298 ft deep and is cased to 63 feet below land surface (ft bls). The caliper log shows major fractures at 73, 99, 111, 140-146, 168, and 178-182 ft bls plus numerous smaller fractures. The fracture at 73 ft bls is the major water-producing zone. A secondary water-producing zone is between 260 and 270 ft bls. The fluid-resistivity and fluid-temperature logs do not indicate borehole flow under nonpumping conditions. This was confirmed with heatpulse-flowmeter measurements at 68, 80, 160, 172, 196, 250, and 280 ft bls that showed no measurable flow.

Heatpulse-flowmeter measurements were made at 68, 80, 160, 196, 250, and 280 ft bls while the well was pumped at approximately 0.35 gal/min with a submersible pump set in the casing. Under pumping conditions, the heatpulse-flowmeter measurements showed the fracture at 73 ft bls produces about 0.3 gal/min of water, and the fracture at 260-270 ft bls produced about 0.05 gal/min of water.

Aquifer-Isolation Tests

On the basis of the borehole geophysical logs and heatpulse-flowmeter measurements, three intervals were selected for aquifer-isolation tests (table 2). Water levels in nearby wells MW-111, MW-2, and MW-108A were monitored in addition to water levels in EW-5 during pumping to determine the effect of pumping on nearby wells. The distance between the center of the top packer and the center of the bottom packer was 17 ft.

Table 2. *Intervals isolated and specific capacities for well EW-5 (CH-5040), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[--, insufficient data to calculate specific capacity]

Interval	Isolated interval[1] (feet below land surface)	Isolated fracture (feet below land surface)	Pumping time (minutes)	Time-weighted average pumping rate (gallons per minute)	Specific capacity (gallons per minute per foot)
1	257-300	260-270	80	1.1	--
2	194-300	260-270	97	.98	0.005
3	63-80	73	70	3.6	.08

[1] Center of packer to center of packer.

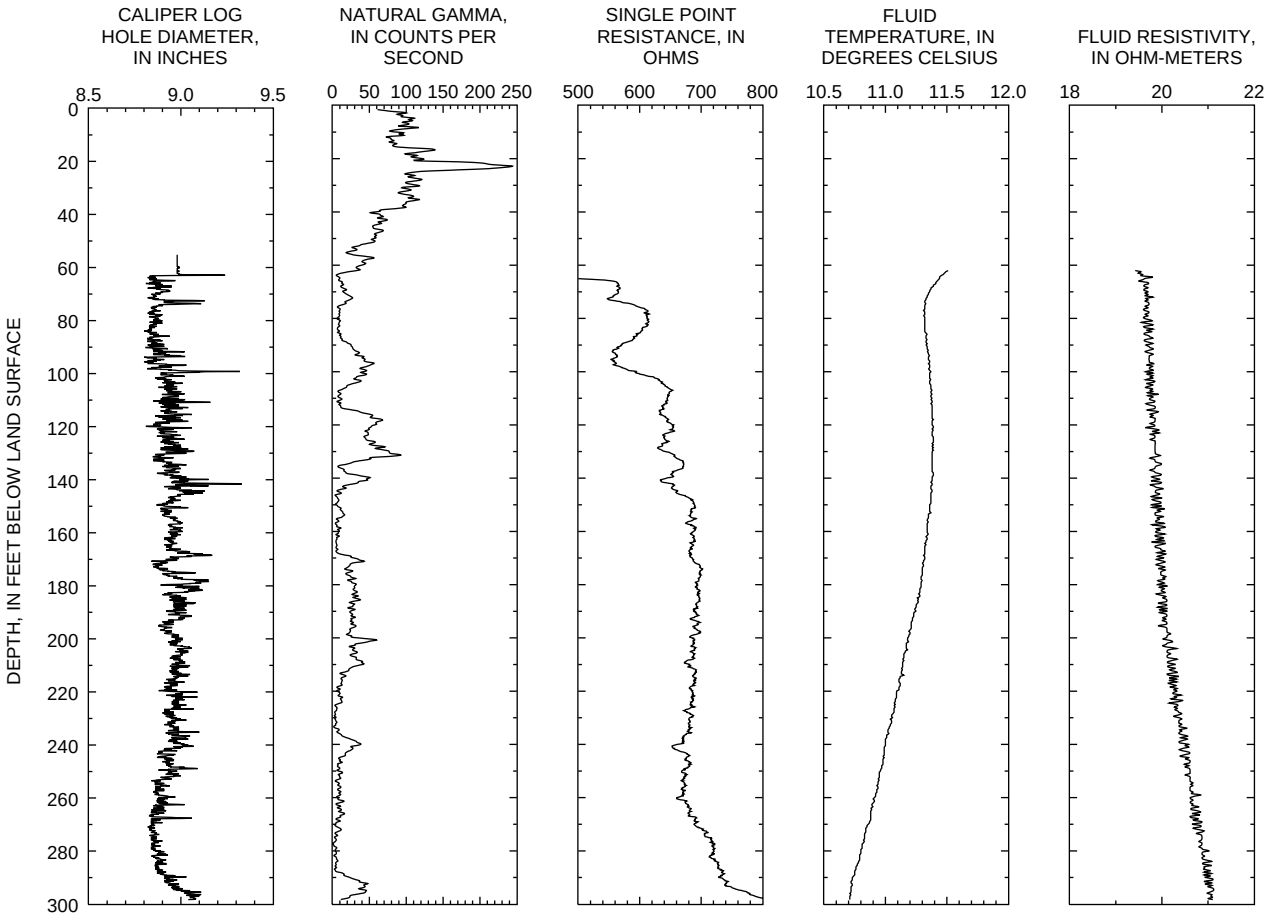


Figure 3. Borehole geophysical logs from well EW-5 (CH-5040), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 1 (257 to 298 Feet Below Land Surface)

For isolated interval 1, the top packer was centered at 257 ft bls, and the bottom packer was not inflated (fig. 2A). The interval of borehole isolated was from 257 to the bottom of the borehole at 298 ft bls. This included the minor water-producing fracture at 260-270 ft bls. The pump was set at 215 ft bls. Isolated interval 1 was pumped four times at rates from 0.5 to 1.5 gal/min resulting in rapid drawdowns with water levels for the first three times dropping below the transducer, which was set at 129.37 ft bls (fig. 4). The maximum drawdown in the interval above the packer was 1.22 ft. The water level in the pumped interval below the packer dropped below the transducer; the maximum drawdown was greater than 105.59 ft. The specific capacity of interval 1 could not be calculated because the exact drawdown was not known. The hydrographs for the intervals above and below the packer and for the observation wells are shown in figure 4. The hydrographs indicate a hydraulic connection outside the borehole between the two intervals. The maximum drawdown in well MW-108A was 0.16 ft, indicating a hydraulic connection between the isolated interval and well MW-108A.

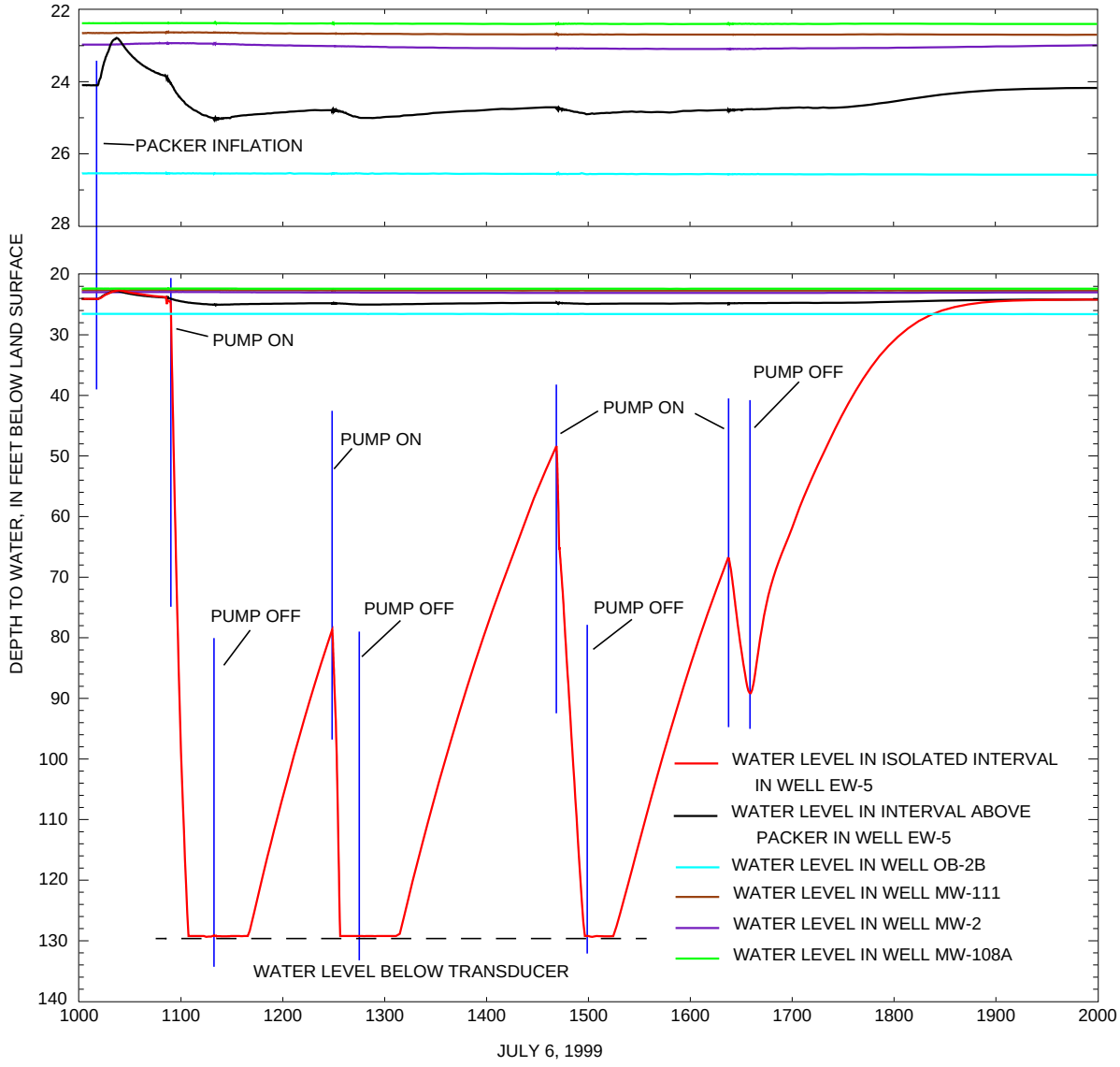


Figure 4. Hydrographs from aquifer-isolation test of interval 1 (257 to 298 feet below land surface) in well EW-5 (CH-5040), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 2 (194 to 298 Feet Below Land Surface)

For isolated interval 2, the top packer was centered at 194 ft bls, and the bottom packer was not inflated (fig. 2A). The interval of borehole isolated was from 194 to 298 ft bls. This isolated the lower part of the well and included the minor water-producing fracture at 260-270 ft bls. Isolated interval 2 was pumped at an average rate of 0.98 gal / min for 97 minutes, which resulted in the water level dropping below the transducer, which was set at 130.65 ft bls (fig. 5). The water level measured by electric tape just before the pump was shut off was 186 ft bls for a measured drawdown of 163 ft. The specific capacity of interval 2 is 0.005 (gal / min) / ft.

Drawdown in the interval above the packer was 5.10 ft. The hydrographs for the isolated interval and the interval above the packer and for the observation wells are shown in figure 5. The hydrographs indicate a hydraulic connection outside the borehole between the two intervals. The maximum drawdown was 0.14 ft in well MW-2 and 0.56 ft in well MW-108A, indicating that the wells are hydraulically connected to isolated interval 2 in well EW-5. Drawdown in well MW-108A continued for 53 minutes after cessation of pumping of well EW-5. Well OB-2B showed no response to pumping.

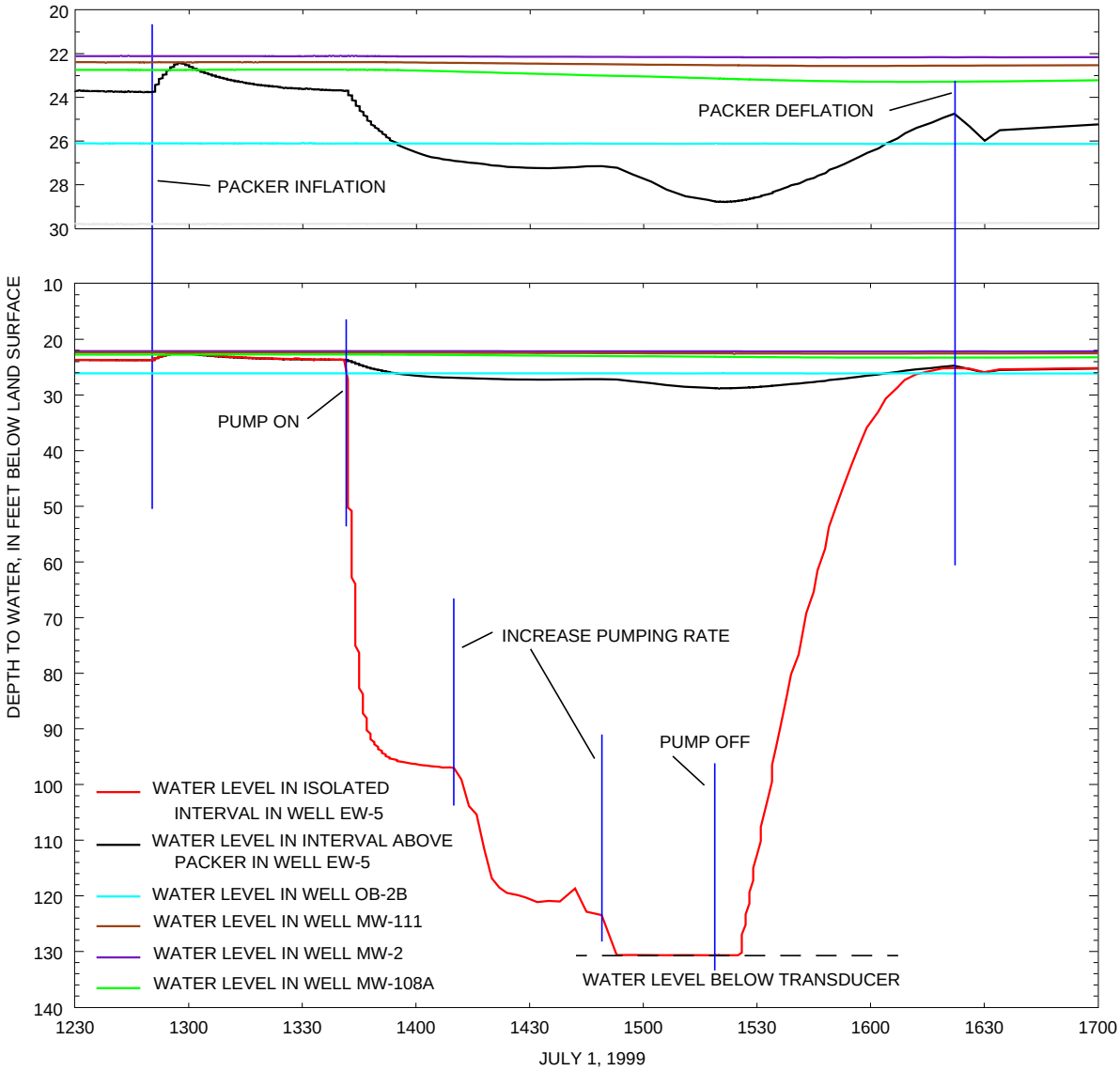


Figure 5. Hydrographs from aquifer-isolation test of interval 2 (194 to 298 feet below land surface) in well EW-5 (CH-5040), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 3 (63 to 80 Feet Below Land Surface)

For isolated interval 3, the bottom packer was centered at 84 bls, and the top packer was not inflated (fig. 2C); this isolated the main water-bearing fracture at 73 ft bls. Isolated interval 3 was pumped at an average rate of 3.6 gal/min for 70 minutes. The maximum drawdown measured in the isolated interval was 42.71 ft (fig. 6). The specific capacity of interval 3 is 0.08 (gal/min)/ft.

Drawdown in the interval above the packer was 39.41 ft, indicating a very strong hydraulic connection outside the borehole between the two intervals. The hydrographs for the isolated interval and the interval above the packer and for the observation wells are shown in figure 6. The maximum drawdown was 0.10, 0.35, and 1.44 ft in wells MW-111, MW-2, and MW-108A, respectively, indicating the wells are hydraulically connected to the isolated interval in well EW-5. Drawdown in well MW-108A continued for 75 minutes after cessation of pumping of well EW-5. Well OB-2B showed no response to pumping.

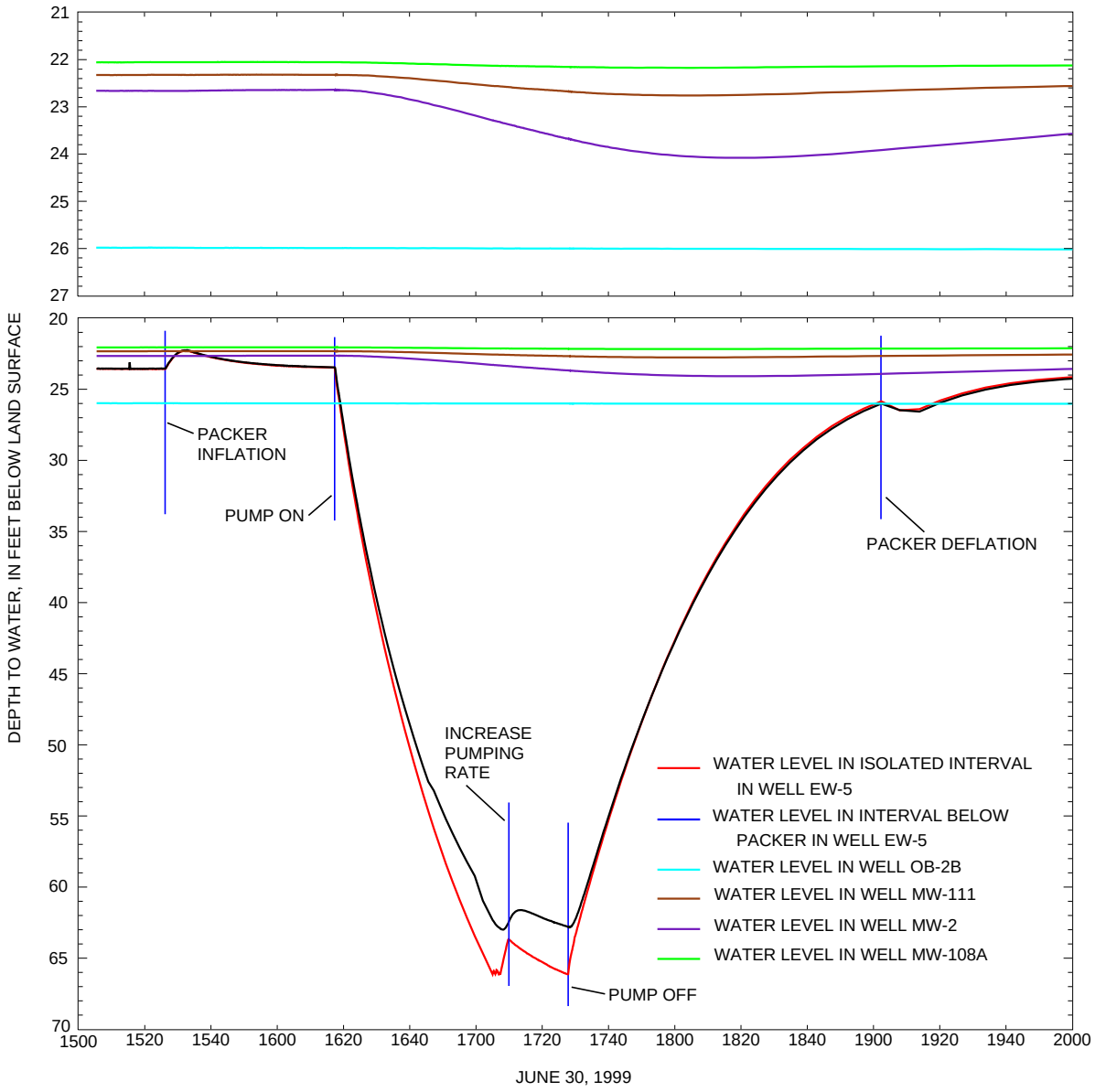


Figure 6. Hydrographs from aquifer-isolation test of interval 3 (63 to 80 feet below land surface) in well EW-5 (CH-5040), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Well RW-2 (CH-5805)

Interpretation of Borehole Geophysical Logs

A suite of borehole geophysical logs (fig. 7) was collected in well RW-2 by the USGS. The caliper log shows the bottom of the well is filled with sediment to about 184 ft bls, and it is cased to 30 ft bls. The caliper log shows major fractures at 34-36, 37, 68-72, and 97-98 ft bls. A minor fracture is located at 168-170 ft bls. An acoustic borehole televiewer log was run in the well. Dip and azimuth for the water-bearing fractures are given in table 3. The water-bearing fractures are very steeply dipping; the dip ranges from 72° to 78.8°. This is consistent with dips measured by Bascom and Stose (1938, plate 1). Heatpulse-flowmeter measurements were made under nonpumping conditions at 47, 62, 86, 104, 120, 140, 158, 162, and 174 ft bls (table 4). On the basis of the geophysical logs, heatpulse-flowmeter measurements, and acoustic borehole televiewer data, water enters the borehole through fractures at 34-36 and 37 ft bls and flows downward. Water also enters the borehole through the minor fracture at 168-170 ft bls and flows upward. Water flowing down the borehole from the fractures at 34-36 and 37 ft bls exits the borehole through fractures at 55, 68-72, and 97-98 ft bls. Water flowing up the borehole from the fracture at 168-170 ft bls exits the borehole through the fracture at 97-98 ft bls. The principal water-bearing zones in well RW-2 are at 34-37, 55, 68-72, 97-98, and 168-170 ft bls.

Table 3. *Fracture dip and azimuth determined with the acoustic borehole televiewer for water-bearing fractures in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

Depth of fracture (feet below land surface)	Dip (degrees)	Azimuth (degrees)
36.8	78.8	162.4
55.7	76.9	166.5
70.2	74.5	165.0
98.7	74.7	163.6
170.1	72.0	149.6

Aquifer-Isolation Tests

On the basis of the borehole geophysical logs and heatpulse-flowmeter measurements, five intervals were selected for isolation by straddle packers (table 5). The distance between the center of the top packer and the center of the bottom packer was 15 ft. During pumping, water levels in nearby observation wells OB2-S, EW-5, OB2-I, MW-108A, and MW-2 were monitored in addition to water levels in RW-2.

Table 4. *Heatpulse-flowmeter measurements made in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[--, not determined]

Depth (feet below land surface)	Flow (gallons per minute)	Flow direction
47	0.69	Down
62	.62	Down
86	.43	Down
104	.20	Up
120	.20	Up
140	.20	Up
158	.20	Up
162	Inconsistent	--
174	Inconsistent	--

Table 5. *Intervals isolated and specific capacities for well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[--, specific capacity not determined]

Interval number	Isolated interval[1] (feet below land surface)	Isolated fracture (feet below land surface)	Pumping time (minutes)	Average pumping rate (gallons per minute)	Specific capacity (gallons per minute per foot)
1	160-184	168-170	114	3.9	--
2	90-105	97-98	94	25	1.3
3	61-76	68-72	97	3.9	.14
4	45-60	55	30	1.8	--
5	30-45	34-37	91	19.9	1.6

[1] Center of packer to center of packer.

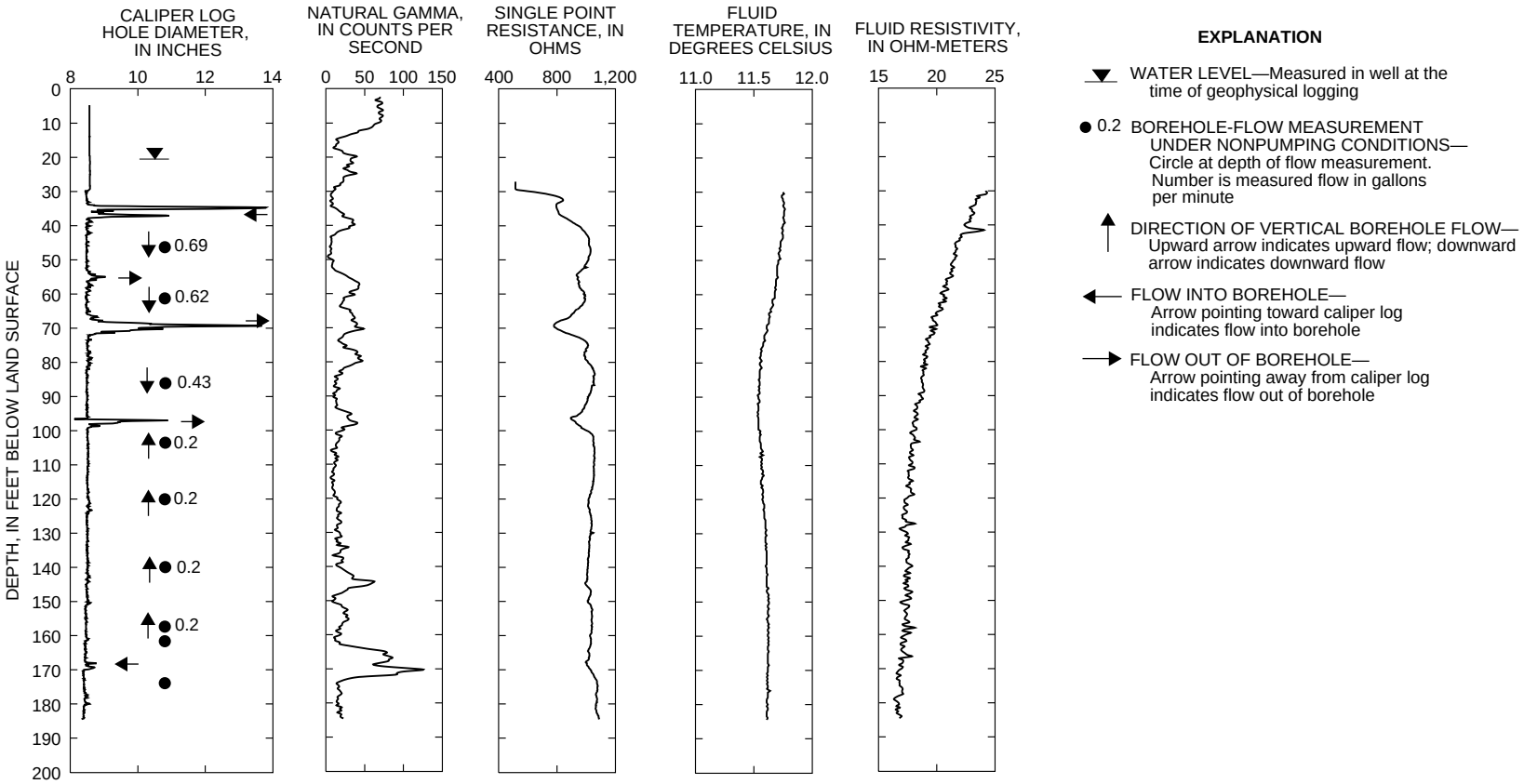


Figure 7. Borehole geophysical logs from well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 1 (160 to 184 Feet Below Land Surface)

For isolated interval 1, the top packer was centered at 160 ft bls, and the bottom packer was not inflated (fig. 2A). The interval of borehole isolated was from 160 ft bls to the bottom of the well at 184 ft bls. This interval includes the water-producing fracture at 168-170 ft bls. Before packer inflation, the depth to water in the open borehole was 21.40 ft bls. Fifty minutes after packer inflation, the depth to water in the isolated interval increased by 0.03 ft., while the depth to water in the interval above the isolated zone decreased by 0.14 ft. This is consistent with the interpretation of the borehole geophysical logs and upward borehole flow shown by the heatpulse-flowmeter measurements, which indicate the isolated water-producing fracture at 168-170 ft bls has a higher head than the water-receiving fractures above. Inflation of the packers had no effect on the water levels in the observation wells.

Isolated interval 1 is a relatively low-yielding zone; it was pumped at an average rate of 3.9 gal/min for 114 minutes (fig. 8). The pumping rate varied during the test. Drawdown in the interval above the packer was 1.66 ft. The water level in the isolated interval dropped below the transducer, which was set at 133 ft bls; the maximum drawdown was greater than 111 ft. The specific capacity of interval 1 could not be calculated because the drawdown was not known.

The hydrographs for well RW-2 and the observation wells are shown in figure 8. The hydrographs indicate a hydraulic connection outside the borehole between the isolated interval and the interval above the packer and with well OB-2S. Drawdown in well OB-2S caused by pumping the interval isolated from 160 to 184 ft bls in well RW-2 was 1.43 ft.

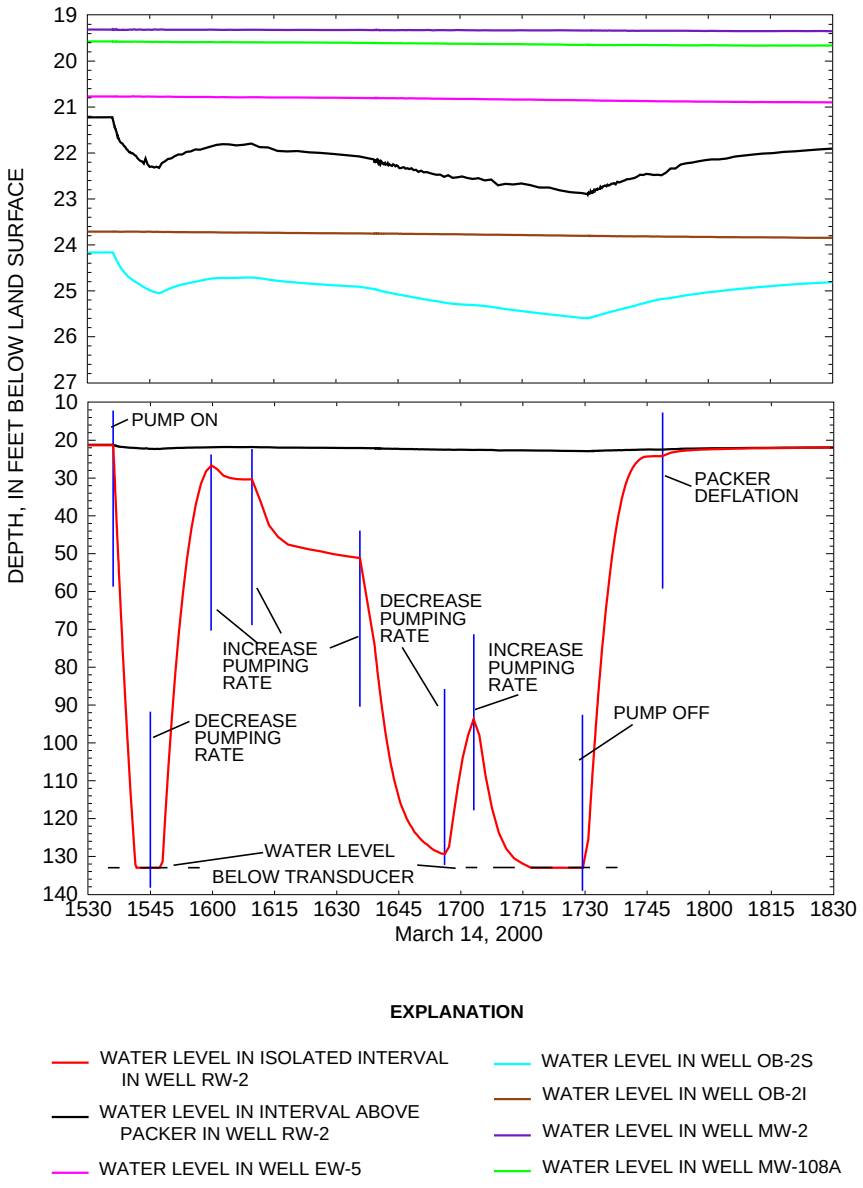


Figure 8. Hydrographs from aquifer-isolation test of interval 1 (160 to 184 feet below land surface) in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

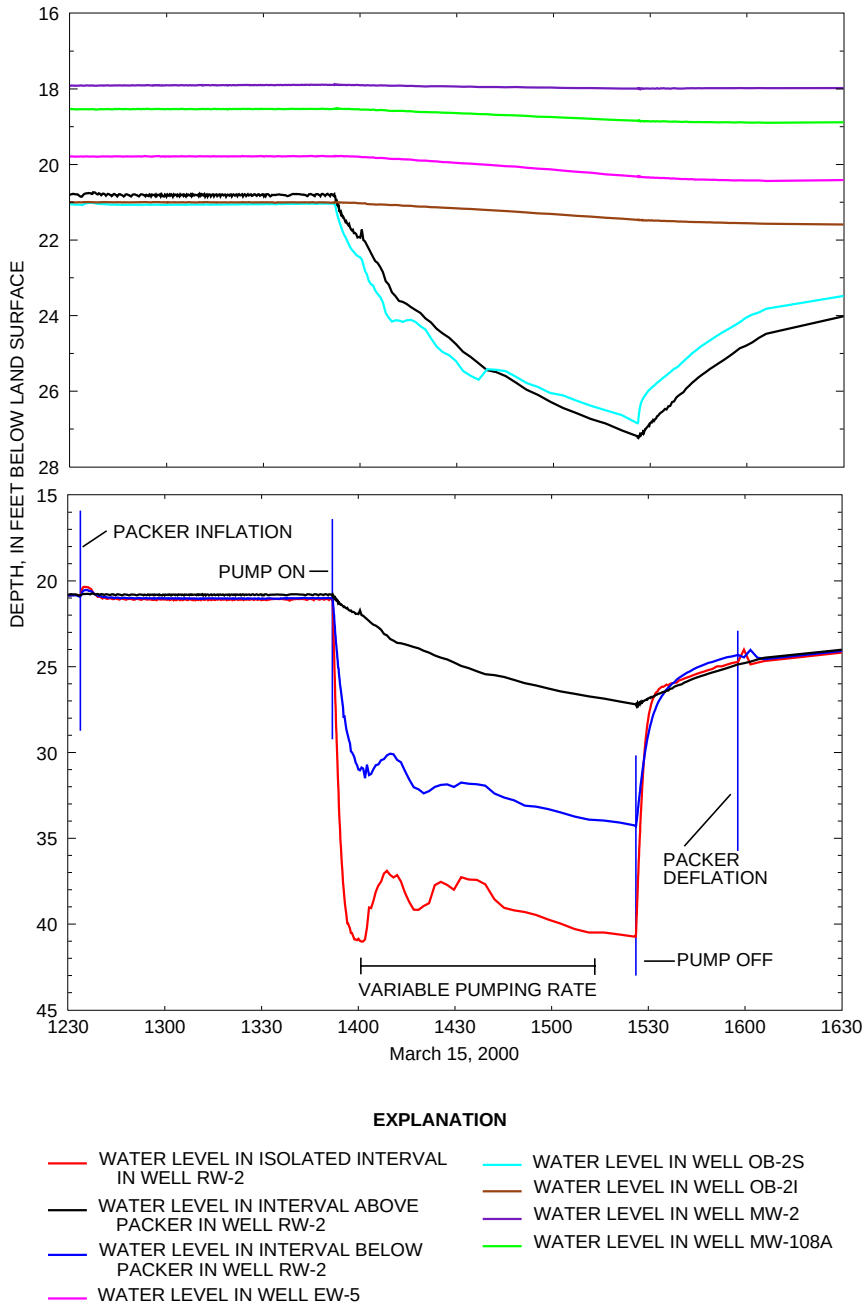


Figure 9. Hydrographs from aquifer-isolation test of interval 2 (90 to 105 feet below land surface) in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 2 (90 to 105 Feet Below Land Surface)

For isolated interval 2, the top packer was centered at 90 ft bls (fig. 2B), and the interval of borehole isolated was from 90 to 105 ft bls. This interval includes the major water-receiving fracture at 97-98 ft bls. Before packer inflation, the depth to water in the open borehole was 20.94 ft bls. Eighty-six minutes after packer inflation, depth to water in the interval above the packers increased 0.12 ft, depth to water in the isolated interval decreased 0.12 ft, and depth to water in the interval below the packers decreased 0.05 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-receiving fracture at 97-98 ft bls has a lower head than the water-producing fractures above and below. Inflating the packers caused a rise in water level of 0.45 ft in well OB-2S.

Isolated interval 2 is a relatively high-yielding zone; it was pumped at an average rate of 25 gal/min for 94 minutes. Drawdown in the interval above the packers was 6.46 ft, drawdown in the isolated interval was 19.63 ft, and drawdown in the interval below the packers was 13.31 ft (fig. 9). The specific capacity of interval 2 is 1.3 (gal/min)/ft. The hydrographs for wells RW-2 and the observation wells are shown in figure 9. The hydrographs indicate a strong hydraulic connection outside the borehole between the isolated interval and the intervals above and below the isolated interval. Drawdown in well OB-2S caused by pumping the isolated interval was 5.82 ft, indicating a strong hydraulic connection between the isolated interval 90-105 ft bls in well RW-2 and well OB-2S.

Aquifer-Isolation Test of Interval 3 (61 to 76 Feet Below Land Surface)

For isolated interval 3, the top packer was centered at 61 ft bls (fig. 2B), and the interval of borehole isolated was from 61-76 ft bls. This interval includes the water-receiving fracture at 67-72 ft bls. Before packer inflation, the depth to water in the open borehole was 20.94 ft bls. Fifty-five minutes after packer inflation, depth to water in the interval above the packer increased 0.04 ft, depth to water in the isolated interval decreased 0.18 ft, and depth to water in the interval below the packer decreased 0.23 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-receiving fracture at 67-72 ft bls has a lower head than the water-producing fractures above it. Inflating the packers caused a rise in water level of 0.12 ft in well OB-2S.

Isolated interval 3 is a relatively low-yielding zone; it was pumped at a time-weighted average rate of 3.9 gal/min for 97 minutes (fig. 10). Drawdown in the interval above the packers was 1.08 ft, drawdown in the isolated interval was 27.14 ft, and drawdown in the interval below the packers was 0.67 ft. The specific capacity of interval 3 is 0.14 (gal/min)/ft. The hydrographs for the intervals above and below the packer and for well OB-2S are shown in figure 10. The hydrographs indicate a strong hydraulic connection outside the borehole between the isolated interval and the intervals above and below the isolated interval. Drawdown in well OB-2S caused by pumping the isolated interval was 1.04 ft, indicating a strong hydraulic connection between the isolated interval 61-76 ft bls in well RW-2 and well OB-2S.

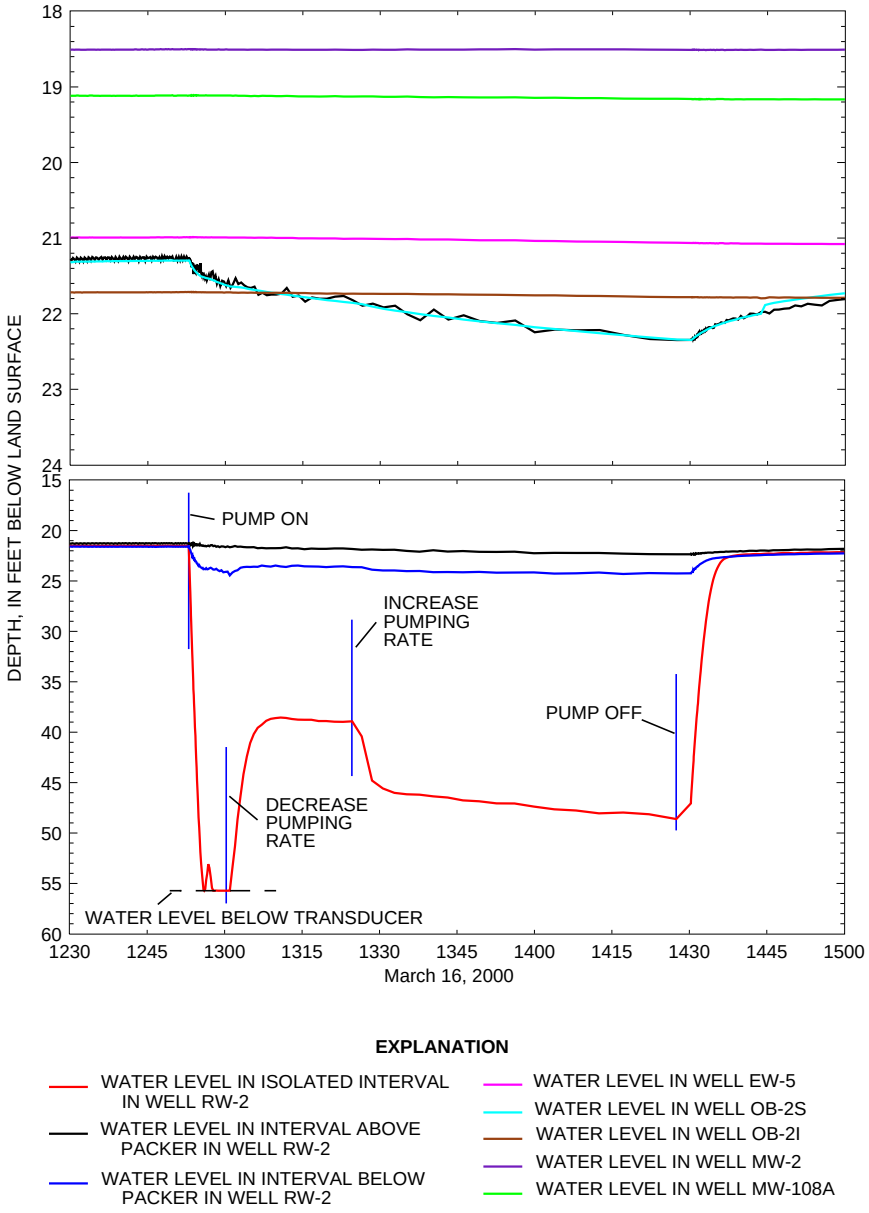


Figure 10. Hydrographs from aquifer-isolation test of interval 3 (61 to 76 feet below land surface) in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 4 (45 to 60 Feet Below Land Surface)

For isolated interval 4, the top packer was centered at 45 ft bls (fig. 2B), and the interval of borehole isolated was from 45-60 ft bls. This interval includes the minor water-receiving fracture at 55 ft bls. Before packer inflation, the depth to water in the open borehole was 21.10 ft bls. Fifty-six minutes after packer inflation, depth to water in the interval above the packer increased 0.03 ft, depth to water in the isolated interval increased 0.08 ft, and depth to water in the interval below the packer decreased 0.10 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-receiving fracture at 55 ft bls has a lower head than the water-producing fracture above it. Inflating the packers caused a rise in water level of 0.13 ft in well OB-2S.

Isolated interval 4 is a very low-yielding zone. It was pumped dry, allowed to recover, and then pumped a second time (fig. 11). The average pumping rate was 1.8 gal/min for 73 minutes. The maximum drawdown in the interval above the packers was 0.37 ft, and the maximum drawdown in the interval below the packers was 0.95 ft. The water level in the isolated interval dropped below the transducer, which was set at 39 ft bls. The maximum drawdown was greater than 17 ft. The specific capacity of interval 4 could not be calculated because drawdown was not known. The maximum drawdown in well OB-2S caused by pumping the isolated interval was 0.35 ft, indicating a hydraulic connection between the isolated interval 45-60 ft bls in well RW-2 and well OB-2S.

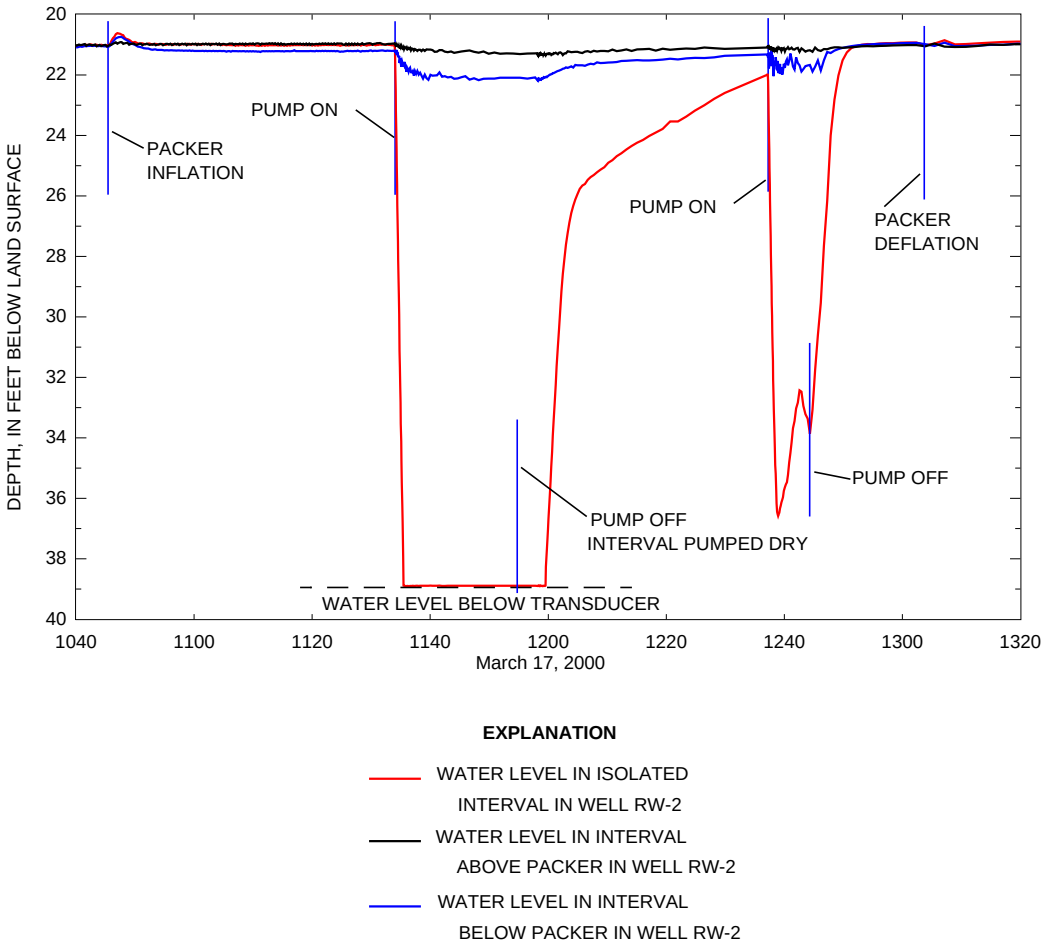


Figure 11. Hydrographs from aquifer-isolation test of interval 4 (45 to 60 feet below land surface) in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 5 (30 to 45 Feet Below Land Surface)

For isolated interval 5, the bottom packer was centered at 45 ft bls (fig. 2C), and the top packer was not inflated. The interval of borehole isolated was from the bottom of casing at 30 ft bls to 45 ft bls. This interval includes the major water-producing fractures at 34-36 and 37 ft bls. Before packer inflation, the depth to water in the open borehole was 20.95 ft bls. Twenty-eight minutes after packer inflation, depth to water in the isolated interval above the packer increased 0.07 ft, and depth to water in the interval below the packer decreased 0.11 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-producing fractures at 34-36 and 37 ft bls has a higher head than the water-receiving fractures below them. Inflating the packers caused a decrease in water level of 0.06 ft in well OB-2S.

Isolated interval 5 is a relatively high-yielding zone; it was pumped at an average rate of 19.9 gal/min for 91 minutes. Drawdown in the isolated interval was 12.65 ft, and drawdown in the interval below the packers was 3.77 ft. The specific capacity of interval 5 is 1.6 (gal/min)/ft. The hydrographs for well RW-2 and the observation wells are shown in figure 12. The hydrographs indicate a strong hydraulic connection outside the borehole between the isolated interval and the interval below the packer. Drawdown in well OB-2S caused by pumping the isolated interval was 8.69 ft, indicating a strong hydraulic connection between the isolated interval 30-45 ft bls in well RW-2 and well OB-2S. Drawdowns were observed in all of the other observation wells. Drawdown was 0.33 ft in well EW-5, 0.28 ft in well OB-2I, 0.19 ft in well WM-108A, and 0.07 ft in well MW-2.

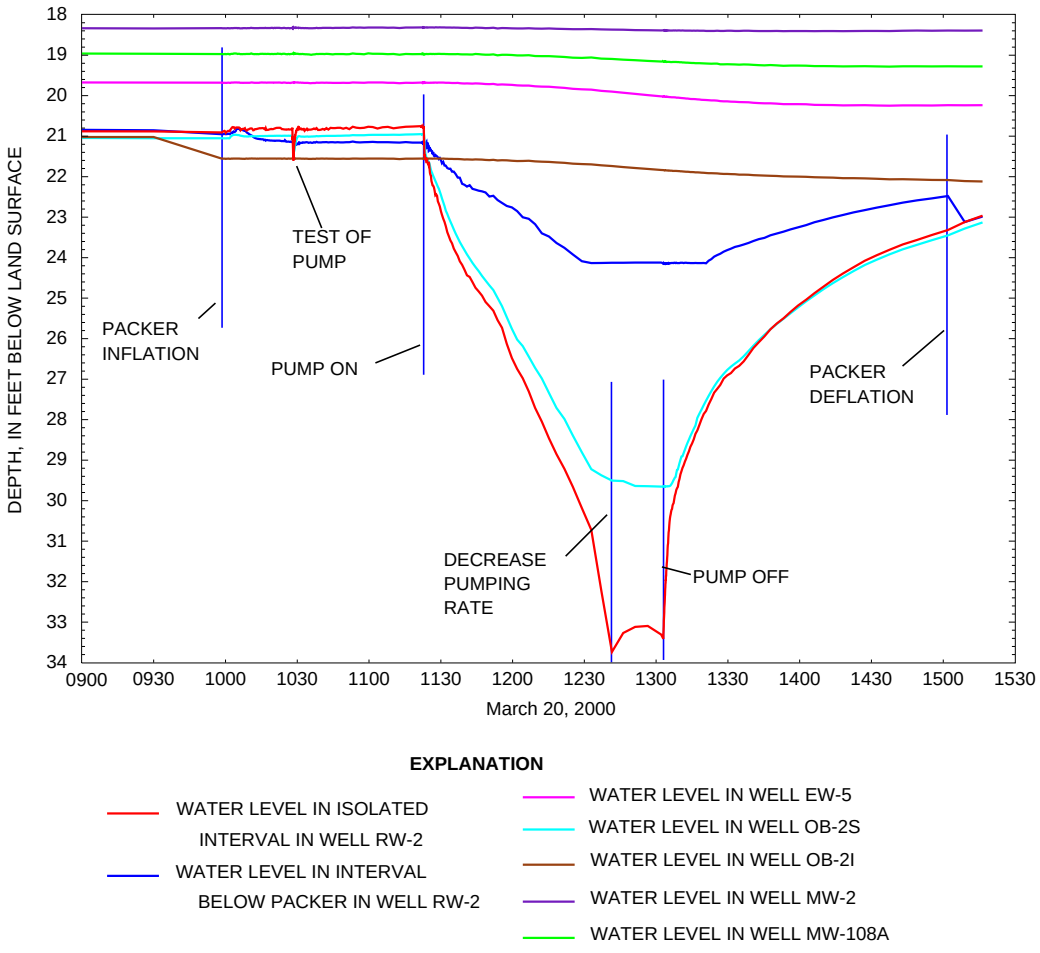


Figure 12. Hydrographs from aquifer-isolation test of interval 5 (30 to 45 feet below land surface) in well RW-2 (CH-5805), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Well RW-3 (CH-5806)

Interpretation of Borehole Geophysical Logs

A suite of borehole geophysical logs (fig. 13) was collected in well RW-3 by the USGS. The caliper log shows the well is 197 ft deep and is cased to 72 ft bls. Major fractures are at 120-124, 154-156, 175-176, and 179 ft bls. Heatpulse-flowmeter measurements were made under nonpumping conditions at 78, 110, 140, 166, and 184 ft bls (table 6). No borehole flow was measurable at 78, 110, and 140 ft bls. Downward borehole flow of 0.17 and 0.23 gal/min was measured at 166 and 184 ft bls, respectively. Water enters the borehole through fractures at 154-156 and 174-179 ft bls, flows downward, and exits the borehole through fractures below 194 ft bls. Heatpulse-flowmeter measurements were made while pumping at 0.7 to 1 gal/min at 78, 110, 140, 166, 184, 190, and 194 ft bls (table 6). On the basis of the geophysical logs and heatpulse-flowmeter measurements, the principal water-bearing zones in the well are at 153-156 ft bls, 174-279 ft bls, and below 194 ft bls.

Aquifer-Isolation Tests

On the basis of the borehole geophysical logs and heatpulse-flowmeter measurements, three intervals were isolated in well RW-3 (table 7). The distance between the center of the top packer and the center of the bottom packer was 19 ft. No observation wells were measured during the aquifer-isolation test of well RW-3.

Table 6. *Heatpulse-flowmeter measurements made in well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

[--, not measured]

Depth (feet below land surface)	Nonpumping conditions		Pumping at 0.7 to 1 gallon per minute	
	Flow (gallons per minute)	Flow direction	Flow (gallons per minute)	Flow direction
78	0		0.62	Up
110	0		.80	Up
140	0		.67	Up
166	.17	Down	.83	Up
184	.23	Down	.71	Up
190	--	--	.49	Up
194	--	--	.60	Up

Table 7. *Intervals isolated and specific capacities for well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

Interval number	Isolated interval[1] (feet below land surface)	Isolated fracture (feet below land surface)	Pumping time (minutes)	Average pumping rate (gallons per minute)	Specific capacity (gallons per minute per foot)
1	164-198	174-179 194-198	107	[2] 25	7.1
2	148-167	153-156	73	[2] .34	.006
3	109-128	122-126	94	4.1	.07

[1] Center of packer to center of packer.
[2] Sediment clogged in-line flowmeter. Estimated by volumetric method.

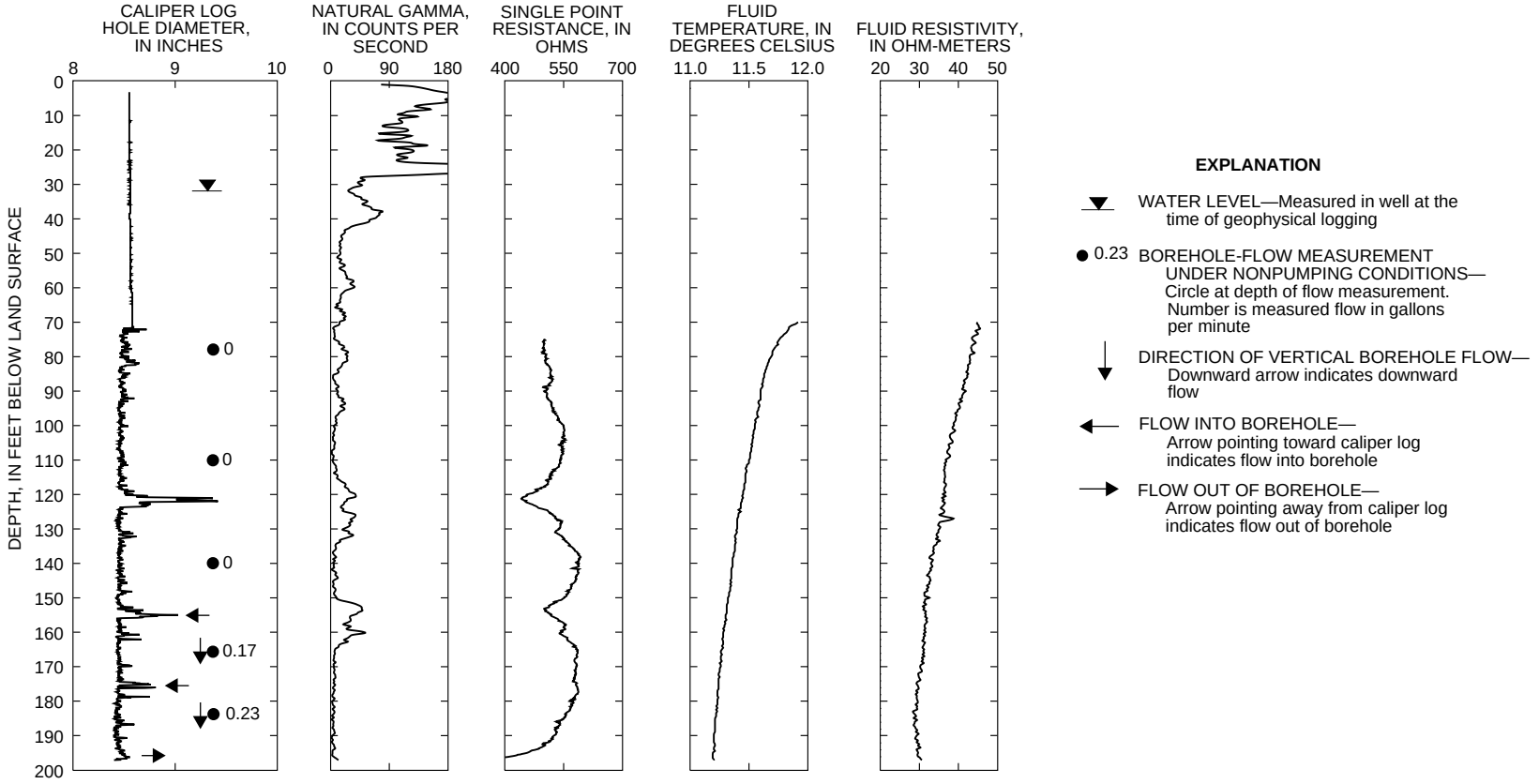


Figure 13. Borehole geophysical logs from well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 1 (164 to 198 Feet Below Land Surface)

For isolated interval 1, the top packer was centered at 164 ft bls and the bottom packer was not inflated (fig. 2A). The interval of borehole isolated was from 164 ft bls to the bottom of the well at 198 ft bls. This interval includes the water-producing fracture at 174-179 ft bls and the water-receiving fracture at 194-198 ft bls. Isolated interval 1 is a high-yielding zone; it was pumped at an estimated average rate of 25 gal/min for 107 minutes. The pumping rate was estimated by making periodic volumetric measurements because sediment in the discharge water clogged the in-line flowmeter. Drawdown in the isolated interval was 3.52 ft, and drawdown in the interval above the packer was 2.34 ft. The specific capacity of interval 1 is 7.1 (gal/min)/ft. The hydrographs for the intervals above and below the packer are shown in figure 14. The hydrographs indicate a strong hydraulic connection outside the borehole between the isolated interval and the interval above the packer.

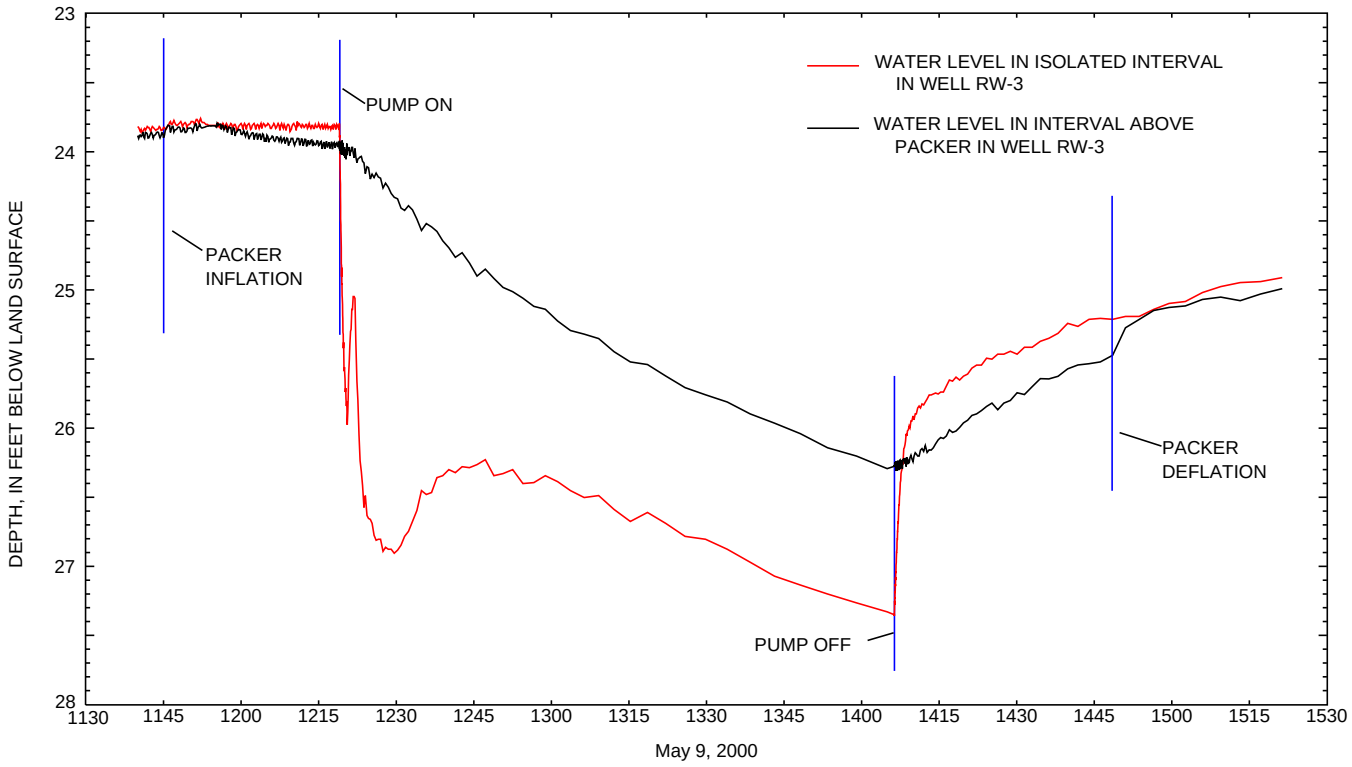


Figure 14. Hydrographs from aquifer-isolation test of interval 1 (164 to 198 feet below land surface) in well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 2 (148 to 167 Feet Below Land Surface)

For isolated interval 2, the top packer was centered at 148 ft bls (fig. 2B), and the interval of borehole isolated was from 148 to 167 ft bls. This interval includes the water-producing fracture at 153-156 ft bls. Isolated interval 2 is a very low-yielding zone; it was pumped at an estimated average rate of 0.34 gal / min for 73 minutes. The pumping rate was estimated by making periodic volumetric measurements because sediment in the discharge water clogged the in-line flowmeter. Drawdown in the interval above the packers was 0.06 ft, drawdown in the isolated interval was 54.96 ft, and drawdown in the interval below the packers was 0.49 ft. The specific capacity of interval 2 is 0.006 (gal / min) / ft. The hydrographs for the isolated interval and the intervals above and below the packers are shown in figure 15. The hydrographs indicate no hydraulic connection outside the borehole between the isolated interval and the interval below and little hydraulic connection between the isolated interval and the interval above.

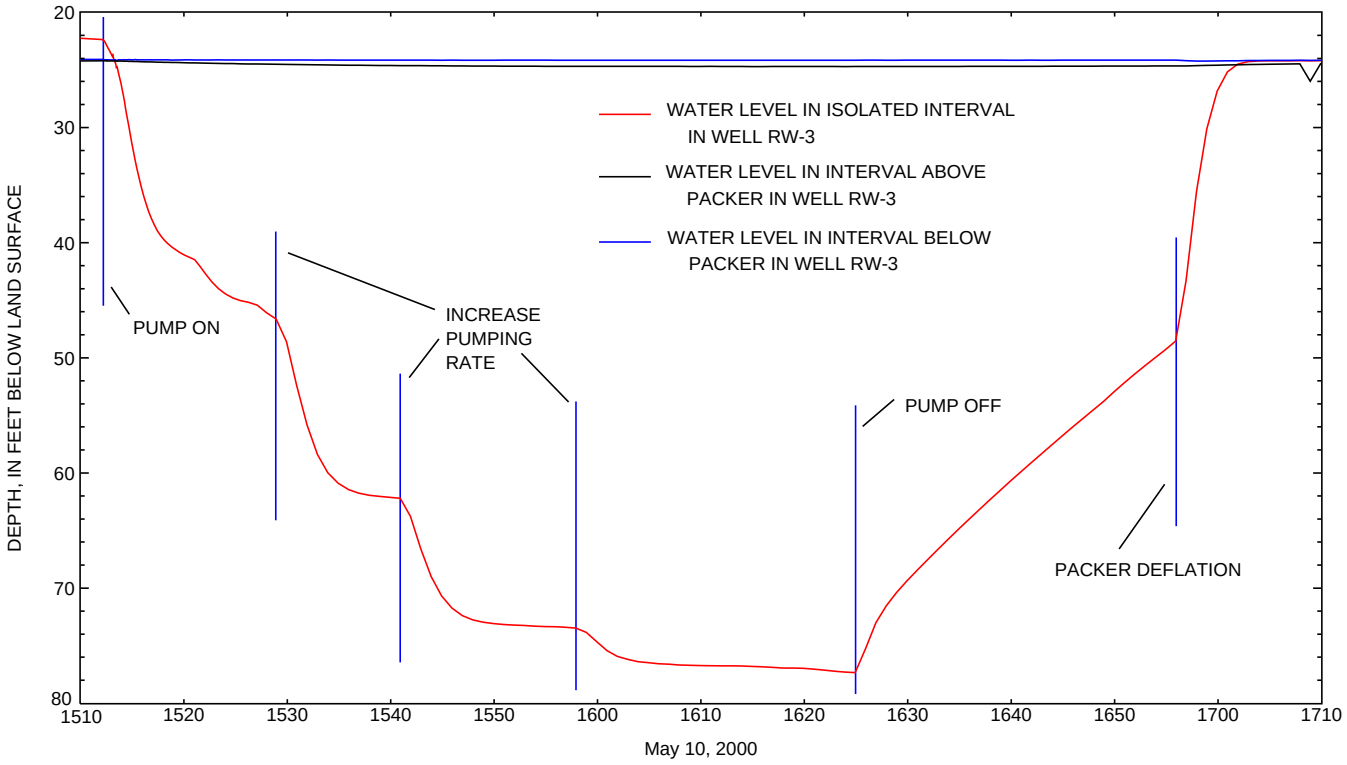


Figure 15. Hydrographs from aquifer-isolation test of interval 2 (148 to 167 feet below land surface) in well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 3 (109 to 128 Feet Below Land Surface)

For isolated interval 3, the top packer was centered at 109 ft bls (fig. 2B), and the interval of borehole isolated was from 109-128 ft bls. This interval includes the large fracture at 122-126 ft bls, which was reported by the driller to yield 10 gal/min. Isolated interval 3 was pumped at an average rate of 4.1 gal/min for 94 minutes. Drawdown in the interval above the packers was 10.77 ft, drawdown in the isolated interval was 61.66 ft, and drawdown in the interval below the packers was 0.91 ft. The specific capacity of interval 3 is 0.07 (gal/min)/ft. The hydrographs for the isolated interval and the intervals above and below the packers are shown in figure 16. The hydrographs indicate some hydraulic connection outside the borehole between the isolated interval and the interval below and good hydraulic connection between the isolated interval and the interval above.

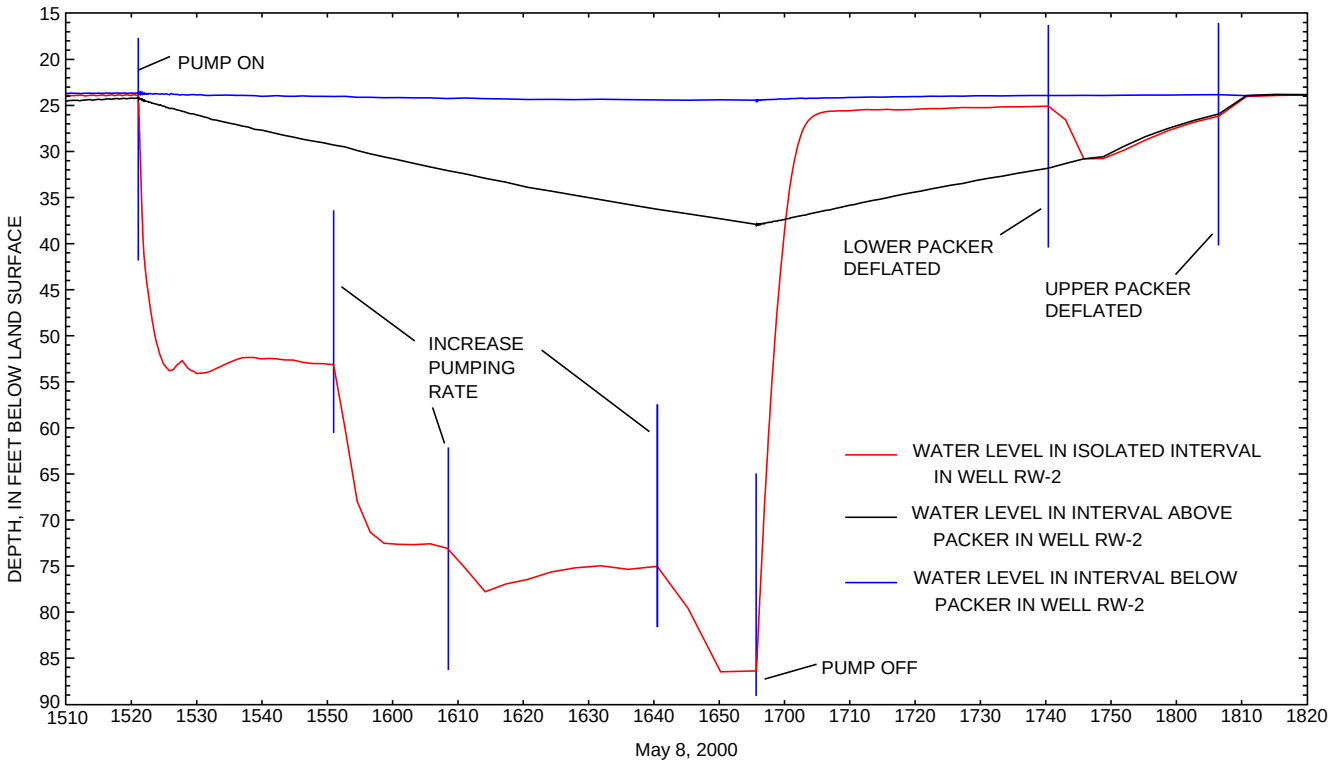


Figure 16. Hydrographs from aquifer-isolation test of interval 3 (109 to 128 feet below land surface) in well RW-3 (CH-5806), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Well RW-6 (CH-5808)

Interpretation of Borehole Geophysical Logs

A suite of borehole geophysical logs (fig. 17) was collected in well RW-6 by the USGS. The caliper log shows the well is 248 ft deep and is cased to 67 ft bls. The caliper log shows major fractures at 90-92, 118-119, 180-182, and 206-208 ft bls. Heatpulse-flowmeter measurements were made under nonpumping conditions at 79, 106, 124, 150, 162, 170, 199, and 214 ft bls (table 8). On the basis of the geophysical logs and heatpulse-flowmeter measurements, water enters the borehole through the fracture at 118-119 ft bls (2.4 gal/min) and flows both upward and downward. Water flowing upward from the fracture at 118-119 ft bls exits the borehole through the fracture at 90-92 ft bls (1.1 gal/min). Some of the water flowing downward from the fracture at 118-119 ft bls exits the borehole through a minor fracture at 169 ft bls (about 0.4 gal/min) but most continues to flow downward (about 0.9 gal/min). Water also enters the borehole through the fracture at 180-184 ft bls (about 0.5 gal/min) and flows downward. The water flowing down the borehole exits the borehole through the fracture at 206-208 ft bls (1.4 gal/min). The principal water-bearing zones in well RW-6 are at 90-92, 118-119, 169, 180-182, and 206-208 ft bls.

Aquifer-Isolation Tests

On the basis of the borehole geophysical logs and heatpulse-flowmeter measurements, four intervals were selected for isolation (table 9). The distance between the center of the top packer and the center of the bottom packer was 19 ft. During pumping of the isolated zone, water levels in nearby wells OB-4 and OB-3 were monitored in addition to water levels in well RW-6.

Table 8. *Heatpulse-flowmeter measurements made in well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

Depth (feet below land surface)	Flow (gallons per minute)	Flow direction
79	0	
106	1.1	Up
124	1.3	Down
150	1.4	Down
162	1.3	Down
170	.87	Down
199	1.4	Down
214	0	

Table 9. *Intervals isolated and specific capacities for well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania*

Interval number	Isolated interval (feet below land surface)	Isolated fracture (feet below land surface)[1]	Pumping time (minutes)	Average pumping rate (gallons per minute)	Specific capacity (gallons per minute per foot)
1	197-216	206-208	94	13.1	0.16
2	177-196	180-182	90	7.5	.09
3	106-125	118-119	127	[2] 23.3	2.3
4	80-99	90-92	96	[2] 25	3.5

[1] Center of packer to center of packer.
[2] Sediment clogged in-line flowmeter. Estimated by volumetric method.

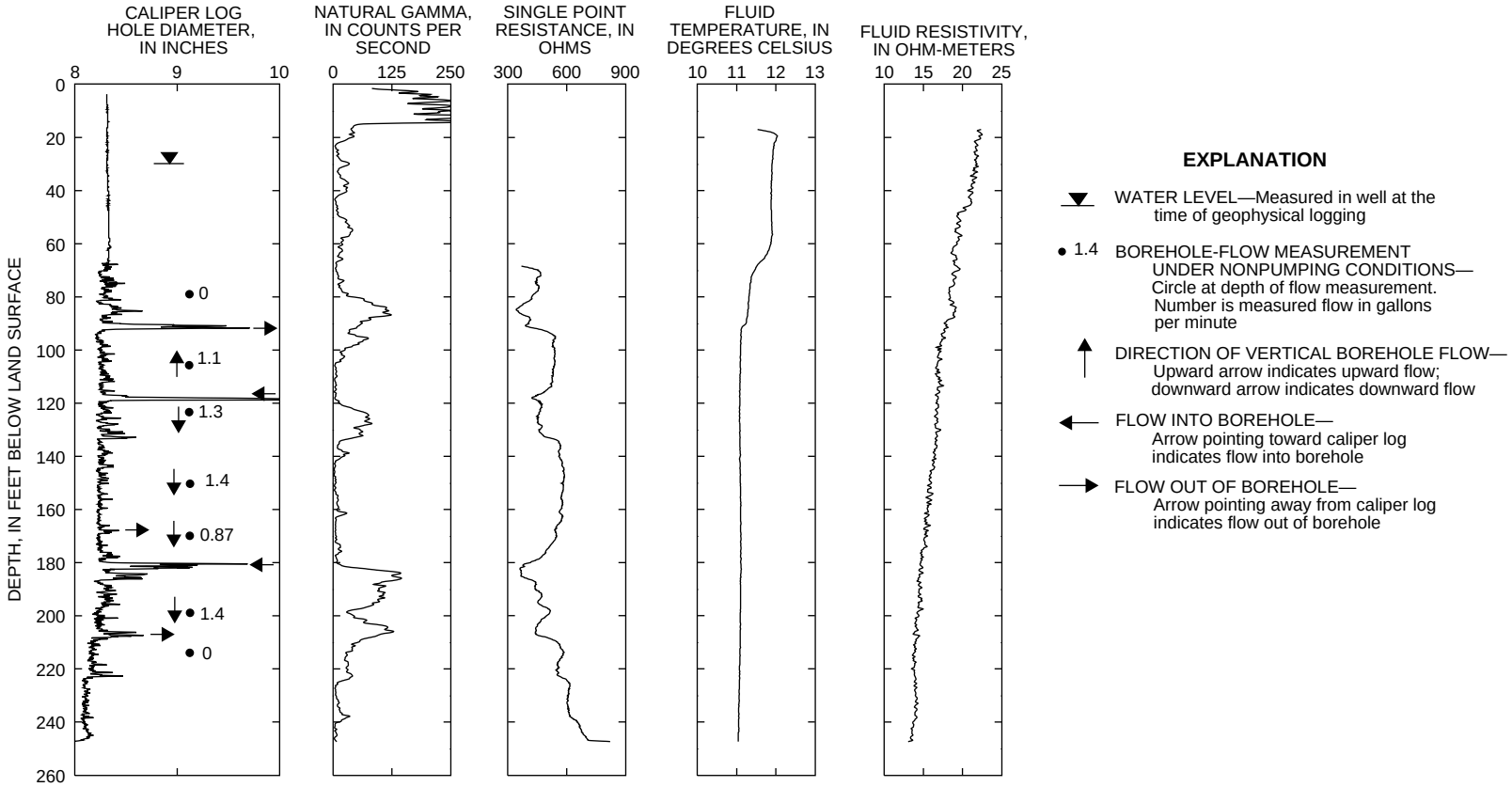


Figure 17. Borehole geophysical logs from well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 1 (197 to 216 Feet Below Land Surface)

For isolated interval 1, the top packer was centered at 197 ft bls, and the lower packer was not inflated (fig. 2A). The interval of borehole isolated was from 197 ft bls to 216 ft bls. This interval includes the major water-receiving fracture at 206-208 ft bls. Before packer inflation, the depth to water in the open borehole was 11.45 ft bls. Eighty-five minutes after packer inflation, the depth to water in the isolated interval decreased 1.59 ft. The depth to water in the interval above the packer increased 0.10 ft. This is consistent with the interpretation of the borehole geophysical logs and downward borehole flow shown by the heat-pulse-flowmeter measurements, which indicate the isolated water-producing fracture at 206-208 ft bls has a lower head than the water-receiving fractures above.

Isolated interval 1 was initially pumped at 20.5 gal/min, but the water level rapidly dropped below the level of the transducer, which was set at 115.57 ft bls (drawdown greater than 102.54 ft). The pumping rate was then reduced to 13 gal/min; the maximum drawdown at that rate was 80.65 ft. Isolated interval 1 was pumped at a time-weighted average rate of 13.1 gal/min for 94 minutes. Drawdown in the interval above the packers was 0.11 ft, and drawdown in the interval below the packers was 37.66 ft. The specific capacity of interval 1 is 0.16 (gal/min)/ft. The hydrographs for well RW-6 and the observation wells are shown in figure 18. The hydrographs indicate a hydraulic connection outside the borehole between the isolated interval and interval below the packer. No drawdown was observed in the observation wells.

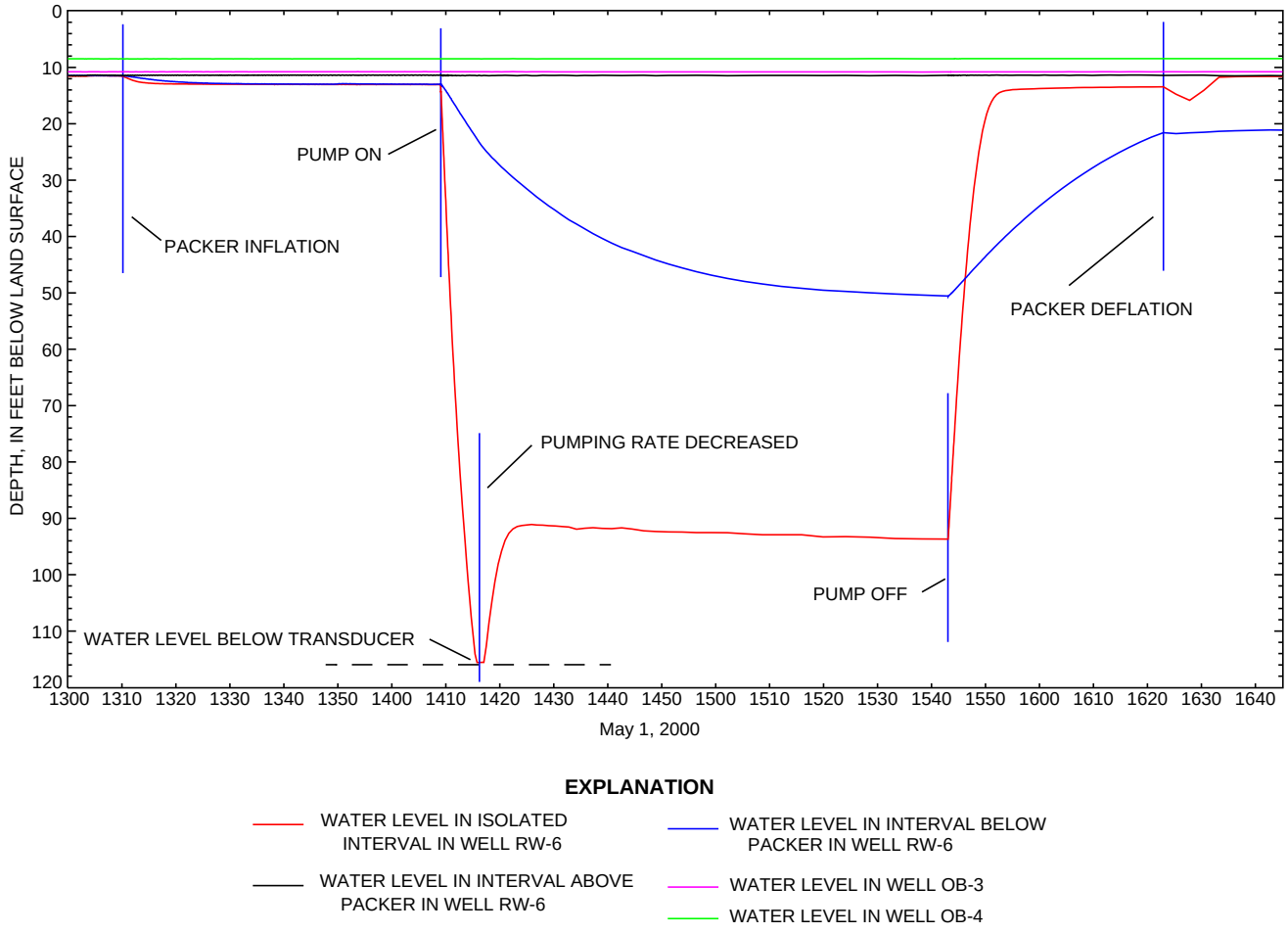


Figure 18. Hydrographs from aquifer-isolation test of interval 1 (197 to 216 feet below land surface) in well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 2 (177 to 196 Feet Below Land Surface)

For isolated interval 2, the top packer was set at 177 ft bls (fig. 2B), and the interval of borehole isolated was from 177 to 196 ft bls. This interval includes the major water-producing fracture at 180-182 ft bls. Before packer inflation, the depth to water in the open borehole was 11.57 ft bls. Fifty-eight minutes after packer inflation, depth to water in the interval above the packer increased 0.06 ft, depth to water in the isolated interval decreased 0.84 ft, and depth to water in the interval below the packer decreased 1.08 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-producing fracture at 180-182 ft bls has a higher head than the water-producing fractures below and a lower head than the water-producing fractures above.

Isolated interval 2 was pumped at a time-weighted average rate of 7.5 gal/min for 90 minutes. The initial pumping rate was 22 gal/min, but the water level in the isolated interval dropped below the transducer, which was set at 114.50 ft bls. The pumping rate was then decreased to 5.4 gal/min for the remainder of the test. Drawdown after the rate increase in the interval above the packers was 0.20 ft, drawdown in the isolated interval was 84.74 ft, and drawdown in the interval below the packers was 5.46 ft. The specific capacity of interval 2 is 0.09 (gal/min)/ft. The hydrographs for the isolated interval and the intervals above and below the packers are shown in figure 19. The hydrographs indicate a hydraulic connection outside the borehole between the isolated interval and the interval below the packer. No drawdown was observed in the observation wells.

Aquifer-Isolation Test of Interval 3 (106 to 125 Feet Below Land Surface)

For isolated interval 3, the top packer was centered at 106 ft bls (fig. 2A), and the interval of borehole isolated was from 106 to 125 ft bls. This interval includes the major water-producing fracture at 118-119 ft bls. Before packer inflation, the depth to water in the open borehole was 11.76 ft bls. Fifty-four minutes after packer inflation, depth to water in the

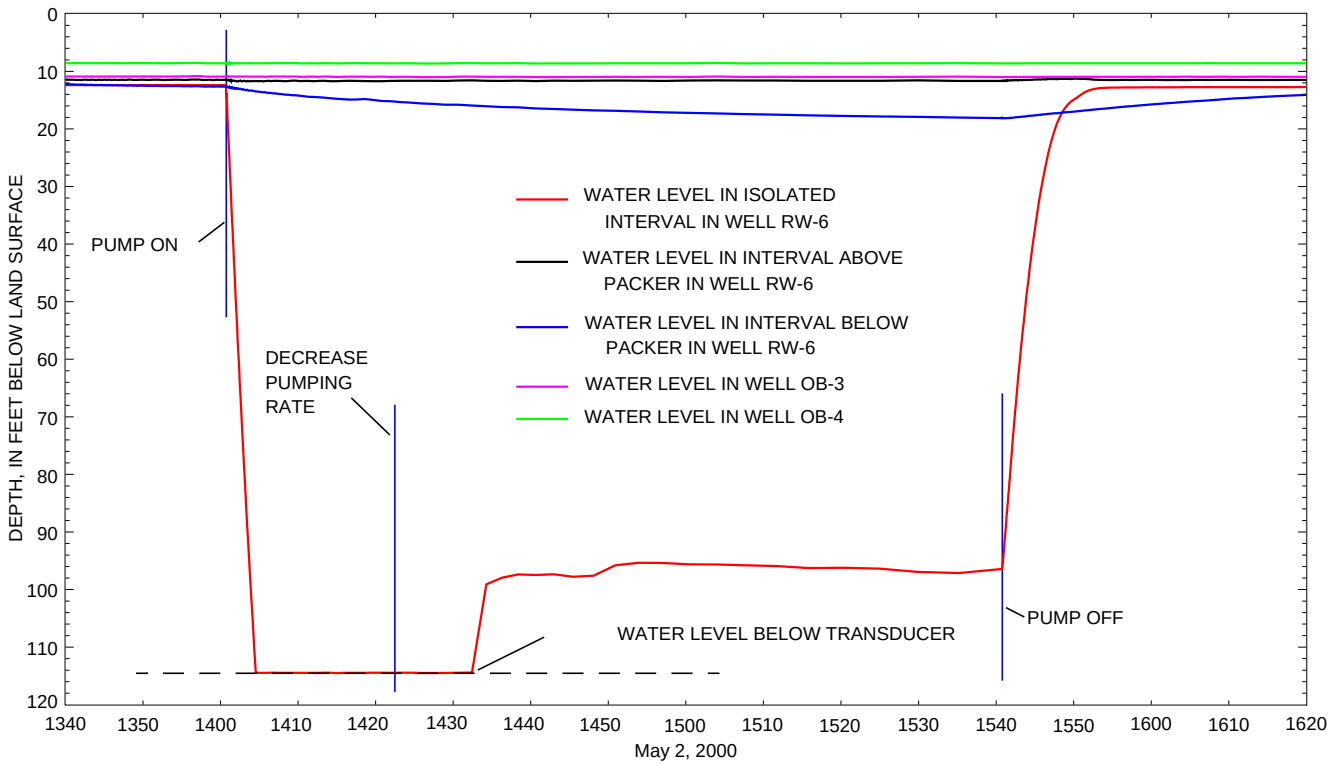


Figure 19. Hydrographs from aquifer-isolation test of interval 2 (177 to 196 feet below land surface) in well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

interval above the packer increased 0.17 ft, depth to water in the isolated interval decreased 0.05 ft, and depth to water in the interval below the packer increased 0.67 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-producing fracture at 118-119 ft bls has a higher head than the water-receiving fractures above and below.

Isolated interval 3 is a high-yielding zone; it was pumped at an estimated average rate of 23.3 gal/min for 127 minutes with a maximum drawdown of 9.98 ft (fig. 20). The pumping rate was estimated by making periodic volumetric measurements because sediment in the discharge water clogged the in-line flowmeter. Drawdown in the interval above the packers was 0.91 ft, and drawdown in the interval below the packers was 2.19 ft. The specific capacity of interval 3 is 2.3 (gal/min)/ft. The hydrographs for well RW-6 and the observation wells are shown in figure 20. The hydrographs indicate a hydraulic connection outside the borehole between the isolated interval and the intervals above and below the isolated interval. Drawdown in wells OB-3 and OB-4 caused by pumping the isolated interval was 0.15 ft and 0.36 ft, respectively, indicating a hydraulic connection between the isolated interval 106-125 ft bls in well RW-6 and the observation wells.

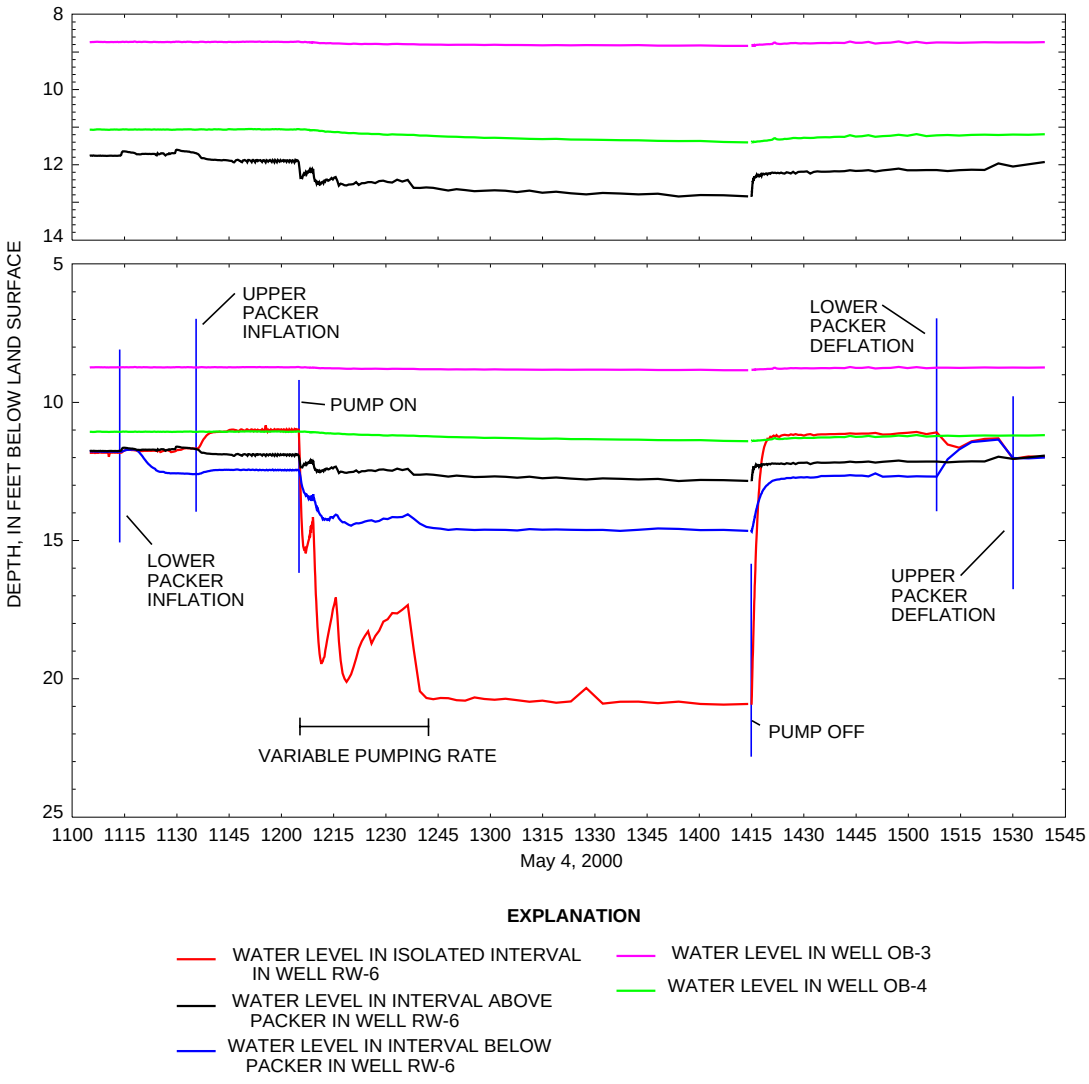


Figure 20. Hydrographs from aquifer-isolation test of interval 3 (106 to 125 feet below land surface) in well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

Aquifer-Isolation Test of Interval 4 (80 to 99 Feet Below Land Surface)

For isolated interval 4, the top packer was centered at 80 ft bls (fig. 2B), and the interval of borehole isolated was from 80 to 99 ft bls. This interval includes the water-receiving fracture at 90-92 ft bls. Before packer inflation, the depth to water in the open borehole was 11.62 ft bls. Thirty-seven minutes after packer inflation, depth to water in the isolated interval decreased 0.15 ft, depth to water in the interval above the packers increased 0.12 ft, and depth to water in the interval below the packers increased 0.57 ft. This is consistent with the interpretation of the borehole geophysical logs, which indicate the isolated water-receiving fracture at 90-92 ft bls has a lower head than the water-producing fracture below.

Isolated interval 4 is a high-yielding zone; it was pumped at an estimated average rate of 25 gal/min for 96 minutes with a maximum drawdown of 7.24 ft (fig. 21). The pumping rate was estimated by making periodic volumetric measurements because sediment in the discharge water clogged the in-line flowmeter. Drawdown in the isolated interval above the packers was 1.17 ft, and drawdown in the interval below the packers was 0.66 ft. The specific capacity of interval 4 is 3.5 (gal/min)/ft. The hydrographs for well RW-6 and the observation wells are shown in figure 21. The hydrographs indicate a hydraulic connection outside the borehole between the isolated interval and the intervals above and below the isolated interval. Drawdown in well OB-4 caused by pumping the isolated interval was 0.20 ft, indicating a hydraulic connection between the isolated interval 80-99 ft bls in well RW-6 and well OB-4.

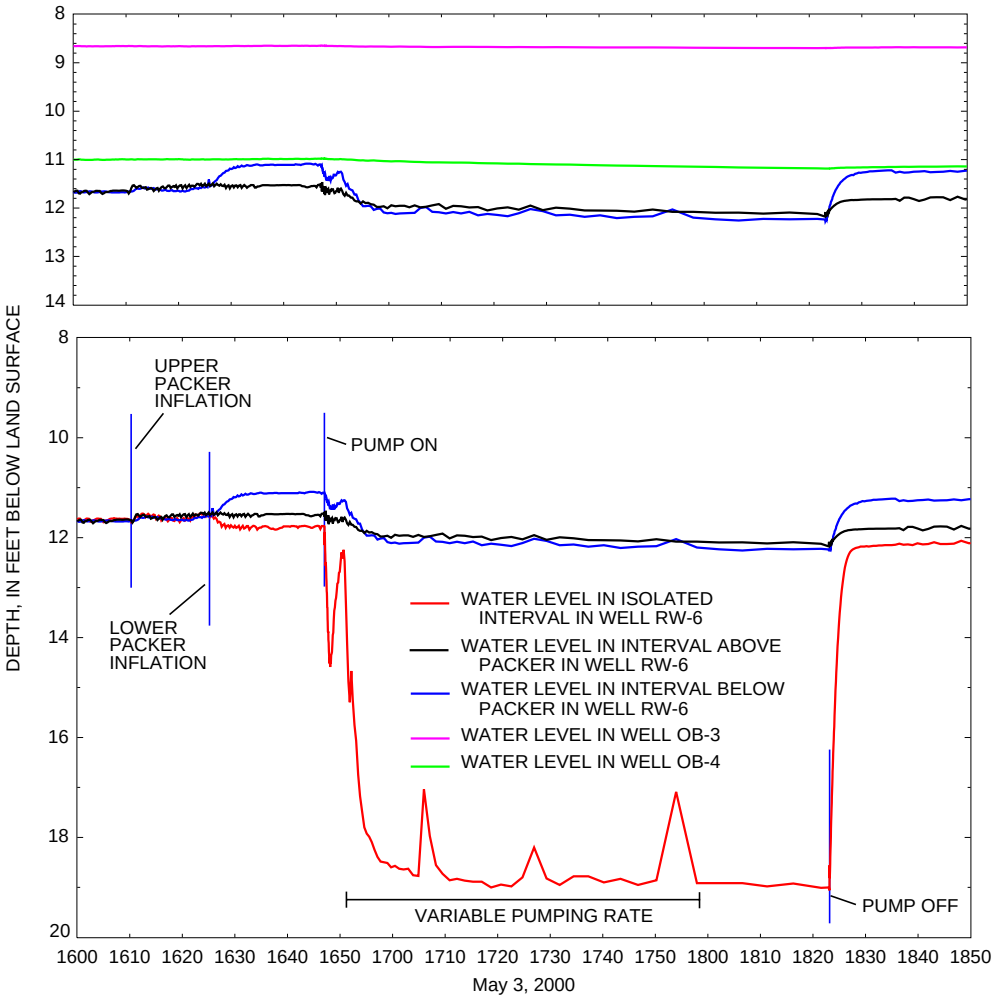


Figure 21. Hydrographs from aquifer-isolation test of interval 4 (80 to 99 feet below land surface) in well RW-6 (CH-5808), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS FOR WELL RW-1 (CH-5804)

A suite of borehole geophysical logs (fig. 22) was collected in well RW-1 by the USGS. The caliper log shows the well is 297 ft deep and is cased to 40 ft bls. The caliper log shows a major fracture at 50-52 ft bls and minor fractures at 59-60, 65, and 169-171 ft bls. The fracture at 50-52 ft bls appears to be the major water-producing fracture. The fluid-resistivity and fluid-temperature logs do not indicate borehole flow under nonpumping conditions. This was confirmed with heatpulse-flowmeter measurements made at 68, 100,164, and 244 ft bls that showed no measurable flow.

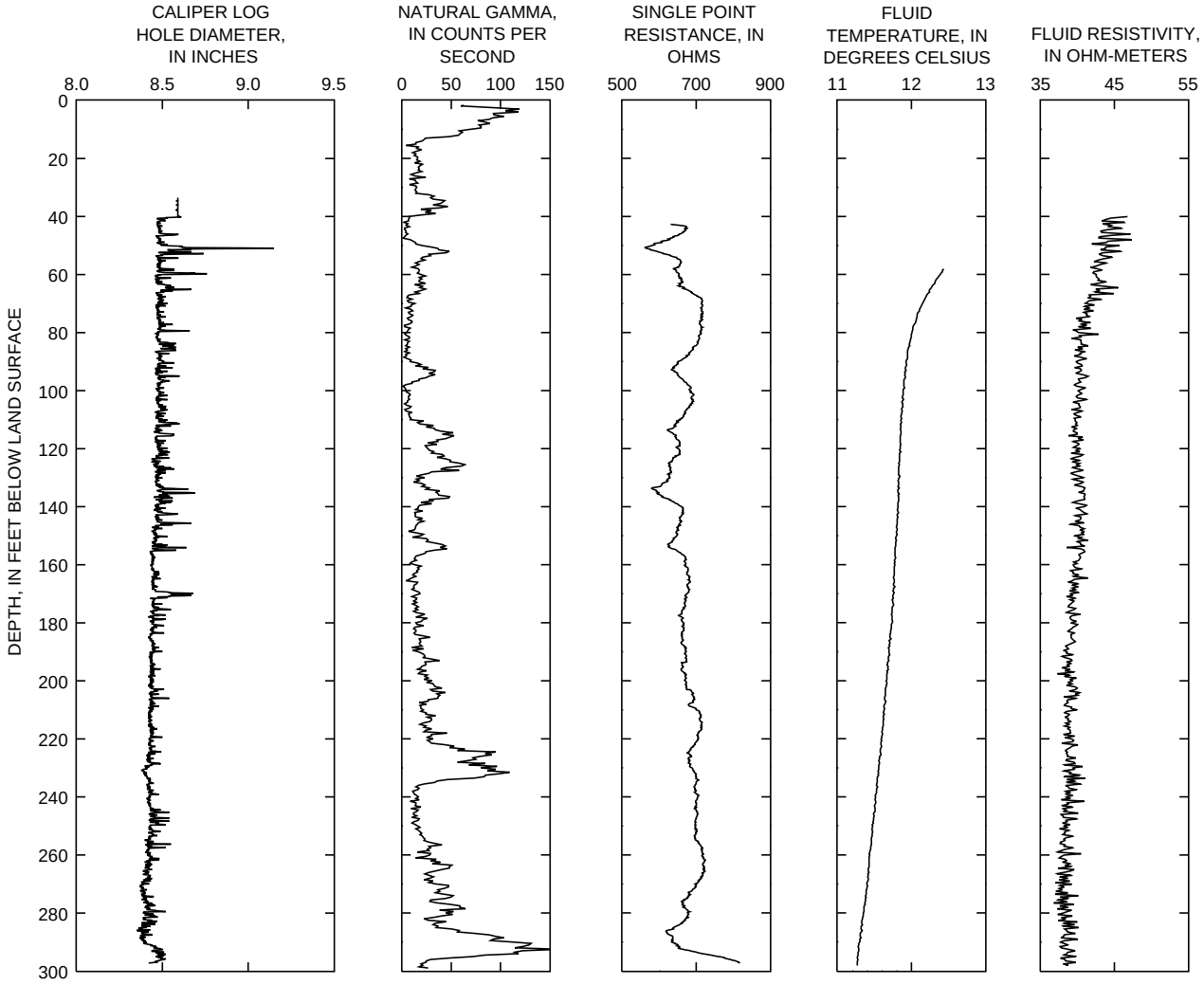


Figure 22. Borehole geophysical logs from well RW-1 (CH-5804), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS FOR WELL RW-4 (CH-5807)

A suite of borehole geophysical logs (fig. 23) was collected in well RW-4 by the USGS. The caliper log shows the well is 298 ft deep and is cased to 18 ft bls. The caliper log shows a major fracture at 24-26 ft bls and several minor fractures. The fluid-resistivity and fluid-temperature logs do not indicate borehole flow under nonpumping conditions. This was confirmed with heatpulse-flowmeter measurements made at 44, 90, 170, and 260 ft bls that showed no measurable flow.

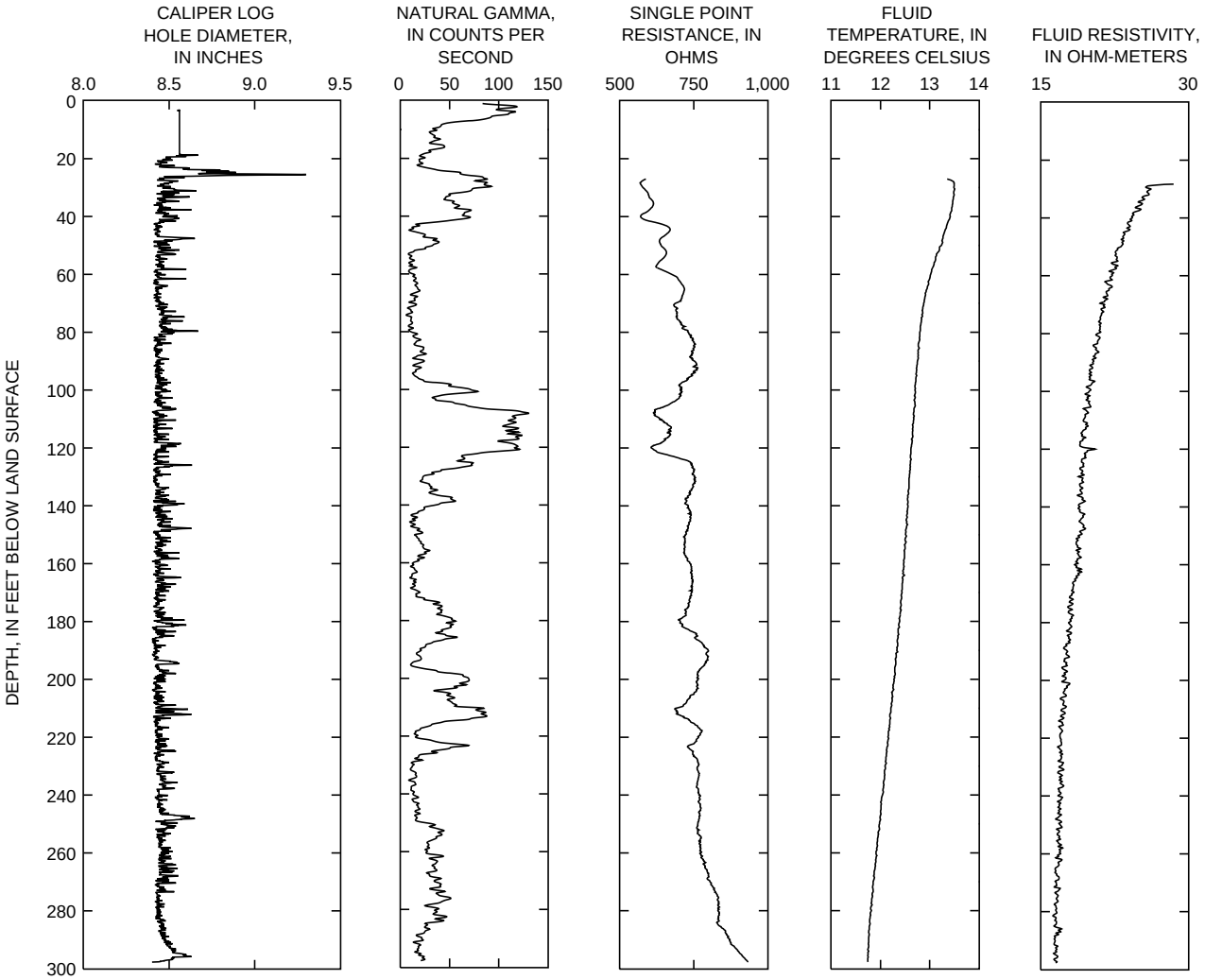


Figure 23. Borehole geophysical logs from well RW-4 (CH-5807), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

EVALUATION OF BOREHOLE GEOPHYSICAL LOGS FOR WELL OB-5 (CH-5447)

A suite of borehole geophysical logs (fig. 24) was collected in well OB-5 by the USGS. The caliper log shows the well is 38 ft deep and is cased to 21.5 ft bls. The caliper log shows a large fracture zone from the bottom of the casing to the bottom of the well. The well may have filled to 38 ft bls with sediment from this fracture zone.

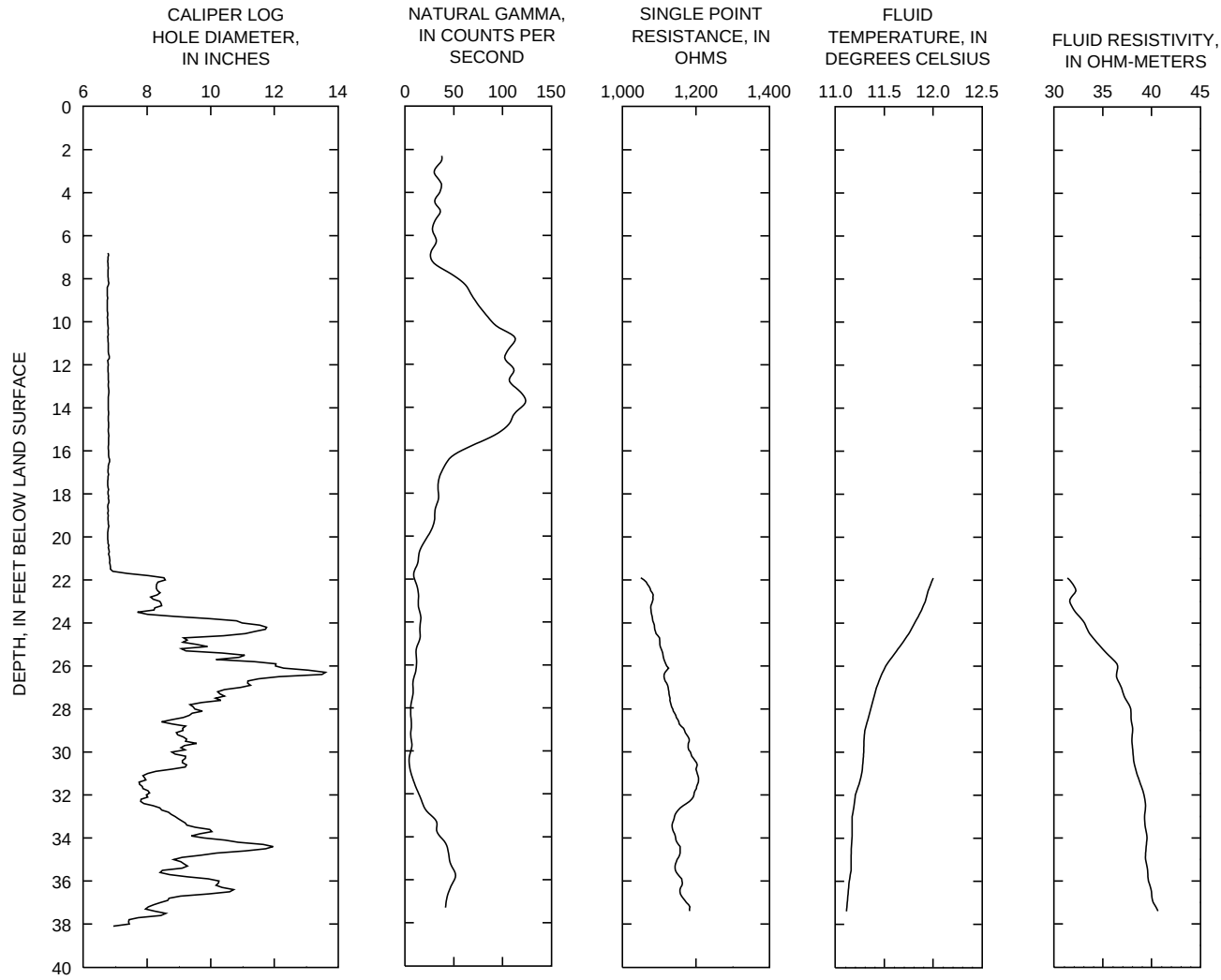


Figure 24. Borehole geophysical logs from well OB-5 (CH-5447), AIW Frank/Mid-County Mustang Superfund Site, Chester County, Pennsylvania.

SUMMARY AND CONCLUSIONS

Borehole geophysical logs, heatpulse-flowmeter measurements, and aquifer-isolation tests were used to characterize the ground-water-flow system at the AIW Frank / Mid-County Mustang Superfund Site in Chester County, Pa. The site is underlain by fractured carbonate rocks.

Caliper, natural-gamma, single-point-resistance, fluid-resistivity, and fluid-temperature logs were collected in six wells. An acoustic borehole televiewer and borehole deviation log were run in one well. The direction and rate of borehole-fluid movement were measured with a high-resolution heatpulse flowmeter for both nonpumping and pumping conditions in four wells. The heatpulse flowmeter was used to determine the hydraulically active fractures in the logged wells. The logs and heatpulse-flowmeter measurements were used to locate water-bearing fractures, determine probable zones of vertical borehole-fluid movement, and determine the depth to set straddle packers.

The heatpulse-flowmeter measurements confirmed the location of water-bearing zones identified by the other logs and showed flow within the borehole during nonpumping conditions in three of the four wells tested. Flow rates up to 1.4 gal / min were measured. Flow was upward in well RW-3, and both upward and downward in wells RW-2 and RW-6.

Aquifer-isolation tests, commonly known as packer tests, were conducted in four wells to determine depth-discrete specific capacity values, to obtain depth-discrete water samples, and to determine the effect of pumping an individual fracture or fracture zone on water levels in nearby wells. Water-level data collected during aquifer-isolation tests were consistent with and confirmed interpretations of borehole geophysical logs and heatpulse-flowmeter measurements. Seven of the 13 fractures identified as water-producing or water-receiving zones by borehole geophysical methods produced water at a rate equal to or greater than 7.5 gal / min when isolated and pumped.

The drawdown in nearby observation wells, and the number of wells affected by pumping isolated fractures in well EW-5, decreased with depth. For well RW-2, pumping the shallowest isolated interval caused drawdown in all five observation wells, while pumping the four deeper isolated intervals caused drawdown only in observation well OB-2S. For well RW-6, pumping the uppermost two isolated intervals caused drawdown in nearby observation wells.

The specific capacity of isolated fractures range over three orders of magnitude from 0.005 to 7.1 (gal / min) / ft. This is typical of fractured-rock aquifers. Vertical distribution of specific capacity between land surface and 298 ft bls is not related to depth. The four highest specific capacities, in descending order, are at depths of 174-198, 90-92, 118-119, and 34-37 ft bls.

REFERENCES CITED

Bascom, Florence, and Stose, G.W., 1938, Geology and mineral resources of the Honeybrook and Phoenixville quadrangles, Pennsylvania: U.S. Geological Survey Bulletin 891, 145 p.

Conger, R.W., Goode, D.J., and Sloto, R.A., 2000, Evaluation of geophysical logs and slug tests, phase II, AIW Framk / Mid-County Mustang Superfund Site, Chester County, Pennsylvania: U.S. Geological Survey Open-File Report 99-452, 28 p.

Halliburton NUS, Inc., 1991, Draft remedial investigation / feasibility study project operations plan, AIW / Frank Site, Chester County, Pennsylvania: EPA work assignment number 37-18-3625.

Keys, W.S., 1990, Borehole geophysics applied to ground-water investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E2, 150 p.

Sloto, R.A., 1994, Geology, hydrology, and ground-water quality of Chester County, Pennsylvania: Chester County Water Resources Authority Water Resources Report 2, 118 p.