U.S. Department of the Interior
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AQUIFER TESTS AND SIMULATION OF GROUND-WATER FLOW IN TRIASSIC SEDIMENTARY ROCKS NEAR COLMAR, BUCKS AND MONTGOMERY COUNTIES, PENNSYLVANIA

by Dennis W. Risser and Philip H. Bird

Water-Resources Investigations Report 03-4159

In cooperation with the

U.S. ENVIRONMENTAL PROTECTION AGENCY

New Cumberland, Pennsylvania
2003

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CONVERSION FACTORS, DATUMS, AND ABBREVIATED WATER-QUALITY UNIT

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second
inch per year (in/yr)	25.4	millimeter per year
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Other abbreviations:

µg/L, micrograms per liter

Aquifer Tests and Simulation of Ground-Water Flow in Triassic Sedimentary Rocks near Colmar, Bucks and Montgomery Counties, Pennsylvania

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ABSTRACT

This report presents the results of a study by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency to evaluate ground-water flow in Triassic sedimentary rocks near Colmar, in Bucks and Montgomery Counties, Pa. The study was conducted to help the U.S. Environmental Protection Agency evaluate remediation alternatives at the North Penn Area 5 Superfund Site near Colmar, where ground water has been contaminated by volatile organic solvents (primarily trichloroethene). The investigation focused on determining the (1) drawdown caused by separately pumping North Penn Water Authority wells NP–21 and NP–87, (2) probable paths of ground-water movement under present-day (2000) conditions (with NP–21 discontinued), and (3) areas contributing recharge to wells if pumping from wells NP-21 or NP–87 were restarted and new recovery wells were installed. Drawdown was calculated from water levels measured in observation wells during aquifer tests of NP–21 and NP–87. The direction of ground-water flow was estimated by use of a three-dimensional ground-water-flow model.

Aquifer tests were conducted by pumping NP–21 for about 7 days at 257 gallons per minute in June 2000 and NP–87 for 3 days at 402 gallons per minute in May 2002. Drawdown was measured in 45 observation wells during the NP–21 test and 35 observation wells during the NP–87 test. Drawdown in observation wells ranged from 0 to 6.8 feet at the end of the NP–21 test and 0.5 to 12 feet at the end of the NP–87 test. The aquifer tests showed that ground-water levels declined mostly in observation wells that were completed in the geologic units penetrated by the pumped wells. Because the geologic units dip about 27 degrees to the northwest, shallow wells up dip to the southeast of the pumped well showed a good hydraulic connection to the geologic units stressed by pumping. Most observation wells down dip from the pumping well penetrated units higher in the stratigraphic section that were not well connected to the units stressed by pumping. The best hydraulic connection to the pumped wells was indicated by large drawdown in observation wells that penetrate the water-bearing unit encountered below 400 feet below land surface in wells NP–21 and NP–87. The hydraulic connection between wells NP–21 (or NP–87) and observation wells in the southern area of ground-water contamination near the BAE Systems facility is good because the observation wells probably penetrate this water-bearing unit.

A 3-dimensional, finite-difference, ground-water-flow model was used to simulate flow paths and areas contributing recharge to wells for current (2000) conditions of pumping in the Colmar area and for hypothetical situations of pumping suggested by the U.S. Environmental Protection Agency that might be used for remediation. Simulations indicate that under current conditions, ground water in the northern area of contamination near the former Stabilus facility moves to the northwest and discharges mostly to West Branch Neshaminy Creek; in the southern area of contamination near BAE Systems facility, ground water probably moves west and discharges to a tributary of West Branch Neshaminy Creek near well NP–21. Model simulations indicate that if NP–21 or NP–87 are pumped at 400 gallons per minute, ground-water recharge is likely captured from the southern area of contamination, but ground-water recharge from the northern area of contamination is less likely to be captured by the pumping. Simulations also indicate that pumping of a new recovery well near BAE Systems facility at 8 gallons per minute and two new recovery wells near the former Stabilus facility at a total of about 30 gallons per minute probably would capture most of the ground-water recharge in the areas where contamination is greatest.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) is in the process of characterizing ground-water contamination and evaluating remediation alternatives for the North Penn Area 5 Superfund Site, Montgomery and Bucks Counties, in southeastern Pennsylvania. The U.S. Geological Survey (USGS) is assisting USEPA by providing geophysical and hydrologic investigations to evaluate the fractured-rock aquifer. The North Penn Area 5 includes numerous industries and commercial operations near Colmar, Pa., where ground water has been contaminated by volatile organic compounds (VOCs). The area of study near Colmar described in this report is shown in figure 1.

North Penn Area 5 is one of seven Superfund sites in the Lansdale area where VOCs have contaminated ground-water resources used for public supply. In August 1979, ground-water contamination became evident near Colmar when the North Penn Water Authority (NPWA) found trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and tetrachloroethene (PCE) in water samples collected from municipal-supply well NP–21 (Earth Technology Corporation, 1993). Through subsequent sampling by industry, utilities, and regulatory agencies, an area of ground-water contamination was identified, and in 1989, the USEPA added North Penn Area 5 to the National Priorities List (NPL).

Since 1998, ground-water sampling for the Remedial Investigation / Feasibility Study (RI / FS) by USEPA and its contractors has verified two general locations of ground-water contamination near well NP–21—one near the BAE Systems facility and one near the former Stabilus facility. These areas, respectively, are referred to as the southern and northern areas of contamination in this report and are indicated by the well symbols shown in red on figure 2. Specifically, red symbols indicate wells where TCE in ground water exceeded 300 µg / L in at least one sample between 1998 and 2002. The concentration of 300 µg / L was chosen to illustrate the two areas of greatest contamination in the study area and does not denote the extent of known ground-water contamination nor represent a specific health-criteria level.

The major contaminant in ground water at both areas is TCE. In the southern area of contamination near BAE Systems, TCE was detected in ground water from well A–12 at a concentration of 1,200 µg / L in 1998, and in the same general area, ground-water samples from RI–20S contained 320 µg / L of TCE (Tetra Tech / Black & Veatch, 2002). To remediate the southern area of contamination, a pump-and-treat system has been in operation since 1986, using well A–10 (fig. 2) as the recovery well. In the northern area of contamination near the former Stabilus facility, ground-water samples from well RI–27S contained 3,800 µg / L of TCE in 2002 (Tetra Tech / Black & Veatch, 2002). Concentrations of TCE in excess of 300 µg / L were measured in water samples from seven other shallow wells in the same general area and at RI–17 since 1998 (fig. 2).

Purpose and Scope

This report presents the results of a study by the USGS to evaluate ground-water flow in the vicinity of well NP–21 near Colmar, Pa. (fig. 2). Specific objectives were to (1) determine the drawdown caused by pumping NPWA wells NP–21 or NP–87, (2) evaluate probable paths of ground-water flow under present-day conditions (2000) (with NP–21 pumping discontinued), and (3) determine the areas contributing recharge if pumping from NP–21 or NP–87 was restarted and new recovery wells were installed. Drawdown was calculated from water levels measured in observation wells during aquifer tests at wells NP–21 and NP–87. Because the dipping geologic units yielding water to the pumping wells impart heterogeneity and anisotropy with respect to hydraulic conductivity, ground-water-flow paths may be difficult to infer directly from the water-table configuration. Ground-water-flow paths and areas contributing recharge were therefore estimated by use of a ground-water-flow model.

The scope of the report is limited to an analysis of ground-water flow near Colmar under current conditions and those imposed by hypothetical pumping of supply well NP–21 or NP–87 and proposed recovery wells; the effects of historical ground-water withdrawals on ground-water flow were not evaluated. Although ground-water flow in the Colmar area was the focus of the study, to ensure that arbitrary boundaries in the ground-water-flow model were sufficiently distant from the Colmar area, the domain of the ground-water-flow model encompassed the larger area shown in figure 1.

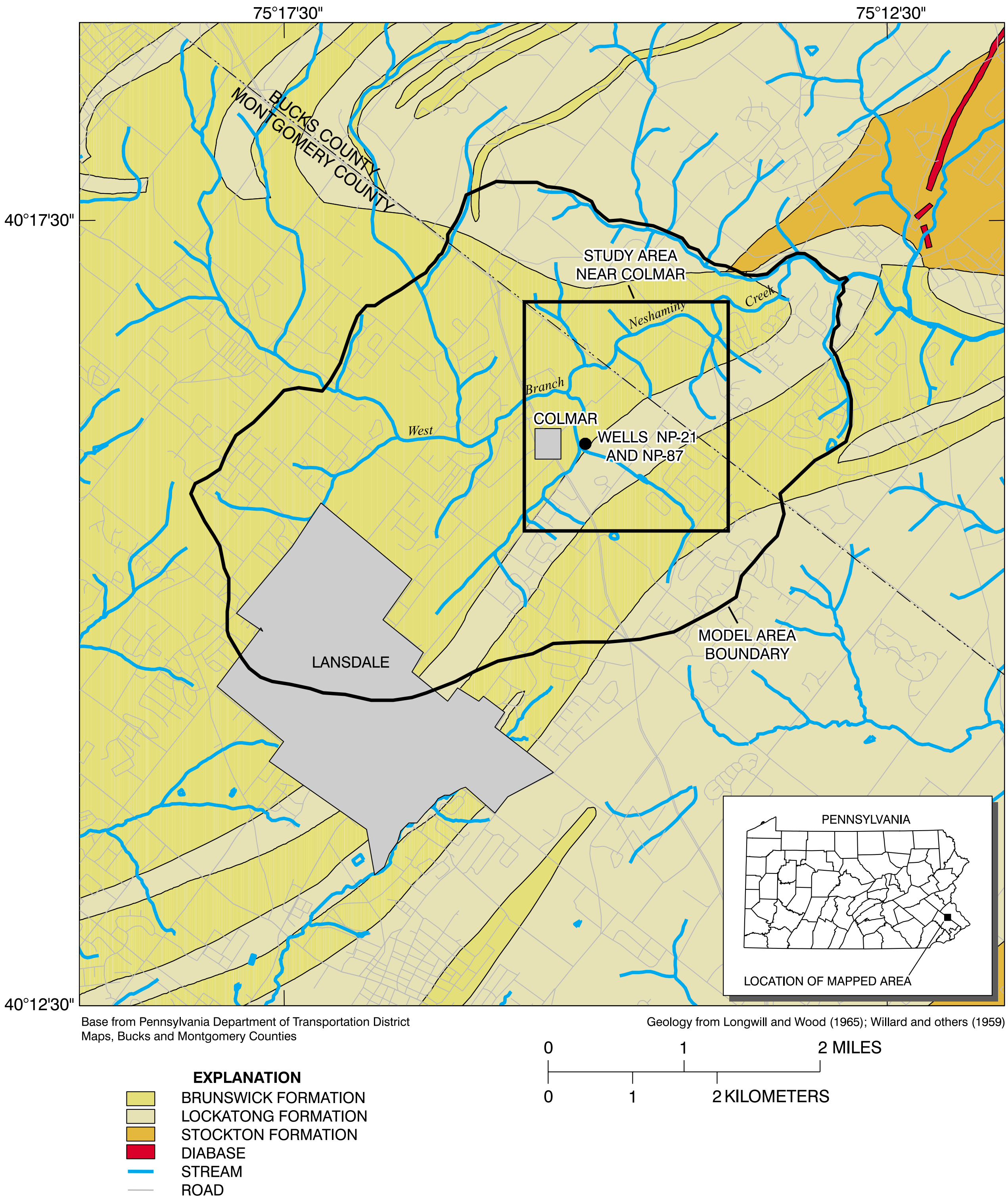
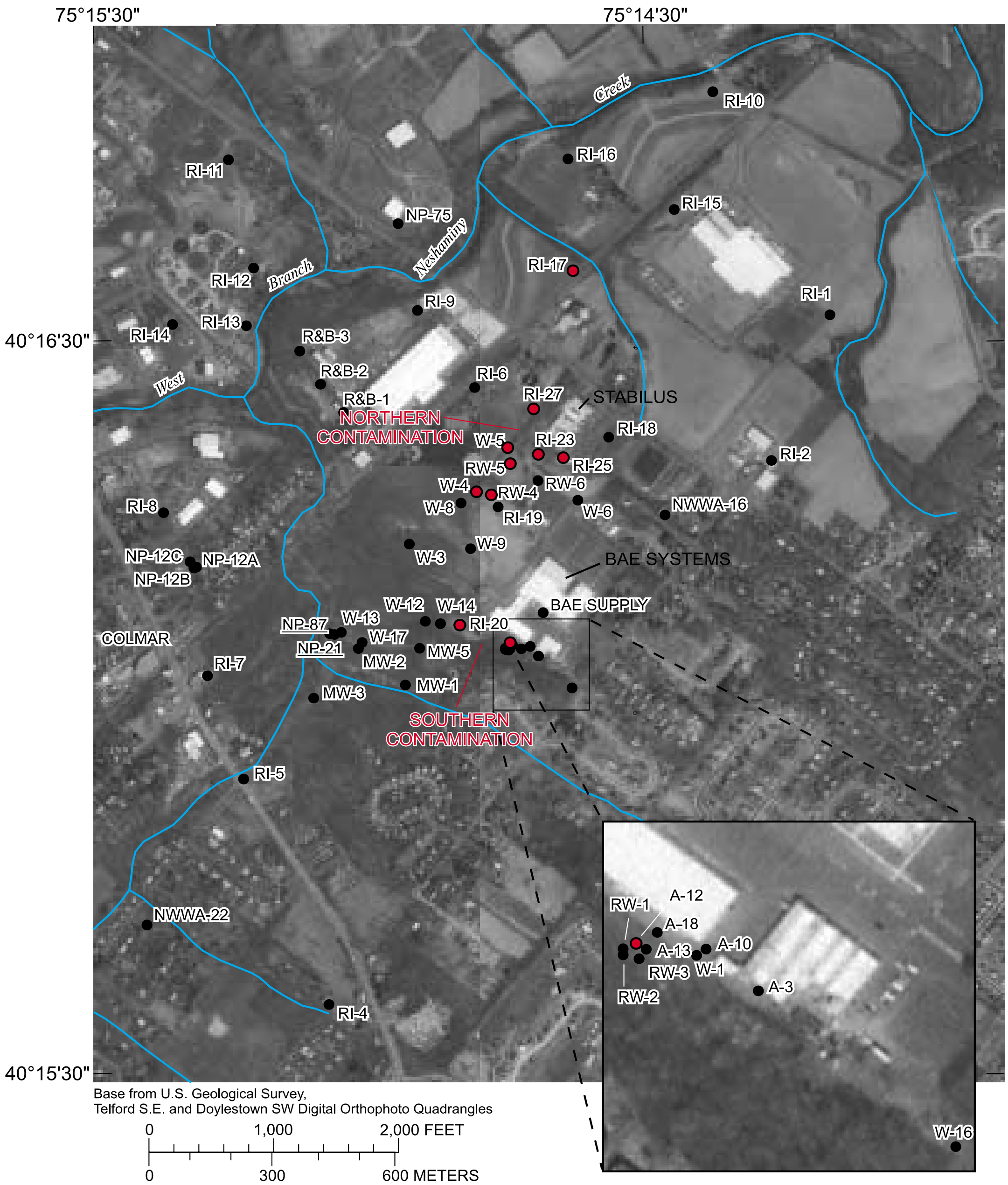


Figure 1. Location of study area near Colmar, geology, and ground-water-flow model domain, Bucks and Montgomery Counties, Pennsylvania.



EXPLANATION

RI-23 WELL AND IDENTIFIER -- TCE IN GROUND WATER EXCEEDED 300 MICROGRAMS PER LITER IN AT LEAST ONE SAMPLE 1998-2002.

W-17 WELL AND IDENTIFIER -- Line under the identifier indicates wells pumped for aquifer test.

Note: RI-Series wells are shallow (S) and deep (D) nested wells except RI-23 and RI-25, which are single wells. RW-4, RW-5, and RW-6 are clusters of 3 wells (shallow, intermediate, and deep) at each location (see table 1)

Figure 2. Location of selected wells in the study area near Colmar, Bucks and Montgomery Counties, Pennsylvania.

Previous Investigations

A number of previous studies provide information about the ground-water resources and geology in the Colmar area. Rima (1955) described the occurrence and movement of ground water in the Lansdale area. Longwill and Wood (1965) and Newport (1971) provided information about well characteristics, ground-water-quality data, and general ground-water resources in Montgomery County. The study by Longwill and Wood (1965) focused on ground water in the Brunswick Formation and contained a geologic map, which in the Lansdale area was based almost entirely on unpublished manuscripts by Dean B. McLaughlin, Pennsylvania Topographic and Geologic Survey. Lyttle and Epstein (1987) compiled a geologic map of the Newark 1° × 2° Quadrangle that updated and revised the geologic nomenclature for the area. Biesecker and others (1968) described the water resources of the Schuylkill River Basin, which drains part of the Lansdale area. Goode and Senior (1998) reviewed aquifer tests conducted in the Lansdale area, including a test at supply well NP–21 in 1980. Senior and Goode (1999) described the ground-water system and the effect of pumping on ground-water flow in the Lansdale area. Their work included an analysis of regional ground-water-flow directions by the use of a ground-water-flow model. The results of geophysical logging conducted in support of the regional study in the Lansdale area were reported by Conger (1999).

Investigations of ground-water contamination at North Penn Area 5 are summarized by Earth Technology Corporation (1993). Their work describes previous ground-water sampling results, remediation actions, and sources of contamination and outlines the approach for the RI/FS study. The most comprehensive description of site characteristics, delineation of ground-water contamination, and discussion of contaminant fate and transport are contained in the RI/FS report by Tetra Tech/Black & Veatch (2002). USGS work in support of the RI/FS is reported in Bird and Conger (2002). They present an analysis of borehole geophysical logging and packer tests, list results of water-quality analyses, and map water levels from wells in North Penn Area 5.

Well-Identification System

Well identifiers used by USGS consist of a county-abbreviation prefix preceding a sequentially assigned well number. The prefix BK denotes a well in Bucks County; the prefix MG denotes a well in Montgomery County. Local site identifiers given to wells by water utilities, local property owners, or contractors are cross-referenced to USGS well identifiers in table 1. In this report, wells are identified by their local identifier to accommodate readers who are familiar with the site and are accustomed to the established local well names. Locations of wells in the Colmar study area described in this report are shown in figure 2.

Acknowledgments

The authors acknowledge the individuals and companies that provided data and allowed access to their wells. Thanks to the NPWA for use of wells NP–21 and NP–87 for aquifer testing. Appreciation is extended to Patrick Till of BAE Systems; David Fennimore of Earth Data Northeast; Kevin McLaughlin of North Wales Water Authority; and Gregory Cavallo of the Delaware River Basin Commission for providing water-use data and information about wells. Thanks also to Tad Yancheski and Dana Small of TetraTech/Black & Veatch for providing data during the study and reviewing this report.

HYDROGEOLOGIC SETTING

The Colmar study area is in the Piedmont Physiographic Province and is underlain by Triassic sedimentary rocks of the Brunswick and Lockatong Formations (fig. 1). Beds in the Brunswick and Lockatong Formations are part of a homoclinal structure, striking NE-SW and dipping about 20 to 30° NW. The dipping bedrock is thinly mantled at the site with soil and unconsolidated weathered rock. The terrain varies from flat to low rolling hills and is drained by the West Branch Neshaminy Creek and its tributaries.

Geology

The Brunswick Formation underlies the northwestern half of the Colmar study area (fig. 1). The Brunswick Formation consists of several thousand feet of primarily reddish brown mudstone, shale, and siltstone, which interfinger with the underlying Lockatong Formation. The contact between the Brunswick and the Lockatong Formations generally is placed where the total thickness

Table 1. *Record of selected wells in the study area near Colmar, Bucks and Montgomery Counties, Pennsylvania*

[NGVD 29, National Geodetic Vertical Datum of 1929; Deg, degree; Min, minute; Sec, second; O, observation; N, industrial; P, public supply; R, remediation; U, unused; W, withdrawal; Z, destroyed; —, no data]

Local well identifier[1]	U.S. Geological Survey well identifier	Latitude			Longitude			Primary use		Measuring point elevation[2] (feet above NGVD 29)	Well depth (feet below land surface)	Well diameter (inches)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)
		Deg	Min	Sec	Deg	Min	Sec	Site	Water					
A–3	MG–1762	40	16	4.62	75	14	40.74	O	U	317.22	11	6	0	11
A–10	MG–1195	40	16	5.23	75	14	41.75	R	U	315.14	104	6	4	104
A–12	MG–1797	40	16	5.34	75	14	43.26	O	U	316.15	24	6	0	24
A–13	MG–1763	40	16	5.27	75	14	43.08	O	U	314.83	19	6	0	19
A–18	MG–1764	40	16	5.56	75	14	42.86	O	U	315.96	13	6	0	13
BAE Supply	MG–876	40	16	8	75	14	40	W	N	318	300	6	—	300
MW–1	MG–1921	40	16	1.67	75	14	54.96	O	U	297.23	50	6	19	50
MW–2	MG–1922	40	16	5.59	75	14	58.70	O	U	295.56	50	6	19	50
MW–3	MG–1923	40	16	.23	75	15	4.25	O	U	289.52	42	6	19	42
MW–5	MG–1924	40	16	5.20	75	14	53.38	O	U	302.58	50	6	19	50
NP–12A	MG–1765	40	16	11.82	75	15	16.20	U	U	300.42	46	6	17.5	46
NP–12B	MG–1691	40	16	11.89	75	15	15.91	U	U	300.19	115	6	22	115
NP–12C	MG–914	40	16	12.32	75	15	16.60	W	U	302.52	620	8	43	620
NP–21	MG–924	40	16	6.38	75	15	1.48	W	U	290.21	500	12	50	500
NP-61[3]	MG-1125	[4]—	—	—	—	—	—	W	P	331	400	10	60	400
NP–75	BK–1292	40	16	40.01	75	14	56.08	O	U	280.31	67	8	20	67
NP–87	MG–1693	40	16	6.46	75	15	1.98	U	U	288.06	476	12	103	476
NWWA–16	MG–1048	40	16	18	75	14	28	Z	U	—	502	12	60	502
NWWA–17[3]	MG–875	[4]—	—	—	—	—	—	W	P	332	500	12	60	500
NWWA–22	MG–1051	[4]—	—	—	—	—	—	W	P	308	500	8	—	500
R&B–1	MG–186	40	16	24.60	75	15	.58	U	U	282.23	286	10	44	286
R&B–2	MG–187	40	16	26.94	75	15	2.99	U	U	279.55	302	10	58	302
R&B–3	MG–188	40	16	29.64	75	15	5.18	U	U	276.81	300	10	58	300
RI–1D	BK–3001	40	16	32.12	75	14	10.46	O	U	296.65	108	2	98	108
RI–1S	BK–3002	40	16	32.12	75	14	10.46	O	U	296.75	66	2	56	66
RI–2D	BK–3003	40	16	20.75	75	14	15.79	O	U	309.94	139	2	129	139
RI–2S	BK–3004	40	16	20.75	75	14	15.79	O	U	309.96	48	2	38	48
RI–4D	MG–1768	40	15	34.81	75	15	2.27	O	U	341.61	146	2	126	146
RI–4S	MG–1769	40	15	34.81	75	15	2.27	O	U	341.64	39	2	20	40
RI–5D	MG–1770	40	15	54.50	75	15	10.94	O	U	296.46	85	2	45	55
RI–5S	MG–1771	40	15	54.50	75	15	10.94	O	U	296.47	33	2	20	30
RI–6D	MG–1772	40	16	26.69	75	14	46.86	O	U	285.23	84	2	64	84
RI–6S	MG–1773	40	16	26.69	75	14	46.86	O	U	285.20	28	2	18	28
RI–7D	MG–1774	40	16	2.96	75	15	14.76	O	U	309.15	96	2	86	96
RI–7S	MG–1775	40	16	2.96	75	15	14.76	O	U	309.09	66	2	56	66
RI–8D	MG–1776	40	16	16.36	75	15	19.40	O	U	302.39	125	2	115	125
RI–8S	MG–1777	40	16	16.36	75	15	19.40	O	U	302.48	90	2	80	90
RI–9D	MG–1902	40	16	32.66	75	14	53.30	O	U	272.62	136	2	126	136
RI–9S	MG–1903	40	16	32.66	75	14	53.30	O	U	272.67	48	2	18	48
RI–10D	BK–3016	40	16	51.46	75	14	22.20	O	U	269.99	63	2	46	61

Table 1. *Record of selected wells in the study area near Colmar, Bucks and Montgomery Counties, Pennsylvania—Continued*

[NGVD 29, National Geodetic Vertical Datum of 1929; Deg, degree; Min, minute; Sec, second; O, observation; N, industrial; P, public supply; R, remediation; U, unused; W, withdrawal; Z, destroyed; —, no data]

Local well identifier[1]	U.S. Geological Survey well identifier	Latitude			Longitude			Primary use		Measuring point elevation[2] (feet above NGVD 29)	Well depth (feet below land surface)	Well diameter (inches)	Top of open interval (feet below land surface)	Bottom of open interval (feet below land surface)
		Deg	Min	Sec	Deg	Min	Sec	Site	Water					
RI–10S	BK–3015	40	16	51.46	75	14	22.20	O	U	270.13	30	2	18	28
RI–11D	MG–1906	40	16	44.62	75	15	13.93	O	U	308.05	150	2	138	148
RI–11S	MG–1907	40	16	44.62	75	15	13.93	O	U	308.09	115	2	80	115
RI–12D	MG–1925	40	16	36.01	75	15	10.76	O	U	273.38	140	2	120	140
RI–12S	MG–1926	40	16	36.01	75	15	10.76	O	U	273.38	30	2	20	30
RI–13D	MG–1778	40	16	31.73	75	15	10.66	O	U	270.65	129	2	112	129
RI–13S	MG–1779	40	16	31.73	75	15	10.66	O	U	270.63	54	2	40	50
RI–14D	MG–1927	40	16	31.62	75	15	19.44	O	U	292.96	123	2	125	135
RI–14S	MG–1928	40	16	31.62	75	15	19.44	O	U	292.99	58	1	48	58
RI–15D	BK–3005	40	16	41.45	75	14	25.98	O	U	292.90	145	2	120	145
RI–15S	BK–3006	40	16	41.45	75	14	25.98	O	U	292.96	65	2	55	65
RI–16D	BK–3007	40	16	45.77	75	14	37.14	O	U	272.07	153	2	130	150
RI–16S	BK–3008	40	16	45.77	75	14	37.14	O	U	271.70	40	2	18	38
RI–17D	BK–3009	40	16	36.30	75	14	36.64	O	U	286.26	194	2	178	188
RI–17S	BK–3010	40	16	36.30	75	14	36.64	O	U	286.20	65	2	43	63
RI–18D	MG–1780	40	16	22.62	75	14	32.82	O	U	293.97	95	2	85	95
RI–18S	MG–1781	40	16	22.62	75	14	32.82	O	U	294.01	64	2	44	64
RI–19D	MG–1782	40	16	16.90	75	14	44.38	O	U	295.06	80	2	70	80
RI–19S	MG–1783	40	16	16.90	75	14	44.38	O	U	295.03	58	2	46	56
RI–20D	MG–1784	40	16	7.18	75	14	48.34	O	U	304.68	110	2	100	110
RI–20S	MG–1785	40	16	7.18	75	14	48.34	O	U	304.72	80	2	70	80
RI–23	MG–1786	40	16	21.22	75	14	40.20	O	U	297.14	23	3.5	4	16
RI–25	MG–1787	40	16	20.96	75	14	37.57	O	U	296.09	14	3.5	4	14
RI–27D	MG–1766	40	16	23.20	75	14	40.88	O	U	298.80	313	2	303	308
RI–27S	MG–1767	40	16	23.20	75	14	40.88	O	U	298.78	55	2	40	55
RW–1	MG–1153	40	16	5.30	75	14	43.58	O	U	313.41	70	6	23	70
RW–2	MG–1154	40	16	5.20	75	14	43.58	O	U	314.96	150	6	80	150
RW–3	MG–1155	40	16	5.12	75	14	43.22	O	U	315.30	210	6	150	210
RW–4D	MG–1929	40	16	17.94	75	14	46.18	O	U	293.46	300	2	150	300
RW–4I	MG–1930	40	16	17.90	75	14	46.07	O	U	293.47	150	2	50	150
RW–4S	MG–1931	40	16	17.87	75	14	45.96	O	U	293.31	50	6	20	50
RW–5D	MG–1932	40	16	20.64	75	14	43.55	O	U	296.81	300	2	150	300
RW–5I	MG–1933	40	16	20.57	75	14	43.48	O	U	296.99	150	2	50	150
RW–5S	MG–1934	40	16	20.53	75	14	43.37	O	U	296.83	50	6	20	50
RW–6D	MG–1935	40	16	18.66	75	14	40.20	O	U	299.92	300	2	150	300
RW–6I	MG–1936	40	16	18.77	75	14	40.38	O	U	296.36	150	2	50	150
RW–6S	MG–1937	40	16	18.62	75	14	40.13	O	U	297.80	50	6	20	50
W–1	MG–1788	40	16	5.23	75	14	41.89	O	U	314.51	40	3.5	9	40
W–3	MG–1789	40	16	14.09	75	14	54.96	O	U	301.39	23	3.5	12	23
W–4	MG–1790	40	16	18.19	75	14	46.68	O	U	293.43	30	3.5	16	30

Table 1. *Record of selected wells in the study area near Colmar, Bucks and Montgomery Counties, Pennsylvania—Continued*

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		Deg	Min	Sec	Deg	Min	Sec	Site	Water					
W–5	MG–1791	40	16	21.50	75	14	43.30	O	U	296.98	30	3.5	9	30
W–6	MG–1792	40	16	17.47	75	14	36.06	O	U	300.56	32	3.5	10	32
W–8	MG–1793	40	16	17.18	75	14	48.26	O	U	290.84	30	3.5	15	30
W–9	MG–1794	40	16	13.44	75	14	47.26	O	U	298.01	45	3.5	13	45
W–12	MG–1796	40	16	7.50	75	14	51.97	O	U	298.97	40	3.5	7	40
W–13	MG–1661	40	16	6.56	75	15	.76	O	U	288.29	44	3.5	10	44
W–14	MG–1798	40	16	7.28	75	14	50.39	O	U	302.83	36	3.5	6	36
W–16	MG–1662	40	16	2.06	75	14	36.60	O	U	319.05	47	3.5	9	47
W–17	MG–1799	40	16	5.74	75	14	58.56	O	U	293.09	44	3.5	6	44

[1] RI-series wells were drilled by U.S. Environmental Protection Agency for Remedial Investigation/Feasibility Study; A-series, MW-series, RW-series, and W-series wells were drilled by industry for ground-water monitoring or recovery; BAE Supply, NP, NWWA, and R&B wells were drilled for public- or industrial-supply wells.

[2] Measuring-point elevation is for top of casing, from survey, unless reported to nearest integer, which is land surface from topographic maps.

[3] Well is located outside of the Colmar study area but is used in the model of ground-water flow; location is shown in figure 25.

[4] Geographic coordinates of public-supply wells are known but not reported.

of interfingered red beds of the Brunswick equals the total thickness of interfingered gray and black beds of the Lockatong, which causes some ambiguity in mapping the stratigraphy. The interfingered thin beds that underlie the southeastern part of the site were mapped as the Lockatong Formation by Willard and others (1959) but are considered the lower beds of the Brunswick Formation by Lyttle and Epstein (1987). The lower beds of the Brunswick Formation contain detrital cycles of medium to dark gray and olive to greenish-gray, thin-bedded and evenly bedded shale and siltstone that are similar to but not as continuous as those in the underlying Lockatong Formation (Lyttle and Epstein, 1987). The mean strike of the Brunswick Formation determined from the acoustic televiewer logs at North Penn Area 5 is N. 62° E., and the dip is 31° NW. (Bird and Conger, 2002, p. 24).

The Lockatong Formation as mapped by Willard and others (1959) underlies the southeastern half of the Colmar study area (fig. 1). The Lockatong Formation consists mainly of thick-bedded argillite, siltstone, mudstone, and shale that underlie and interfinger with the Brunswick Formation. The argillite is a tough, firmly cemented, non-fissile rock that is very resistant to weathering. Drilling of monitor wells in the Colmar area indicates that the upper beds of the Lockatong Formation are mostly dark red shale and siltstone that interfinger with gray beds that appear very similar to the Brunswick Formation. The strike of the Lockatong Formation as mapped by Willard and others (1959) changes direction across the Colmar study area from about N. 35° E. in the southern part to N. 70° E. in the northern part (fig. 1). The mean strike of the Lockatong Formation determined from the acoustic televiewer logs at North Penn Area 5 is N. 67° E., and the dip is 19° NW. (Bird and Conger, 2002, p. 24).

Regolith consisting of soil and unconsolidated weathered bedrock mantles the dipping bedrock formations. Thickness of the regolith varies considerably. On the basis of drilling records from 56 monitor wells in the Colmar study area, reported depth to bedrock ranges from 3 to 45 ft, and median depth is 10 ft (fig. 3). Fifty percent of the reported depths to bedrock were between 8 and 13 ft.

Ground Water

Ground water in the Colmar area originates from infiltration of local precipitation, moves through regolith and fractured bedrock, and discharges to streams and wells. A generalized con-

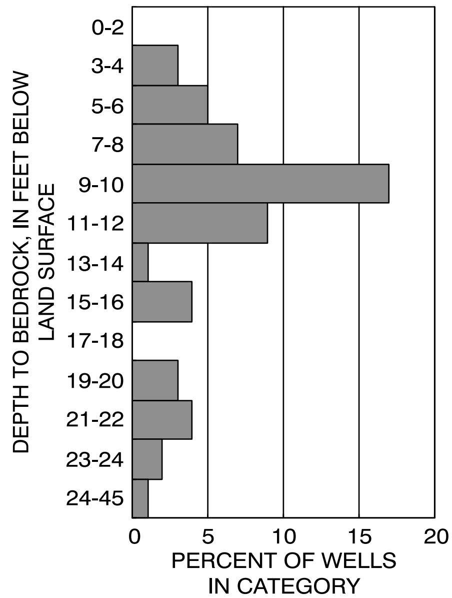


Figure 3. Depth to bedrock reported from 56 wells in the Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

ceptual model of natural flow as it moves through dipping geologic units is illustrated in figure 4. Although greatly simplified, the conceptual model illustrates the potential for preferential flow within units of large hydraulic conductivity and across the interbeds of small hydraulic conductivity.

Occurrence

Ground water in rocks of the Brunswick and Lockatong Formations may occur under unconfined or confined conditions. Unconfined conditions usually are assumed for the shallowest part of the aquifer, but confined conditions are indicated at many locations by monitor wells that display barometric efficiencies from 50 to 80 percent. For example, in monitor well W–6, which is open to the aquifer from 10 to 36 ft below land surface, the magnitude of water-level fluctuation is about 50 percent of the change in barometric pressure as expressed in feet of water (fig. 5). This indicates a 50-percent barometric efficiency for well W–6, which probably is the result of confinement of the shallow, fractured bedrock by clayey soil. Ground water in the deeper part of the fractured-bedrock aquifer is confined or partially confined, resulting in local artesian conditions. Well NP–87, open to the fractured bedrock at 82 ft below land surface and from 104 to 500 ft below land surface is a flowing artesian well for many days during the year. (fig. 6).

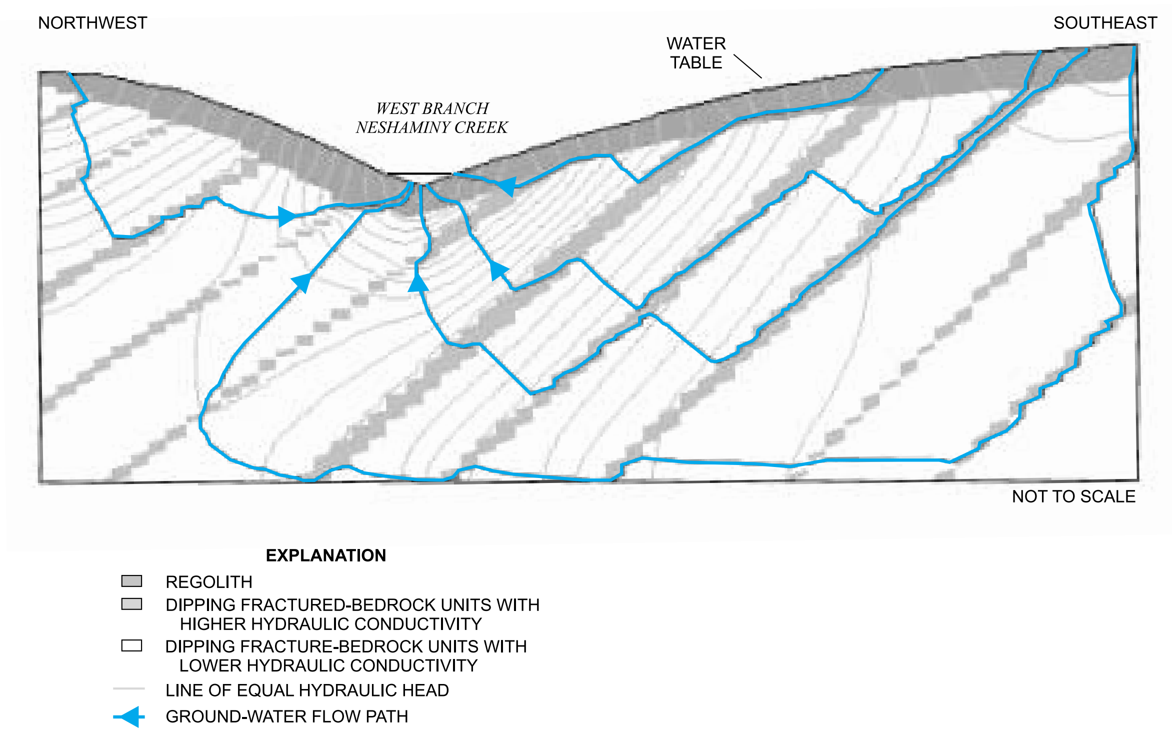


Figure 4. Ground-water-flow paths in dipping geologic units of differing hydraulic properties.

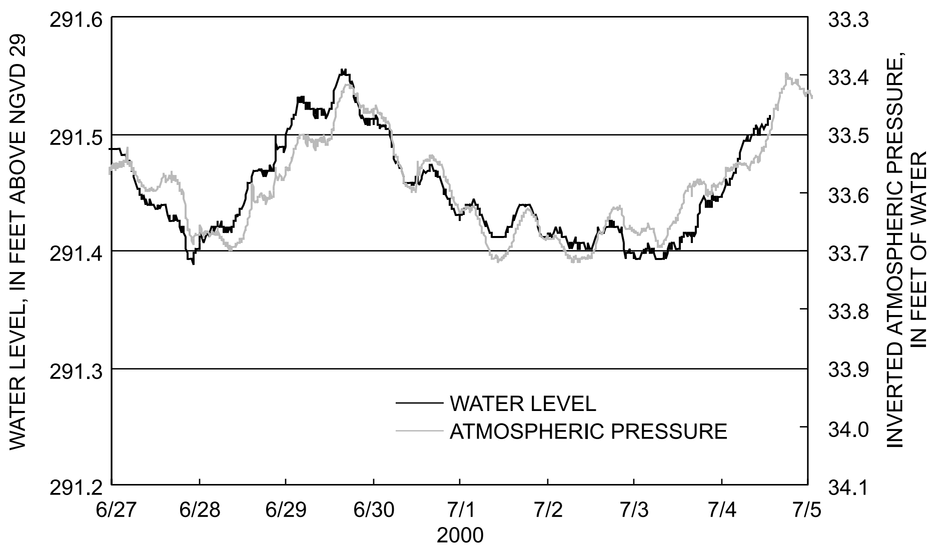


Figure 5. Water-level fluctuations in observation well W–6 and changes in atmospheric pressure from June 27 to July 5, 2000, Colmar study area, Bucks and Montgomery Counties, Pennsylvania. (Note that the y-axis showing atmospheric pressure is inverted and the full scale covers twice the range of the y-axis showing water level so that the graphical traces could be directly compared for a well efficiency of 50 percent.)

Figure 6. Water flowing from well NP–87 on June 24, 2002, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

Water-Yielding Fractures

After infiltrating through soil and regolith, ground water moves preferentially through fractures in the bedrock because the hydraulic conductivity of the rock matrix is very low. Bird and Conger (2002) used acoustic-televiewer and heat-pulse-flowmeter surveys in 31 boreholes to investigate the fractured-bedrock system. They identified two populations of fractures in the Triassic bedrock—(1) low-angle fractures that are probably bedding-plane partings and (2) high-angle fractures. The bedding-plane partings had a mean strike of N. 62° E. and mean dip of 27° NW. The high-angle fractures had a mean strike of N. 58° E., which was nearly parallel to the strike of the bedding-plane partings, and mean dip of 72° SE., which was almost perpendicular to the dip of the bedding-plane partings. These fracture populations are shown schematically in figure 7.

The bedding-plane and high-angle fractures can be seen in outcrops of the Brunswick and Lockatong Formations, but in the Colmar area the rocks are poorly exposed. Although not taken in the study area, a photograph of Triassic bedrock from Wood (1980) illustrates the nature of fractures in the dipping, layered, sequences of siltstone and shale similar to rocks in the Colmar area (fig. 8). As seen in outcrop, thin siltstone beds tend to be more highly fractured than the shale and thicker siltstone beds. High-angle fractures may be more abundant in siltstone beds because they are more brittle than shale; however, they undoubtedly also are present throughout the shale beds. The high-angle fractures shown in figure 8 tend not to be extensive features; they are abundant within individual beds but terminate at the contacts between beds.

Results of heatpulse-flowmeter surveys indicate that only 18 percent of the fractures yielded water to wells (Bird and Conger, 2002, p. 24). Eighty-three percent of the water-yielding fractures were high-angle fractures. Because the high-angle fractures probably are best developed in the brittle siltstone, those beds are probably the most permeable water-bearing zones. Where a highly fractured, dipping siltstone bed is bounded above and below by less permeable shale, ground water will move preferentially through the fractured siltstone bed. Consequently, ground-water movement probably is affected significantly by the orientation and lateral extent of the dipping beds as illustrated schematically in figure 4. Vertical fractures in the shale probably provide hydraulic connections between siltstone beds.

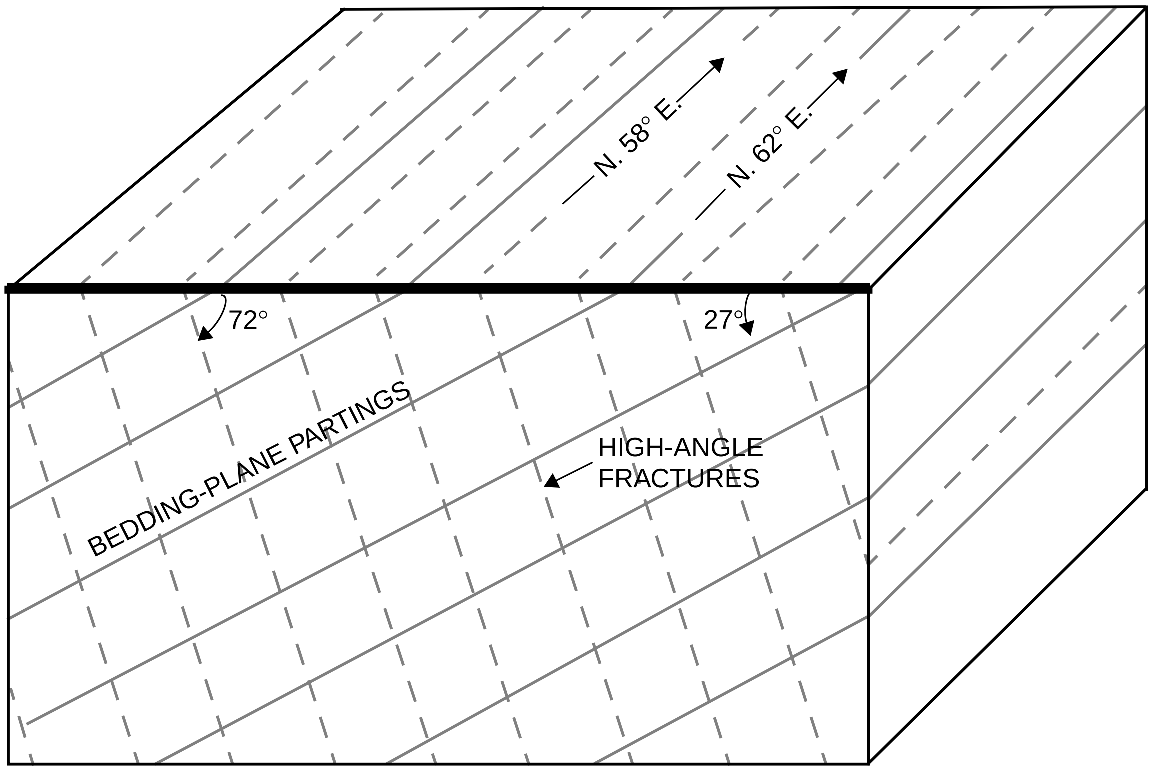


Figure 7. Schematic diagram of bedding-plane and high-angle fractures identified by use of the acoustic televiewer in the Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

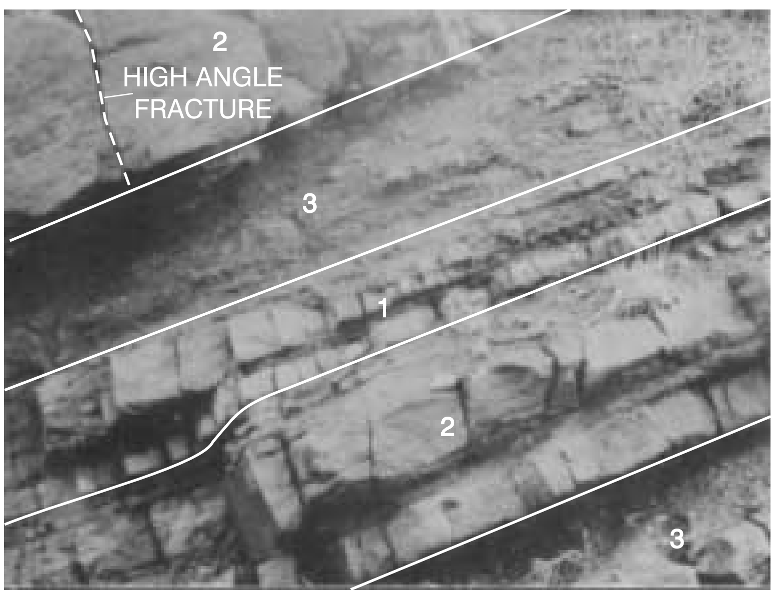


Figure 8. Sedimentary bedrock of Triassic age similar to bedrock in the Colmar area showing (1) thin beds of highly fractured siltstone, (2) thicker siltstone beds where fractures are less well developed, and (3) interbeds of soft low-permeability shale. Bed in top left corner of photograph is 4 ft thick. (from Wood, 1980, fig. 2).

The distribution of the water-yielding fractures with depth in the Colmar area was evaluated from results of heatpulse-flowmeter surveys (fig. 9). Flowmeter surveys in 30 wells showed that the highest density of water-bearing zones was in the upper 40 ft of the wells. However, drilling reports from the RI–series wells seemed to contradict this finding because they describe almost no water produced in the 0-40-ft depth interval. Possibly, the weathered bedrock from land surface to a depth of 40 ft has a large number of water-yielding fractures (identified by flowmetering) that yield small quantities of water not identified on drilling reports. The low yields from 0-40 ft below land surface may be the result of clay that has filled fractures in the most intensely weathered surficial parts of the aquifer. Driller's reports indicate that the increase in well yield appears to be greatest from about 80 to 90 ft below land surface. The increase in yield at that depth may represent an optimum depth where weathering has enhanced fracture openings and interconnections without filling them with clay.

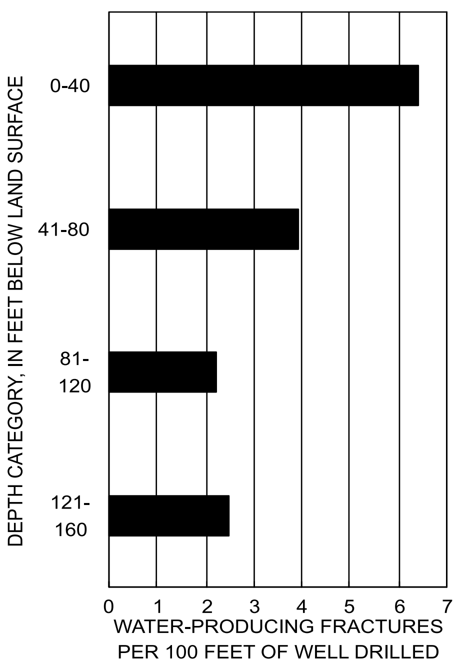


Figure 9. Density of water-yielding fractures with depth determined from flowmeter surveys in the Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

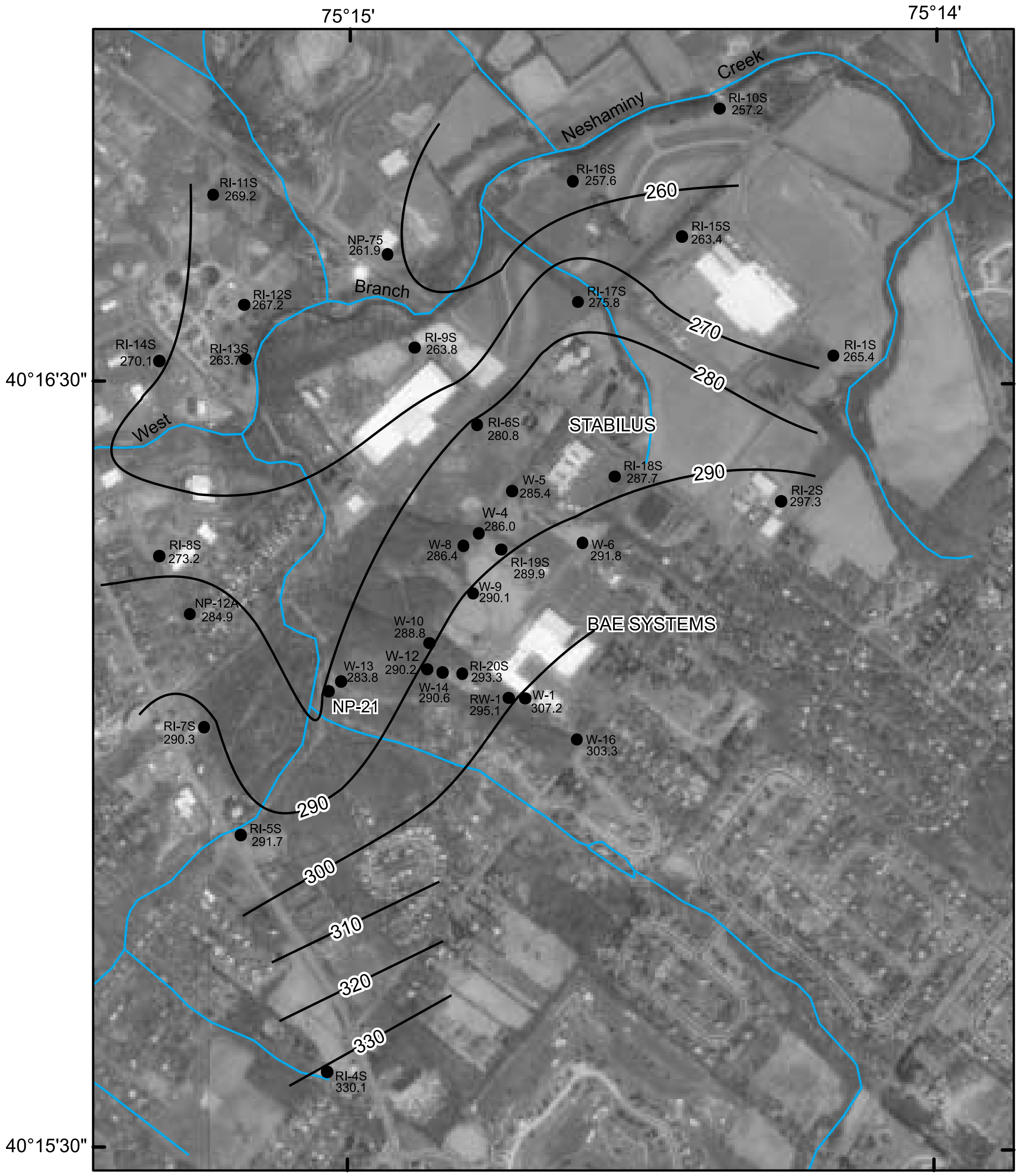
Recharge

Ground-water recharge to Triassic rocks in Pennsylvania ranges from about 6 to 10 in / yr on the basis of base-flow analysis of streamflow hydrographs (Wood, 1980; Sloto and Schreffler, 1994). The magnitude of annual, average recharge in the Colmar area probably is similar to that estimated by Senior and Goode (1999, p. 78); they found the optimum value of recharge to be 8.3 in / yr from calibration of a model to simulate ground-water flow in the vicinity of Lansdale.

Movement

Ground water moves from areas of high hydraulic head to areas of low hydraulic head. A map shows the configuration of water levels in wells less than 100 ft deep in the Colmar area on June 19-20, 2000 (fig. 10). Wells NP–21 and NP–87 were not pumping. The map shows ground-water levels are lowest near Neshaminy Creek and its tributaries; thus, the hydraulic gradient is driving ground water toward the streams.

If the aquifer system is homogeneous and isotropic, ground water will move in a direction orthogonal to contours of hydraulic head and can be inferred directly from water-level maps. However, in the Colmar area, the hydrogeologic framework consisting of multiple, dipping, fractured, water-yielding zones produces an aquifer that is heterogeneous and anisotropic with respect to hydraulic conductivity. The movement of ground water through such a layered multi-aquifer system is shown schematically in figure 4. Note how ground water moves preferentially along the dipping high-permeability fractured units and cuts perpendicularly across the less permeable interbedded shales. Figure 4 also illustrates that the vertical hydraulic gradients are upward in most all of the eastern half of the cross section (east of West Branch Neshaminy Creek) where beds dip to the west. Measurement of vertical hydraulic gradients in nested piezometers and vertical flow of water in wells having long open intervals confirms that hydraulic gradients mostly are upward in the Colmar area east of the creek and downward west of the creek (Bird and Conger, 2002; Tetra Tech / Black & Veatch, 2002).



Base from U.S. Geological Survey,
Telford S.E. and Doylestown S.W. Digital Orthophoto Quadrangles

0 1,000 2,000 FEET

0 300 600 METERS

EXPLANATION

STREAM

—290— WATER-LEVEL CONTOUR -- Shows altitude of water level measured in shallow wells less than 100 feet deep. Contour interval 10 feet. Datum is NAVD 88.

RI-5S 291.7 ● WELL AND IDENTIFIER -- Number is altitude of water level in well, in feet above NAVD 88.

Figure 10. Altitude and configuration of water levels in selected shallow wells less than 100 feet deep in the Colmar study area, June 19-20, 2000.

Discharge

Ground water in the Colmar area discharges to Neshaminy Creek and its tributaries or to wells. Ground-water discharge to streams provides their base flow; however, some stream reaches in the study area have periods when they gain water and other periods when they lose water.

Currently, the only known pumping wells are ground-water remediation well A–10 at BAE Systems, the BAE Systems supply well, and North Wales Water Authority (NWWA) well NWWA–22. In 2000, withdrawals from A–10 averaged about 15 gal / min, withdrawals from the BAE Systems supply well averaged about 13 gal / min (Patrick Till, BAE Systems Inc. written commun., 2001), and withdrawals from NWWA–22 averaged about 20 gal / min (North Wales Water Authority, written commun., 2001). Previously, large ground-water withdrawals were made by the NWWA and the NPWA from former public-supply wells NP–12C, NP–21, and NWWA–16 in the Colmar area. Wells NP–12C, NP–21, and NWWA–16 were taken out of service in March 1999, December 1995, and September 1994, respectively. Well NP–21 has not been in operation since December 1995.

AQUIFER TESTS

Aquifer tests were conducted in June 2000 at well NP–21 and May 2002 at well NP–87 to identify hydraulic connections and to quantify the drawdown caused by pumping. The tests also supported efforts to simulate areas contributing recharge to wells NP–21 and NP–87, which, in turn, will support management decisions regarding ground-water remediation. The tests were performed primarily to determine if the area influenced by pumping reached the northern and southern areas of ground-water contamination shown in figure 2. Drawdown observed in areas of contamination indicates a hydraulic connection to the pumped well and that pumping could alter the direction of ground-water flow in the vicinity of the contamination. However, measurement of drawdown at an observation well does not necessarily indicate the movement of ground water from that observation well to the pumped well. Ground-water flow direction is controlled by the hydraulic gradient (not drawdown), aquifer heterogeneities, and boundary conditions of the hydrologic system.

Design of Tests

The aquifer test in June 2000 was designed with the intention of pumping NP–21 at 400 gal / min for 3 days. However, soon after the pumping began, it was apparent that a rate of 400 gal / min could not be obtained with the existing pump without lowering the water level below the pump intake. Thus, the test of NP–21 was conducted at an average rate of 257 gal / min, and as a result of a large rainstorm and a lack of stabilization of water levels, the duration of pumping was extended to 7 days. Subsequent to completion of the aquifer test of NP–21 in June 2000, interest in determining the drawdown caused by pumping at a greater rate (about 400 gal / min) continued. Because obstructions in NP–21 made it impossible to set a large capacity pump deeper, a second aquifer test was conducted by pumping nearby well NP–87 at 402 gal / min for 3 days. The two wells (NP–21 and NP–87) are only about 40 ft apart and are similar in depth and construction; thus, it was assumed that pumping either well would result in drawdown of a similar magnitude and extent.

Wells NP–21 and NP–87

Wells NP–21 and NP–87 are near an unnamed tributary to the West Branch Neshaminy Creek (fig. 2). Well NP–21 is an inactive public-supply well owned and operated by NPWA. The well is 500 ft deep and is cased to 50 ft below land surface. The interval from 50 to 500 ft below land surface is completed as an open hole (fig. 11). The diameter of the well is 12 in. from land surface to a depth of 250 ft below land surface and 6 in. from 250 ft below land surface to the bottom. Well NP–87 is 476 ft deep, is cased to 103 ft below land surface, and is completed as a 12-in. open hole. A broken casing joint in NP–87 at 82 ft below land surface allows water to enter (or exit) the well at that location.

On the basis of geologic maps and an average dip of 27° NW., wells NP–21 and NP–87 penetrate the Brunswick Formation in the upper 70 to 90 ft and the Lockatong Formation in the remainder of the well. The driller’s log of the well indicates gray and brown rock throughout, with no clear differentiation between the Brunswick and Lockatong Formations. Geophysical logs show a good correlation of rock units between NP–21 and NP–87 (Bird and Conger, 2002).

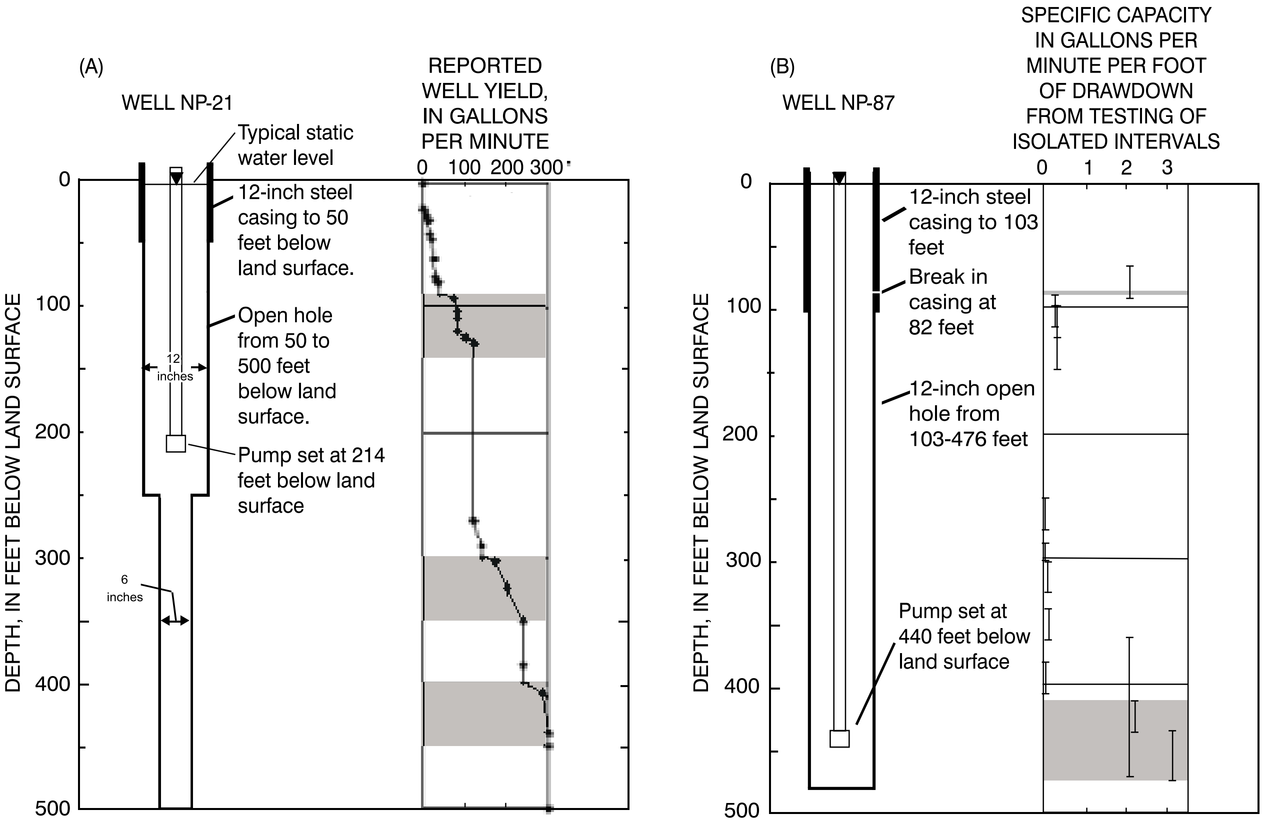


Figure 11. Well construction and (A) driller-reported yield of supply well NP–21 and (B) specific capacity of isolated intervals in NP–87. Shaded areas represent major water-yielding zones.

The driller's log of well NP–21 indicated a yield of 300 gal / min; three principal water-yielding zones were at 90-140, 300-350, and 400-450 ft below land surface (fig. 11A). On the basis of the driller's log, about 40 percent of the pumped water enters above 140 ft below land surface, and 60 percent enters from 300 to 450 ft below land surface.

Well inspection conducted by a down-hole video camera during the aquifer tests allowed for improved understanding of the hydraulic connections of the major water-producing zones between NP–21 and NP–87. Video logs in well NP–87 recorded during the June 2000 aquifer test of NP–21 showed a large quantity of water cascading from a break in the casing at 82 ft below land surface. By trolling the video camera downward at a velocity equal to the downward velocity of the smallest visible particulates in the well (assumed to be moving at the velocity of water), a vertical downward flow rate of about 100 gal / min was estimated. The downward movement ended at 425 ft below land surface, indicating water appeared to be leaving the well through the high-angle fractures at 417-435 ft below land surface. NP–87 represents a "short-circuit" that facilitates vertical flow in the natural flow system from 82 to 417-435 ft below land surface when well NP–21 is pumped and potentially improves the yield of NP–21 by as much as 100 gal / min.

In NP–87, packers were used to isolate and test the water-yielding properties of different depth intervals. The 13 zones tested had specific capacities ranging from 0.04 to 3.1 (gal / min) / ft of drawdown (fig. 11B). The uppermost zone tested was the break in the casing at 82 ft below land surface. The principal water-yielding zones determined from the testing of isolated intervals were the break in casing at 82 ft and the interval from 412 ft to the bottom of the well at 476 ft, which are shown with shaded patterns in figure 11B. The interval from 300 to 350 ft below land surface that was identified as a major water-yielding zone in the drilling report of NP–21 was not shown to yield much water to well NP–87 based on its specific capacity of 0.09 (gal / min) / ft of drawdown.

Taken together, the driller's reported yield data from NP–21 and results from testing of isolated intervals in NP–87 indicate most water probably enters both wells from a shallow interval about 50 to 140 ft below land surface and from a deep interval below 400 ft below land surface. When one well is pumped, the wells act together as if each were being pumped because of the good hydraulic connection between the wells within the deep interval below 400 ft below land surface.

Observation Wells

Water levels were monitored at 45 observation wells during the June 2000 aquifer test of NP–21 and in 34 observation wells during the May 2002 test of NP–87. Most of the wells were drilled specifically to monitor water levels and chemical quality of the shallow ground-water flow system. The RI–series wells were drilled by USEPA contractors for the current RI / FS; the A–series, MW–series, RW–series, and W–series wells were drilled by private industry for ground-water monitoring or recovery. Wells RW–1, RW–2, and RW–3 were drilled as possible recovery wells but were not used for that purpose. Other observation wells (NP, NWWA, and R&B notation) are inactive public- or industrial-supply wells. An active recovery well (A–10) and industrial-supply well (BAE Systems supply well) also were monitored during the May 2002 test of NP–87. Not all the same wells were available for monitoring during each aquifer test. Wells MW–1, MW–2, MW–3, and MW–5 (all of which are in the immediate vicinity of well NP–21); RI–27S; RI–27D; and well clusters RW–4, RW–5, and RW–6 (shallow, intermediate, and deep wells at each cluster) were installed after the June 2000 aquifer test. Thus, these newer wells were monitored only during the May 2002 test of NP–87.

Water levels were monitored using pressure transducers and electric water-level tapes. Water levels in most wells were monitored for at least 5 days prior to the start of the aquifer test.

Atmospheric pressure was monitored prior to and during the aquifer test to determine if measured drawdown should be adjusted for changes in atmospheric pressure. In confined aquifers, an increase in atmospheric pressure can cause water levels in wells to decline; a decrease in atmospheric pressure can cause water levels to rise. The water-level response is typically 20 to 70 percent of the change in atmospheric pressure (Todd, 1980, p. 236). For some observation wells, sufficient pretest water-level measurements were available to establish a barometric efficiency. The barometric efficiency was multiplied by the change in atmospheric pressure during the aquifer test (expressed as feet of water) to arrive at the water-level change caused by the change in pressure. Pressure was measured in inches of mercury and multiplied by 1.13 to convert units to feet of water. When barometric efficiency was not determined, an efficiency of 50 percent was assumed for purposes of computing drawdown unless those adjustments produced drawdown values that seemed anomalous when plotted, which was the case for wells RW–6S and W–8. For wells where a large drawdown was observed, the maximum potential effect of the barometric-pressure adjustment was small, so the barometric efficiency of the well was not determined.

NP–21 Test of June 20–27, 2000

The aquifer test was conducted by pumping well NP–21 and measuring drawdown in the pumped well and 45 observations wells. Supply well NP–21 was pumped at an average rate of 257 gal / min. The rate determined from periodic readings of a totalizing flowmeter ranged from 281 to 256 gal / min. During the aquifer test, ground water pumped from NP–21 was discharged directly into the sewer system to avoid recharging the aquifer. Pumping began at 9 a.m. on June 20, 2000, and ended 7 days and 6 hours later at 3 p.m. on June 27. Wells that were monitored and drawdown values measured at the end of the 7 days of pumping are shown in table 2 and figure 12. Hydrographs of water levels monitored before, during, and after the aquifer test are shown in figures 13 and 14.

Climatic Conditions and Resultant Water-Level Trends

Prior to the aquifer test, water levels in pumped well NP–21 and observation wells were monitored to determine climatic effects on water levels, prepumping trends, and effects of any nearby pumping wells. Probably the greatest factor affecting the measured water levels (other than the pumping from well NP–21) was ground-water recharge from precipitation that began about 9:45 p.m. the night of June 21, 2000. Because of the storm, atmospheric-pressure changes were large enough to cause water-level fluctuations of several tenths of a foot in observation wells during the pumping period. Ground-water withdrawals from well NWWA–22 and the BAE Systems supply well also caused significant water-level fluctuations in several observation wells during the aquifer test.

Table 2. *Summary of observations from wells monitored during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania*

[—, not determined; <, less than; ?, reported drawdown may be partially or entirely caused by natural ground-water recession]

Local well name	Distance from pumped well NP–21, in feet	Drawdown after 7 days of pumping, in feet	Direction of pre-test water-level trend	Water-level rise caused by rainstorm during test, in feet	Comments
WELLS WITH MEASURABLE DRAWDOWN DURING AQUIFER TEST OF NP–21					
A–13	1,428	2.4	None	0	Barometric efficiency 50 percent, no water-level recovery.
NP–21	0	200	None	0	Pumped well.
NP–87	40	95	None	0	Water cascades from break in casing at 82 feet below land surface.
RI–5D	1,408	1.2	Up	.4	Affected by pumping from NWWA–22; reported drawdown has effects of NWWA–22 removed; assumed barometric efficiency of 50 percent.
RI–5S	1,408	.9	Up	.2	Affected by pumping from NWWA–22; reported drawdown has effects of NWWA–22 removed; barometric efficiency 50 percent.
RI–7D	1,086	1.4	None	.2	Barometric efficiency 70 percent.
RI–7S	1,086	1.4	None	.2	Barometric efficiency 50 percent.
RI–19D	1,697	.4?	Down	<.1	Drawdown may be natural water-level recession; barometric efficiency 70 percent.
RI–19S	1,697	.8?	Down	Slight	Drawdown may be natural water-level recession.
RI–20D	1,020	4.0	None	.4	Barometric efficiency 70 percent.
RI–20S	1,020	2.8	None	.1	Barometric efficiency 50 percent.
RW–1	1,391	3.9	None	.2	Water levels in RW–1, RW–2, and RW–3 were affected by pumping from BAE supply well during early part of test; drawdown reported here was adjusted to remove those pumping effects. Barometric efficiency 50 percent.
RW–2	1,392	about 3.5	None	.3	RW–2 not monitored for entire period of aquifer test; barometric efficiency assumed 50 percent.
RW–3	1,418	about 3.5	None	.3	RW–3 not monitored for entire period of aquifer test; barometric efficiency assumed 50 percent.
W–1	1,520	4.0	None	.5	No water-level recovery apparent after pumping ceased; large response to precipitation because surface water flows into flush-mounted well. No barometric response detected.
W–6	2,265	.5?	None	.3	Slow water-level recovery after pumping ceased. Barometric efficiency 50 percent.
W–9	1,312	.9 to 1.8	Down	0	Drawdown of 0.9 ft incorporates effect of pre-test water-level recession; 1.8 ft. if no adjustment made for recession; barometric efficiency 50 percent; poor recovery after pumping ceased.
W–12	745	3.5	None	0	Barometric efficiency 50 percent.
W–13	58	6.8	None	1.8	Manual measurements only from June 23 to July 6, 2000; cause unknown for recovery measured at 200 to 500 minutes into the test; barometric efficiency 50 percent.
W–14	863	3.1	None	.1	Barometric efficiency 75 percent.
W–16	1,977	2.8	None	.5	Early drawdown affected by pumping from BAE supply well; barometric efficiency 50 percent; poor recovery after pumping ceased.
W–17	234	about 5.3	—	.2	Transducer installed June 22, 2000; some manual water-level measurements June 14-22, 2000; shows apparent recharge boundary.

Table 2. *Summary of observations from wells monitored during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania*

[—, not determined; <, less than; ?, reported drawdown may be partially or entirely caused by natural ground-water recession]

Local well name	Distance from pumped well NP–21, in feet	Drawdown after 7 days of pumping, in feet	Direction of pre-test water-level trend	Water-level rise caused by rainstorm during test, in feet	Comments
WELLS WITH NO MEASURABLE DRAWDOWN DURING AQUIFER TEST OF NP–21					
A–3	1,616	0	Down	1.6	Shows large response to precipitation.
A–18	1,444	0	Down	4.8	Shows large response to precipitation. Well dry except after precipitation.
R&B–1	1,843	—	Down	—	Data not recoverable from data logger memory.
R&B–2	2,081	0	Down	.7	
R&B–3	2,369	0	None	.8	
NP–12A	1,266	0	None	<.1	Water level was affected by unknown pumping source after NP–21 pumping ceased.
NP–12B	1,251	0	None	<.1	Water level was affected by unknown pumping source after NP–21 pumping ceased.
NP–12C	1,318	0	None	<.1	Water level was affected by unknown pumping source after NP–21 pumping ceased.
RI–2D	3,825	0	None	—	
RI–2S	3,825	0	None	.4	
RI–4D	3,196	0	Up	.8	Affected by pumping from NWWA–22.
RI–4S	3,196	0	Up	.8	Affected by pumping from NWWA–22.
RI–6D	2,345	0	None	.4	
RI–6S	2,345	0	None	.4	
RI–8D	1,717	0	None	0	
RI–8S	1,717	—	—	—	Miscellaneous manual measurements during test.
RI–13D	2,661	0	Down	1.0	
RI–17S	3,587	—	—	—	
RI–18D	2,761	0	None	.3	
RI–18S	2,761	0	None	.3	
RI–23	2,230	0	Down	.3	
RI–25	2,368	0	—	—	Monitored only during recovery period.
W–4	1,657	0	Down	.2	Barometric efficiency assumed 50 percent.
W–5	2,080	0	Down	—	Barometric efficiency assumed 50 percent.
W–8	1,497	0	None	.3	May show drawdown of <0.3 ft; no apparent water-level recovery after pumping ceased; barometric efficiency assumed 40 percent.

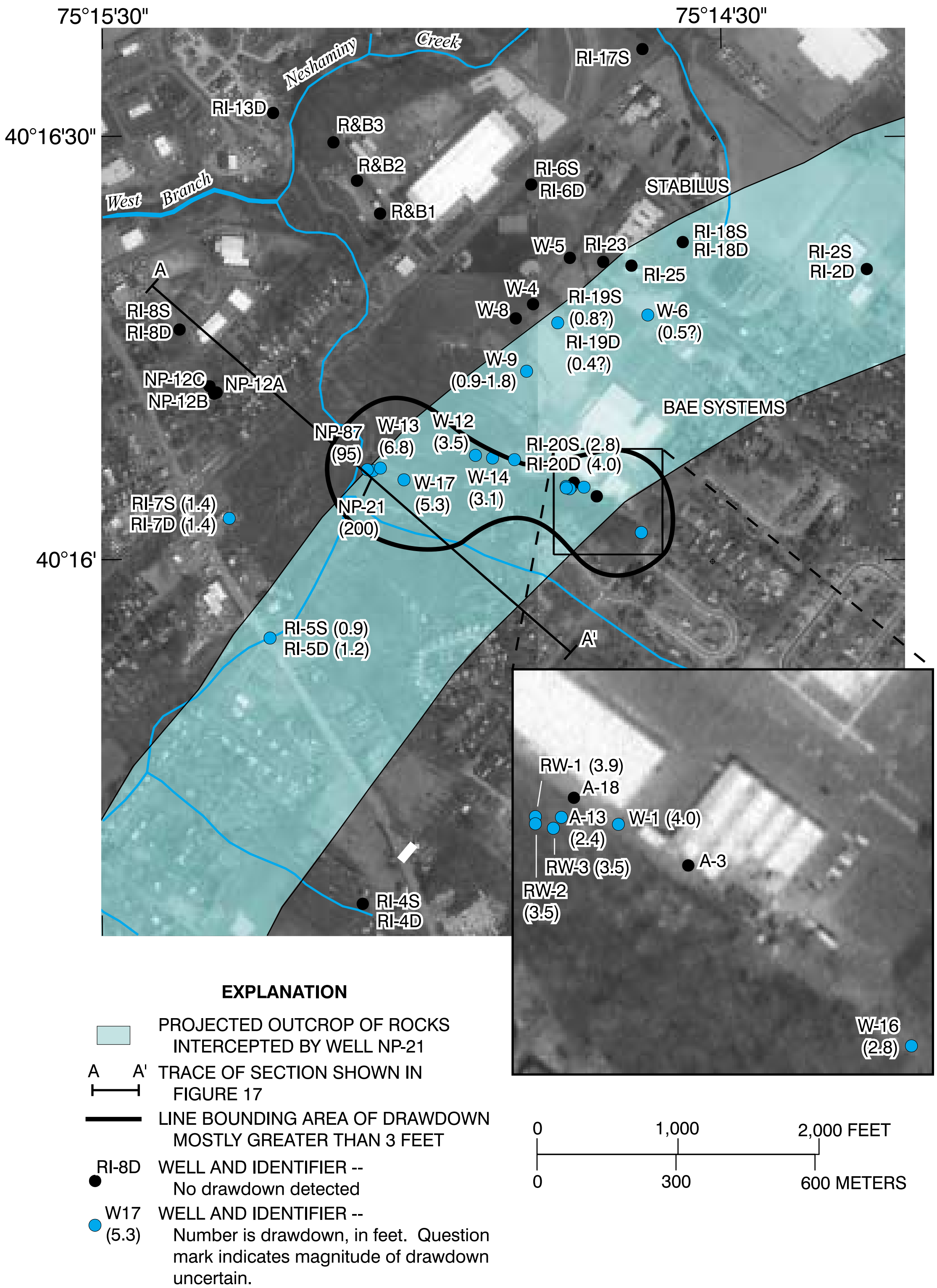
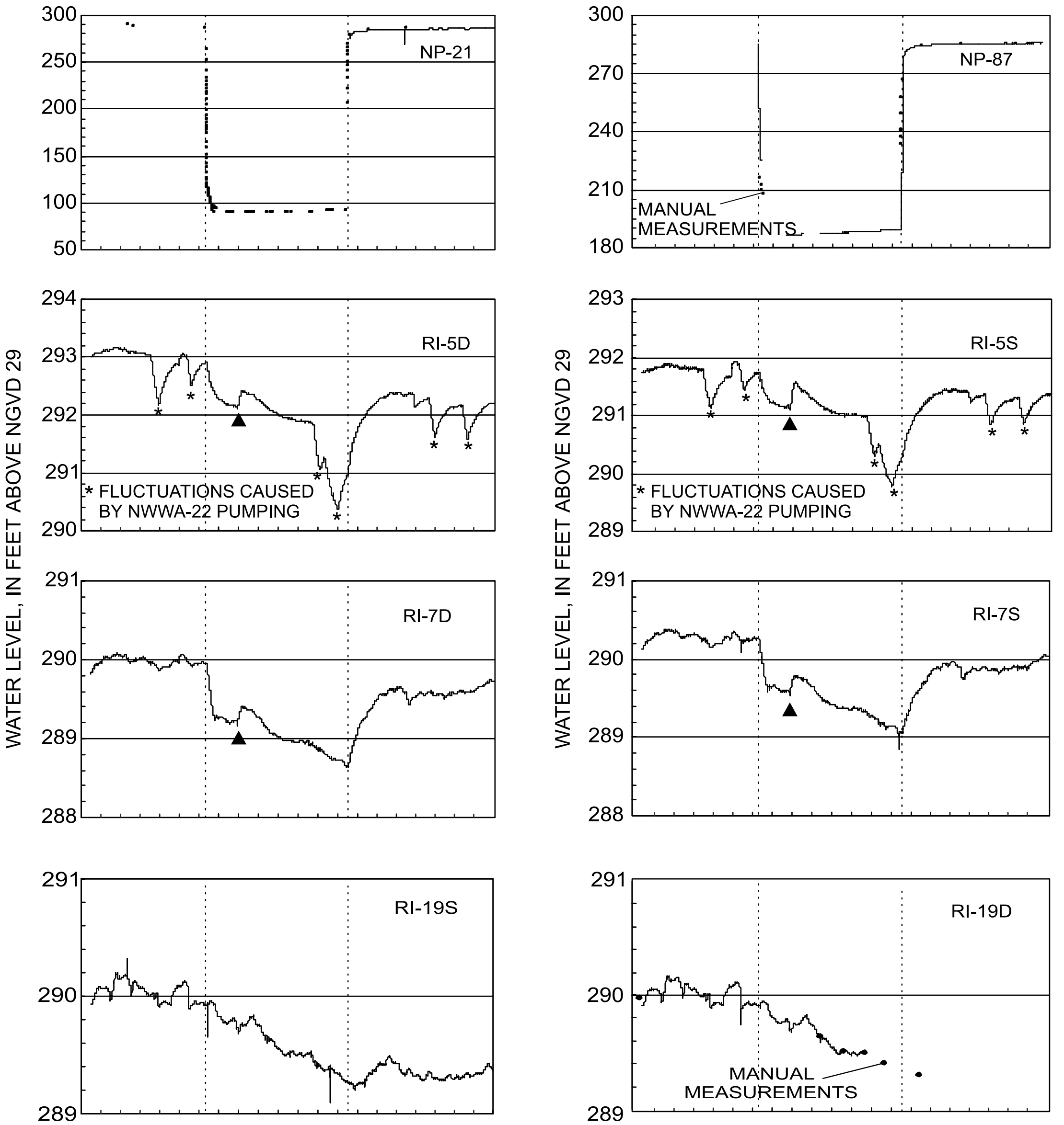
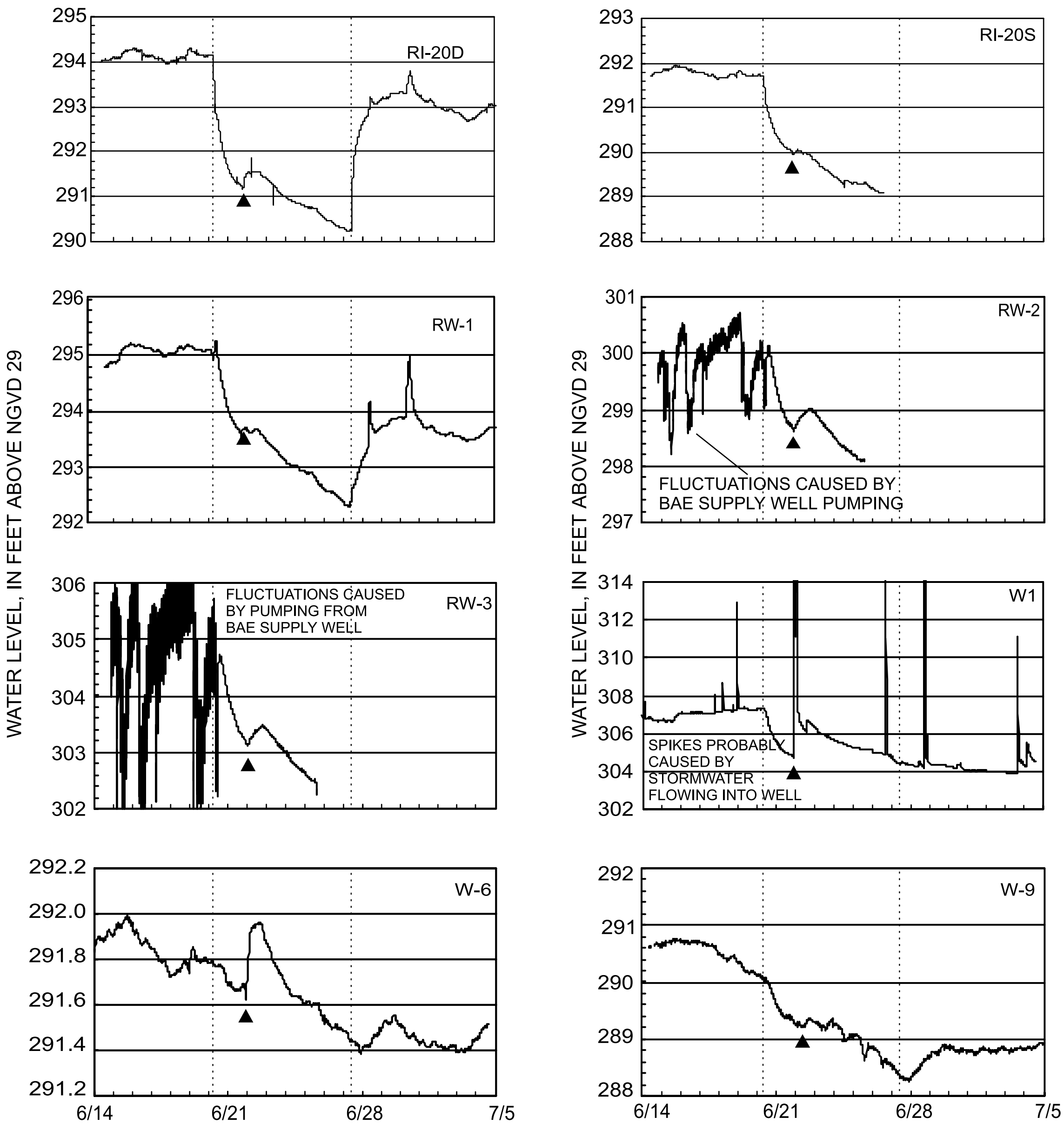


Figure 12. Observation wells monitored and drawdown after 7 days of pumping from supply well NP–21 during the June 2000 aquifer test, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.



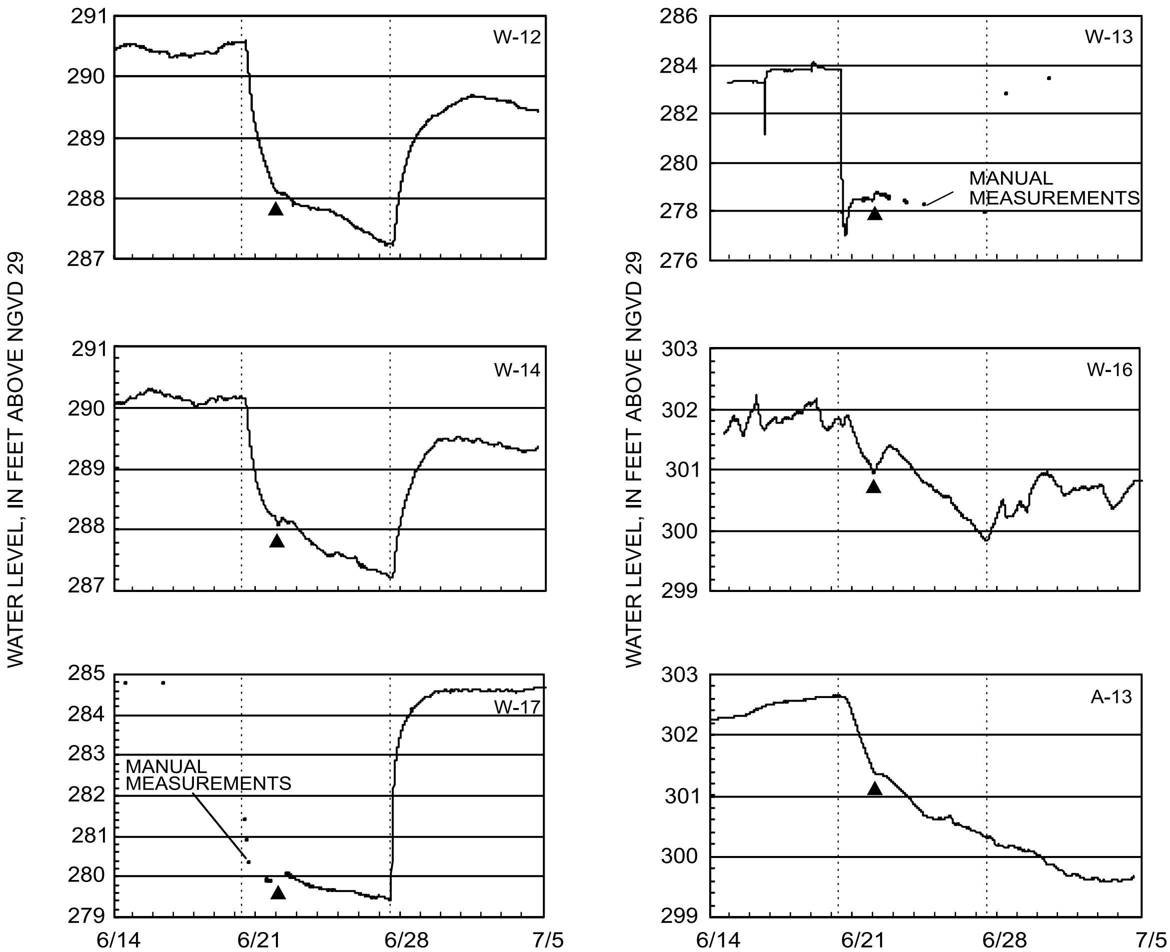
Note: ▲ *indicates beginning of precipitation on June 21, 2000; dashed lines indicate start and end of pumping of well NP-21. Small spikes probably caused by movement of transducer during manual measurement.*

Figure 13. Water levels in wells where drawdown was observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.



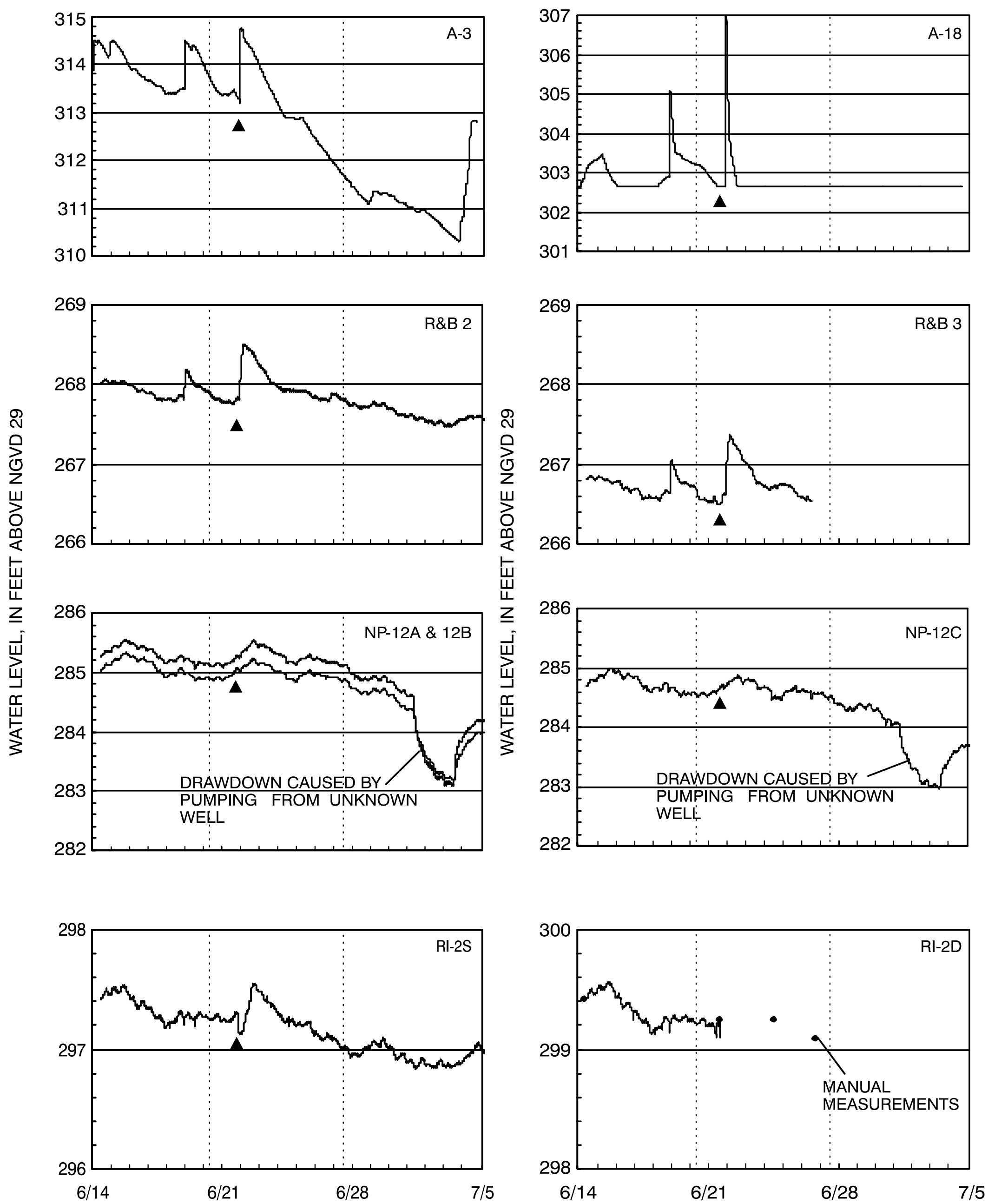
Notes: ▲ *indicates beginning of precipitation on June 21, 2000; dashed lines indicate start and end of pumping of well NP-21. Small spikes probably caused by movement of transducer during manual measurement.*

Figure 13. Water levels in wells where drawdown was observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.



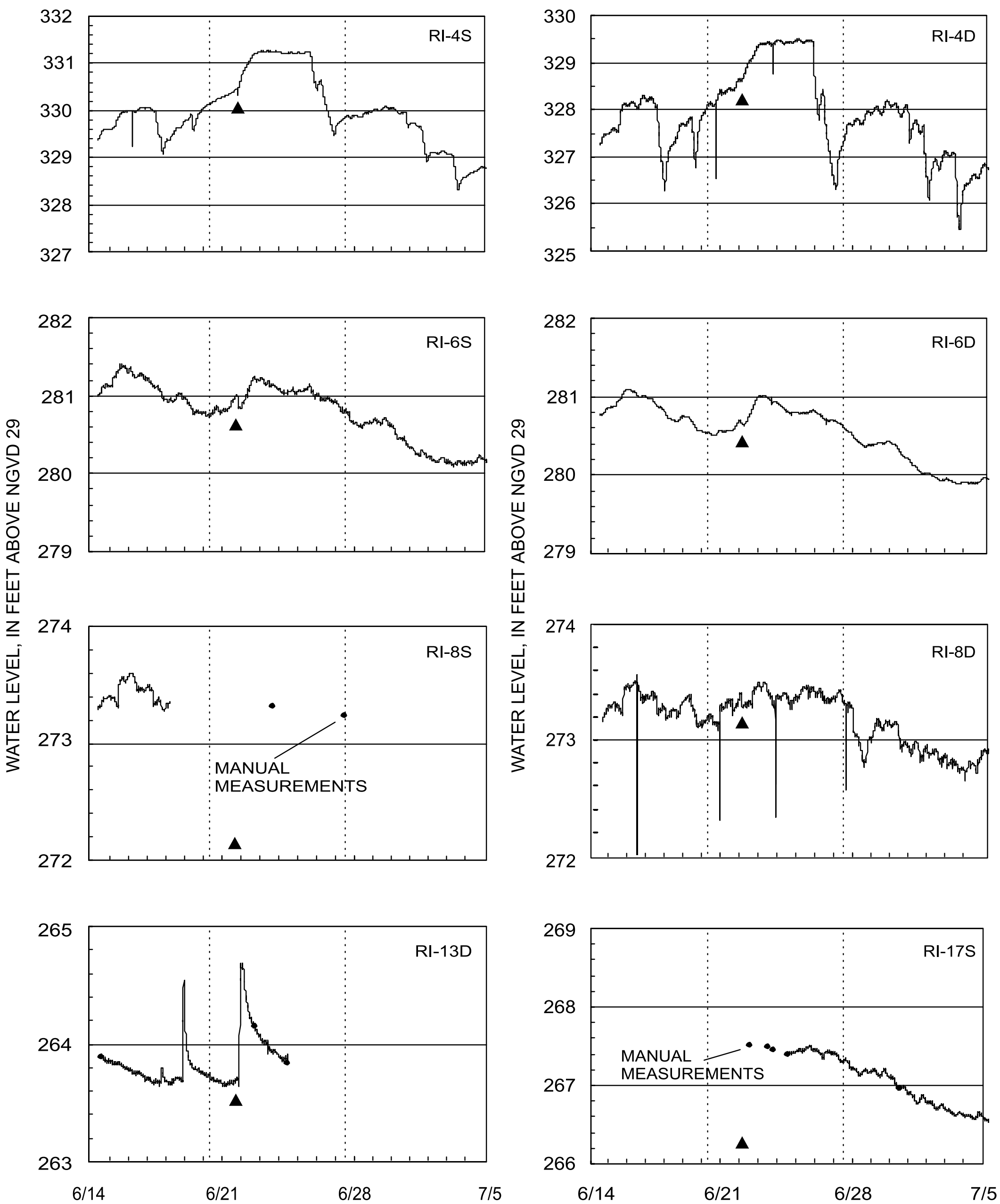
Notes: ▲ *indicates beginning of precipitation on June 21, 2000; dashed lines indicate start and end of pumping of well NP-21. Small spikes probably caused by movement of transducer during manual measurements.*

Figure 13. Water levels in wells where drawdown was observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.



Note: ▲ *indicates beginning of precipitation on June 21, 2000; dashed lines indicate start and end of pumping of well NP-21. Small spikes probably caused by movement of transducer during manual measurements.*

Figure 14. Water levels in wells where drawdown was not observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.



Note: ▲ *indicates beginning of precipitation on June 21, 2000; dashed lines indicate start and end of pumping of well NP-21. Spikes probably caused by movement of transducer during manual measurements.*

Figure 14. Water levels in wells where drawdown was not observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.

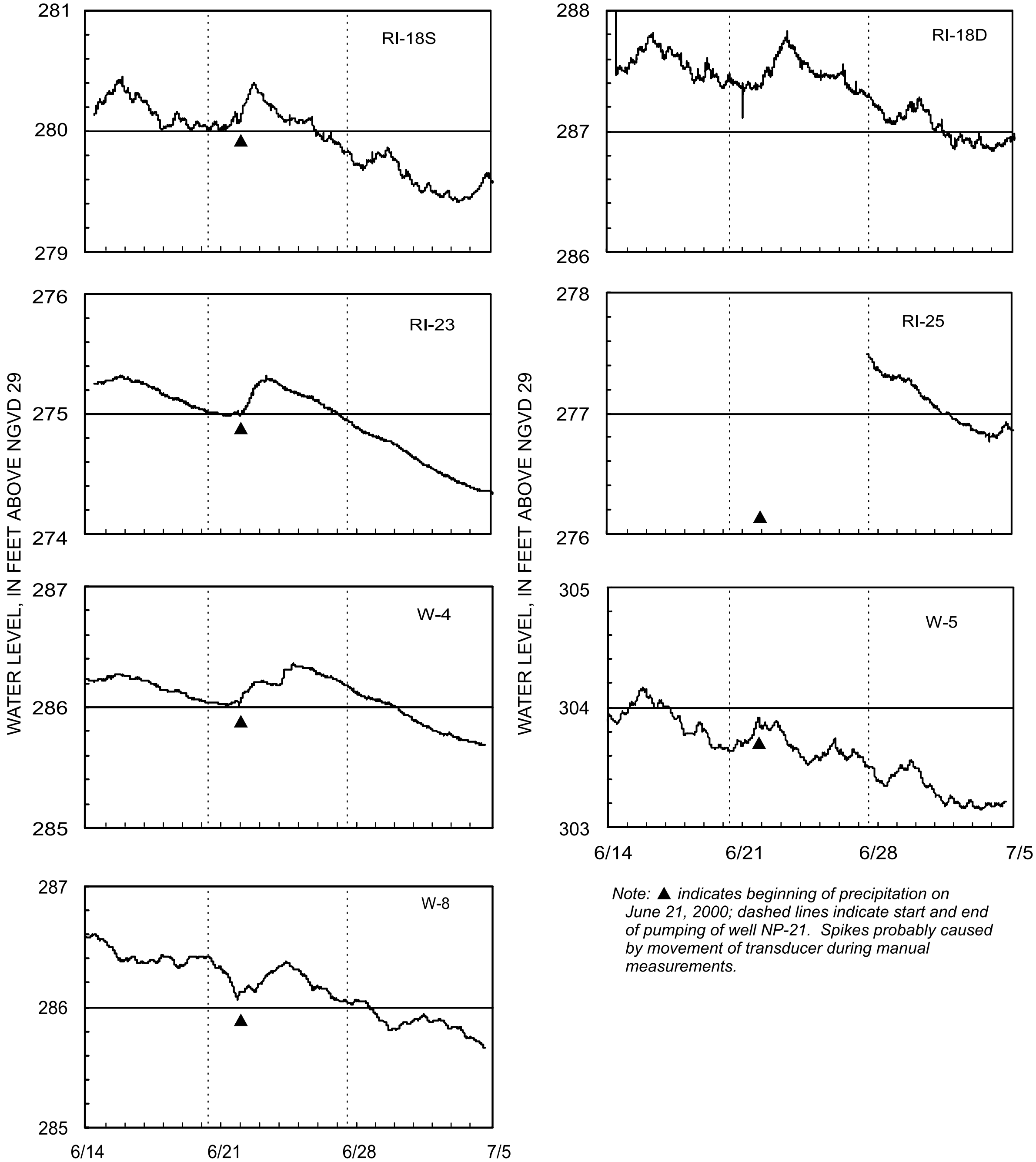


Figure 14. Water levels in wells where drawdown was not observed during the aquifer test at well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.

Precipitation during test

Water levels in many of the observation wells were affected quickly by ground-water recharge from precipitation. Rainfall of 0.98 in. was measured in the Colmar area from 9:45 p.m. on June 21, 2000, through 2:45 a.m. on June 22, 2000 (Kevin McLaughlin, North Wales Water Authority, written commun., 2001). The rain began about 1.5 days (2,205 minutes) into the aquifer test. Water levels in some wells rose, and in others, the rate of decline caused by the pumping of well NP–21 was reduced. Measured water-level rises ranged from 0 to about 9.5 ft. The recharge caused water levels in both shallow and deep monitor wells to rise. However, by the end of the test, the effect of the precipitation was fairly negligible on the total drawdown computed after 7 days of pumping.

Changes in atmospheric pressure

During the aquifer test, the atmospheric pressure changed a maximum of about 0.5 ft of water (fig. 15). From June 20–22, 2000, the atmospheric pressure decreased as a result of the storm that came through the night of June 21, then increased until June 24. Atmospheric pressure slowly fell from that time until the end of the test at 3 p.m. on June 27. Thus, in wells where only a few tenths of a foot of drawdown were measured during the aquifer test, changes in atmospheric pressure could significantly affect the interpretation of drawdown, depending on the barometric efficiency of the well.

The effect of atmospheric-pressure changes on water levels was evaluated, and drawdown values were corrected for some wells as noted in table 2. Barometric efficiency of wells ranged from 50 to 75 percent for most wells. Water levels in both shallow and deep monitor wells showed the effects of changes in atmospheric pressure, indicating that shallow parts of the "water-table" aquifer are confined to some extent by the overlying clayey regolith and soil.

Pre-test trends

Pre-test water-level measurements indicated that trends could be defined in 15 wells (table 2). The upward trend in wells RI–5S, RI–5D, RI–4S, and RI–4D was caused by cessation of pumping from supply well NWWA–22. The downward pre-test trend in water levels measured in wells A–3, A–18, R&B–1, R&B–2, RI–13D, RI–19S, RI–19D, RI–23, W–4, W–5, and W–9 is probably the natural ground-water recession subsequent to a 0.2-in. rainfall on June 18. Drawdown at the end of the 7-day test was adjusted for the natural pre-test water-level trend only at well W–9, because water levels at this well appeared to be affected by both pumping and the natural recession. The difficulty in making this correction for a 7-day aquifer test is that the trend is assumed to continue at a constant rate for the entire 7-day period.

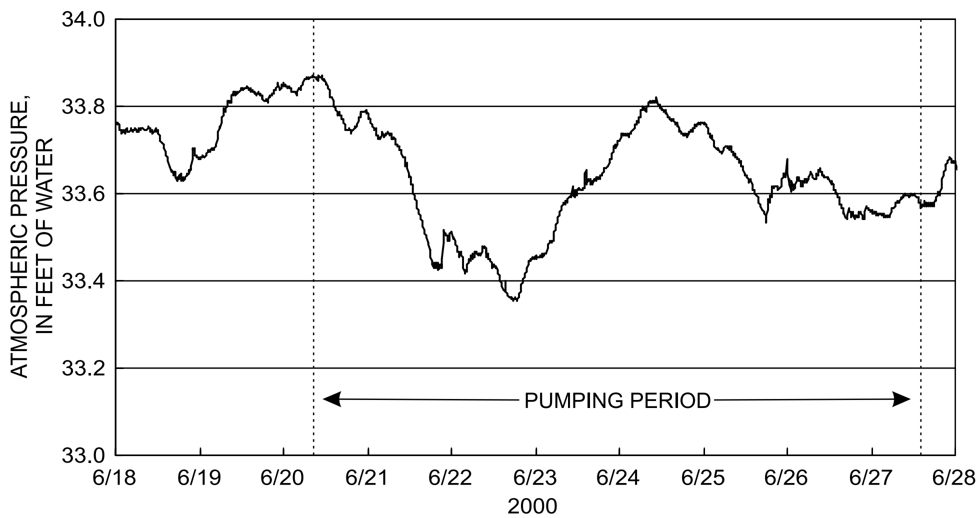


Figure 15. Atmospheric pressure during the aquifer test of supply well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

Withdrawals from other wells

Ground-water withdrawals from wells other than NP–21 caused water-level fluctuations during the aquifer test. The most significant effect was from pumping of well NWWA–22 and the industrial-supply well at the BAE Systems facility. Water levels in monitor wells RI–4S, RI–4D, RI–5S, and RI–5D (figs. 13 and 14) were affected by pumping from NWWA–22 at a rate of about 230 gal / min. NWWA–22 was pumped twice—about 8 hours on the evening of June 25 and 4 hours on the morning of June 26 (table 3). At the start of the aquifer test on June 20, water levels in the deep and shallow RI–4 and RI–5 well clusters were recovering from the pumping of NWWA–22 on June 19.

Table 3. *Pumping of NWWA–22 from June 17–30, 2000, Colmar study area, Bucks and Montgomery Counties, Pennsylvania*

[Data from Kevin McLaughlin, North Wales Water Authority, oral commun., 2001]

Time pumping began	Time pumping ended
6 / 17 / 00 at 12:45 p.m.	6 / 17 / 00 at 10 p.m.
6 / 19 / 00 at 8:30 a.m.	6 / 19 / 00 at 1:30 p.m.
6 / 25 / 00 at 6:45 p.m.	6 / 26 / 00 at 2:15 a.m.
6 / 26 / 00 at 8:15 p.m.	6 / 27 / 00 at 12:45 a.m.
6 / 30 / 00 at 8:15 p.m.	6 / 30 / 00 at 9:45 p.m.

Water levels in monitor wells W–16, RW–1, RW–2, and RW–3 were affected by pumping from the BAE Systems supply well during the aquifer test (fig. 16). The cyclic pumping of the supply well is evident on hydrographs of RW–2 and RW–3, indicating a good hydraulic connection between these monitor wells and the supply well. The hydrographs indicate that the supply well was in operation for the first 100 minutes of the aquifer test beginning at 9 a.m. on June 20, 2000. Monitor wells RW–1 and W–16 are not as well connected hydraulically to the supply well, so water levels in these wells do not fluctuate with the cyclic pumping but they are affected gradually by changes in the supply-well pumping. When the BAE Systems supply well was shut off, water levels in all four monitor wells recovered from 0.2 to about 2 ft for the next 100 to 300 minutes. Thus, water levels during the aquifer test were affected by pumping from the BAE Systems supply well for about the first 200 to 400 minutes of the test.

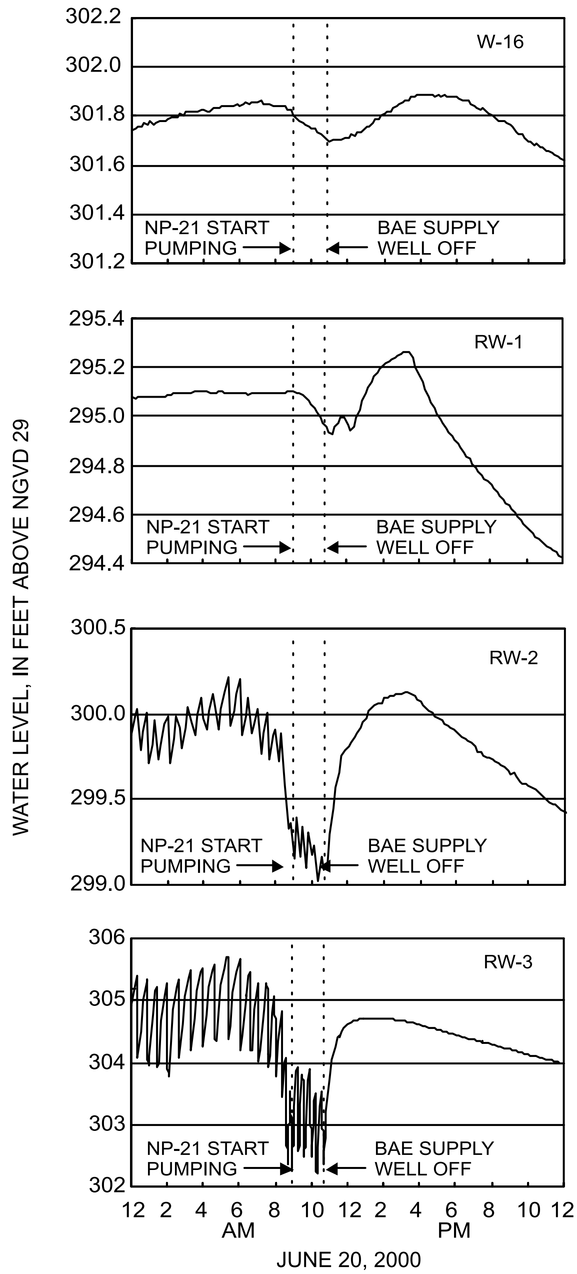


Figure 16. Effect of pumping from BAE Systems supply well on water levels in monitor wells W–16, RW–1, RW–2, and RW–3 during the aquifer test of supply well NP–21, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

Pumping from an unknown source caused water levels in wells NP–12A, NP–12B, and NP–12C to decline from July 1–3, 2000, as shown on the hydrographs of those wells in figure 14. The pumping did not affect water levels during the aquifer test of supply well NP–21, which ended on June 27, 2000.

Drawdown Caused by Pumping NP–21

Pumping of well NP–21 caused measurable drawdown in the pumped well and 21 observation wells monitored during the aquifer test. Drawdown at the end of 7 days of pumping from well NP–21 was 200 ft in the pumped well and 95 ft in well NP–87 and ranged from 0 to 6.8 ft in the other observation wells (fig. 12 and table 2). Drawdown values were adjusted for pre-test trends, changes in atmos-pheric pressure, and effects of pumping from NWWA–22 and the BAE supply well as summarized in table 2. Water-level hydrographs for wells where drawdown was observed are shown in figure 13.

Most of the observation wells monitored during the aquifer test are shown in cross section on figure 17. The wells are projected along the strike of the Lockatong Formation to a section through pumped well NP–21 shown in figure 12. Figure 17 shows that most observation wells are monitoring the shallow part of the aquifer less than 150 ft deep. Only well NP–12C, drilled to 620 ft below land surface, penetrates rocks at depths below 400 ft where a considerable water-yielding zone was encountered in NP–21. However, well NP–12C is far enough downdip from NP–21 that the water-yielding zone is probably stratigraphically below the bottom of NP–12C.

The water-level response to pumping from well NP–21 was obvious in some observation wells, but in many others, the response was subtle and is certainly open to various interpretations. In observation wells NP–87, RI–5D, RI–5S, RI–7D, RI–7S, RI–20D, RI–20S, RW–1, RW–2, RW–3, W–1, W–12, W–13, W–14, W–16, and W–17, drawdown from NP–21 pumping was clearly indicated (fig. 2). However, for observation wells W–6, W–9, RI–19D, and RI–19S, the water-level decline measured during the 7-day pumping period could be interpreted as the result of NP–21 pumping or the natural ground-water recession because the water-level decline was not large and the recovery was not clearly evident after the pumping stopped. The water-level response in well A–13 is especially difficult to explain because the water level appeared to clearly decline in response to pumping of NP–21 but did not recover at all after pumping stopped. The 0.98 in. of precipitation the night of June 21 also complicates the interpretation because recharge caused water levels to rise in some wells.

The drawdown in wells and the projected outcrop of rocks intercepted by supply well NP–21 are shown in figure 17. The outcrop band was projected assuming an average dip of 20° NW. Water-level measurements during the aquifer test showed that, except at RI–7, ground-water levels declined almost exclusively in observation wells completed within or updip of the geologic units penetrated by the pumped well NP–21 (figs. 12 and 17). Because the geologic units become deeper to the northwest, shallow wells updip to the southeast of the pumped well showed more drawdown than observation wells an equal distance but downdip from the pumping well. Although this observation fits well with the conceptual model of the hydrogeologic framework, it must be acknowledged that few observation wells were available for monitoring immediately downdip (north and northwest) of pumped well NP–21. Regardless, a good hydraulic connection (2.4 to 4.0 ft of drawdown) was shown for observation wells updip in the southern area of contamination near the BAE Systems facility. The northern area of contamination in the vicinity of the former Stabilus facility did not appear to be within the area of influence of the supply well NP–21 after 7 days of pumping at 257 gal / min.

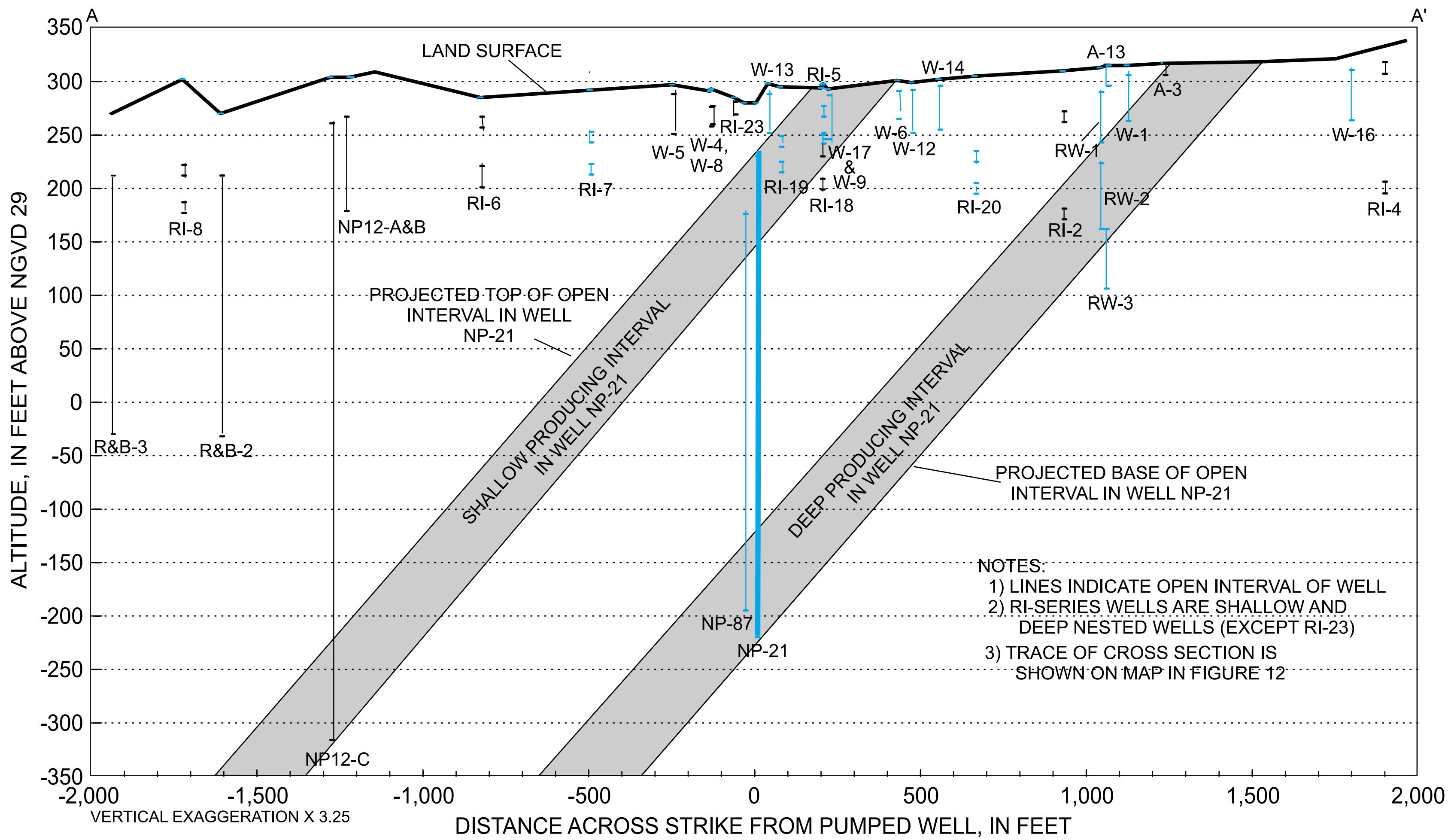


Figure 17. Cross section showing pumped well NP–21 and observation wells monitored during the June 2000 aquifer test, Colmar study area, Bucks and Montgomery Counties, Pennsylvania. (Blue lines indicate wells where drawdown was observed.)

NP–87 Test of May 7–10, 2002

Well NP–87 was pumped for 72 hours at an average rate of 402 gal / min beginning on 11 a.m. on May 7, 2002. The aquifer test was conducted to evaluate the drawdown caused by pumping at a greater rate than was possible during the previous test of NP–21 in June 2000. The test also allowed monitoring of drawdown in several deep observation wells (RI–27D, RW–4D, RW–5D, and RW–6D) in or near the northern area of contamination that were drilled subsequent to the NP–21 aquifer test. Computed drawdown values for shallow and deep wells monitored during the May 2002 aquifer test of NP–87 are shown in table 4 and figures 18 and 19. The wells are shown in a cross section trending perpendicular to the strike of beds in figure 20.

Water levels were measured in the pumped well NP–87 and 35 observation wells listed in table 4. Stream stage was measured with a pressure transducer installed in the western tributary of the West Branch Neshaminy Creek in the vicinity of NP–87. Water levels were monitored by the use of pressure transducers except at the BAE Systems supply well where the pressure gauge attached to an air line was read periodically. Water levels were checked periodically during the test with electric tapes, and it was found that the transducer readings needed adjustment to match the manual measurements in some wells. Most of the manual measurements differed from the transducer readings by a constant amount for each well. Most likely, the transducers were bumped during the many visits by USGS and other personnel to make water-level measurements and collect samples prior to the start of the aquifer test. Water levels were monitored for 20 days prior to the start of the aquifer test and at least 6 days after pumping stopped. Hydrographs of water levels monitored before, during, and after the aquifer test are shown in figure 21.

Climatic Conditions and Resultant Water-Level Trends

The period prior to the test was wet for several weeks, which helped ease the drought conditions that were prevalent in southeastern Pennsylvania during 2002. Ground-water levels were rising but had leveled off at most observation wells before the test. During the 3-day aquifer test, streamflow in the unnamed tributary of the West Branch Neshaminy Creek declined, and soil dried out considerably until the rainstorm that began about 6 a.m. on May 9.

Precipitation during test

As with the June 2000 aquifer test of NP–21, a rainstorm occurred during the May 2002 test of NP–87. Precipitation of about 0.7 in. fell mostly between 6 to 10 a.m. on May 9, 2002. The rain began about 43 hours (2,580 minutes) into the aquifer test. Water levels in many of the observation wells rose in response to the precipitation, and stream stage increased quickly. Measured water-level rises ranged from 0 to about 3.0 ft, but most were only several tenths of a foot. As with the NP–21 test, by the end of the 3-day pumping period, the effect of the precipitation was probably fairly negligible on the total drawdown.

Table 4. *Summary of observations from wells monitored during aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania*

[—, not determined; <, less than; >, greater than; ?, reported drawdown may be partially or entirely caused by natural ground-water recession]

Local well name	Distance from well NP-87, in feet	Drawdown after 3 days of pumping, in feet	Direction of pre-test water-level trend	Water-level rise caused by rainstorm during test, in feet	Comments
WELLS WITH MEASURABLE DRAWDOWN DURING AQUIFER TEST OF NP–87					
A–10	1,572	7.0	None	0.7	BAE recovery well; not in operation during pumping of NP–87; responds rapidly to rainstorms, may receive direct runoff from parking lot because of flush-mount construction.
BAE Supply	1,693	11.5	—	—	Monitored water level with pressure gage on air line.
MW–1	728	3.1	Down	.2	Well drilled after NP–21 aquifer test was conducted; shows apparent recharge boundary.
MW–2	269	6.3	None	.3	Well drilled after NP–21 aquifer test was conducted; shows apparent recharge boundary
MW–3	654	1.6	None	.3	Well drilled after NP–21 aquifer test was conducted.
MW–5	679	3.0	None	.2	Well drilled after NP–21 aquifer test was conducted; shows apparent recharge boundary.
NP–21	40	225	None	0	Water cascades during pumping of NP–87.
NP–87	0	343	None	0	Pumped well. Water cascades from break in casing at 83 feet below land surface.
RI–19D	1,724	.8	None	<.1	Drawdown from pumping is evident, but recovery incomplete; barometric efficiency 70 percent.
RI–19S	1,724	.8	None	.1	Drawdown from pumping is evident, but recovery incomplete.
RI–20D	1,059	5.5	None	.1	Barometric efficiency 70 percent.
RI–20S	1,059	3.0	None	.1	Barometric efficiency 50 percent.
RI–27D	2,355	1.6	None	.1	Well drilled after NP–21 aquifer test was conducted; shows effects of earth tides.
RI–27S	2,355	.9 ?	None	.1	Well drilled after NP–21 aquifer test was conducted. Incomplete water-level recovery.
RW–1	1,432	4.2	Up	<.1	Barometric efficiency 50 percent.
RW–3	1,459	12.0	Up	0	Shows strong response to pumping from BAE Systems supply well.
RW–4D	1,665	2.0	None	.1	Well drilled after NP–21 aquifer test was conducted. Barometric efficiency assumed 50 percent.
RW–4I	1,667	.9	None	.1	Well drilled after NP–21 aquifer test was conducted. Water runs into casing after storms. Incomplete water-level recovery after pumping ceased. Barometric efficiency assumed 50 percent.
RW–4S	1,695	.6 ?	Down	.1	Well drilled after NP–21 aquifer test was conducted. No water-level recovery apparent after pumping ceased. Barometric efficiency assumed 50 percent.
RW–5D	2,024	1.2	None	.2	Well drilled after NP–21 aquifer test was conducted. Barometric efficiency assumed 50 percent.
RW–5I	2,025	1.0	None	.6	Well drilled after NP–21 aquifer test was conducted. Surface water pours into casing during rainstorm. Barometric efficiency assumed 50 percent.
RW–5S	2,028	1.0	None	.1	Well drilled after NP–21 aquifer test was conducted. Barometric efficiency assumed 50 percent.
RW–6D	2,091	3.7	None	.1	Well drilled after NP–21 aquifer test was conducted.
RW–6I	2,086	.8	None	0	Well drilled after NP–21 aquifer test was conducted. Barometric efficiency assumed 20 percent.
RW–6S	2,093	.6?	None	<.1	Well drilled after NP–21 aquifer test was conducted. No water-level recovery apparent after pumping ceased. Barometric efficiency assumed 20 percent.
W–3	947	1.4	None	<.1	Barometric efficiency assumed 70 percent.

Table 4. *Summary of observations from wells monitored during aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued*

Local well name	Distance from well NP-87, in feet	Drawdown after 3 days of pumping, in feet	Direction of pre-test water-level trend	Water-level rise caused by rainstorm during test, in feet	Comments
W–4	1,680	.6	Down	0.1	No water-level recovery apparent after pumping ceased. Barometric efficiency assumed 50 percent.
W–5	2,102	1.0	None	.1	Slow water-level recovery after pumping ceased. Barometric efficiency assumed 50 percent.
W–6	2,297	.5	Down	.2	Slow water-level recovery after NP–21 and NP–87 pumping ceased. Barometric efficiency 50 percent.
W–8	1,520	.6 ?	Down	.1	Slow water-level recovery after pumping ceased. Barometric efficiency assumed 40 percent.
W–9	1,343	.9	None	<.1	Drawdown of 0.9 ft incorporates effect of pre-test water-level recession; 1.8 ft. if no adjustment made for recession; barometric efficiency 50 percent.
W–13	96	6.0	None	.1	Manual measurements only from June 23 to July 6, 2000; cause unknown for recovery measured at 200 to 500 minutes into test; barometric efficiency 50 percent.
W–16	2,018	5.2	Up	0	Barometric efficiency 50 percent.
W–17	275	6.0	None	.2	Shows apparent recharge boundary.
WELLS WITH NO MEASURABLE DRAWDOWN DURING THE AQUIFER TEST OF NP–87					
A–3	1,657	0	Down	3.0	Shows large response to precipitation.
A–13	1,469	0	None	<.1	Barometric efficiency 50 percent.

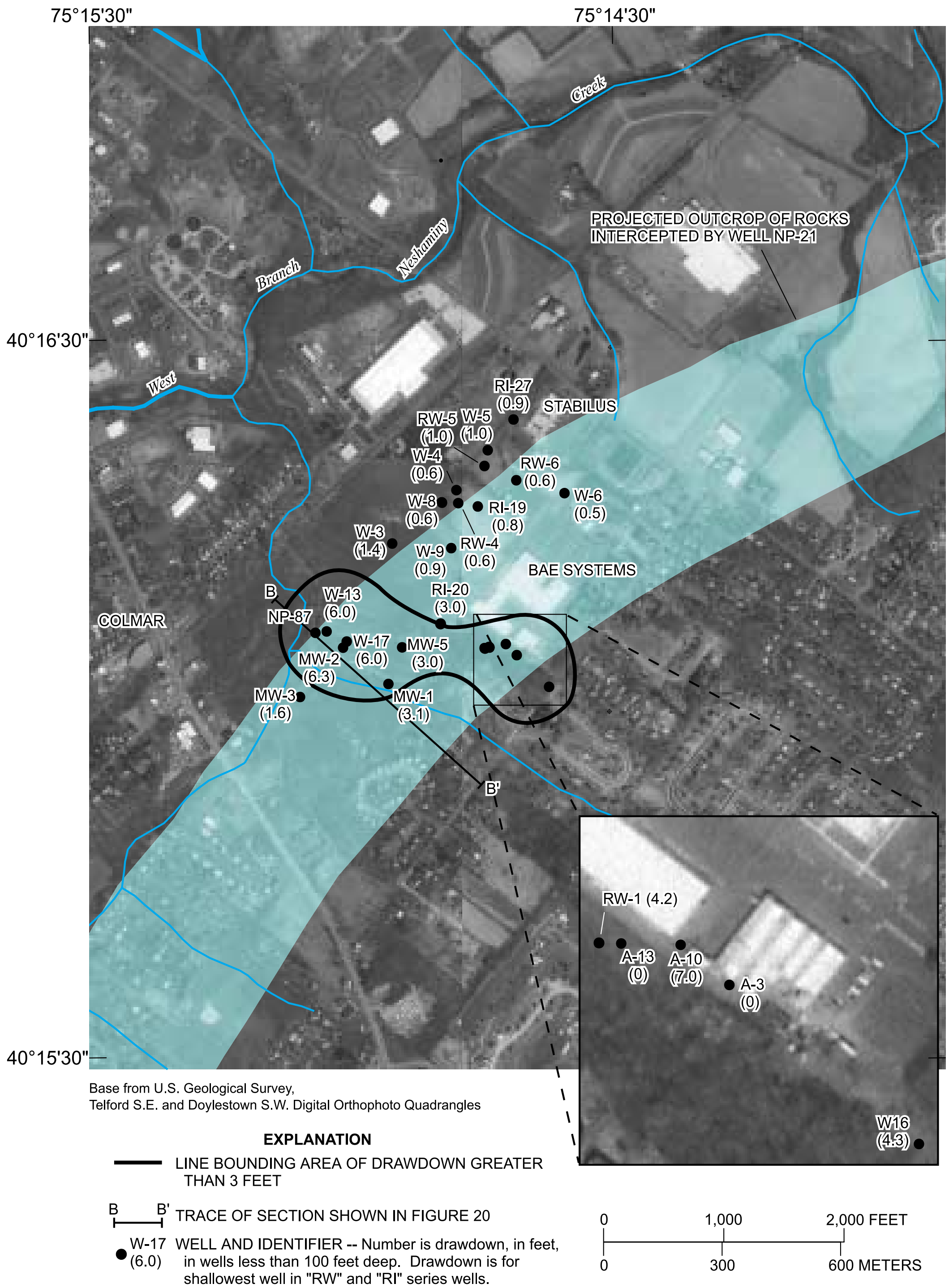
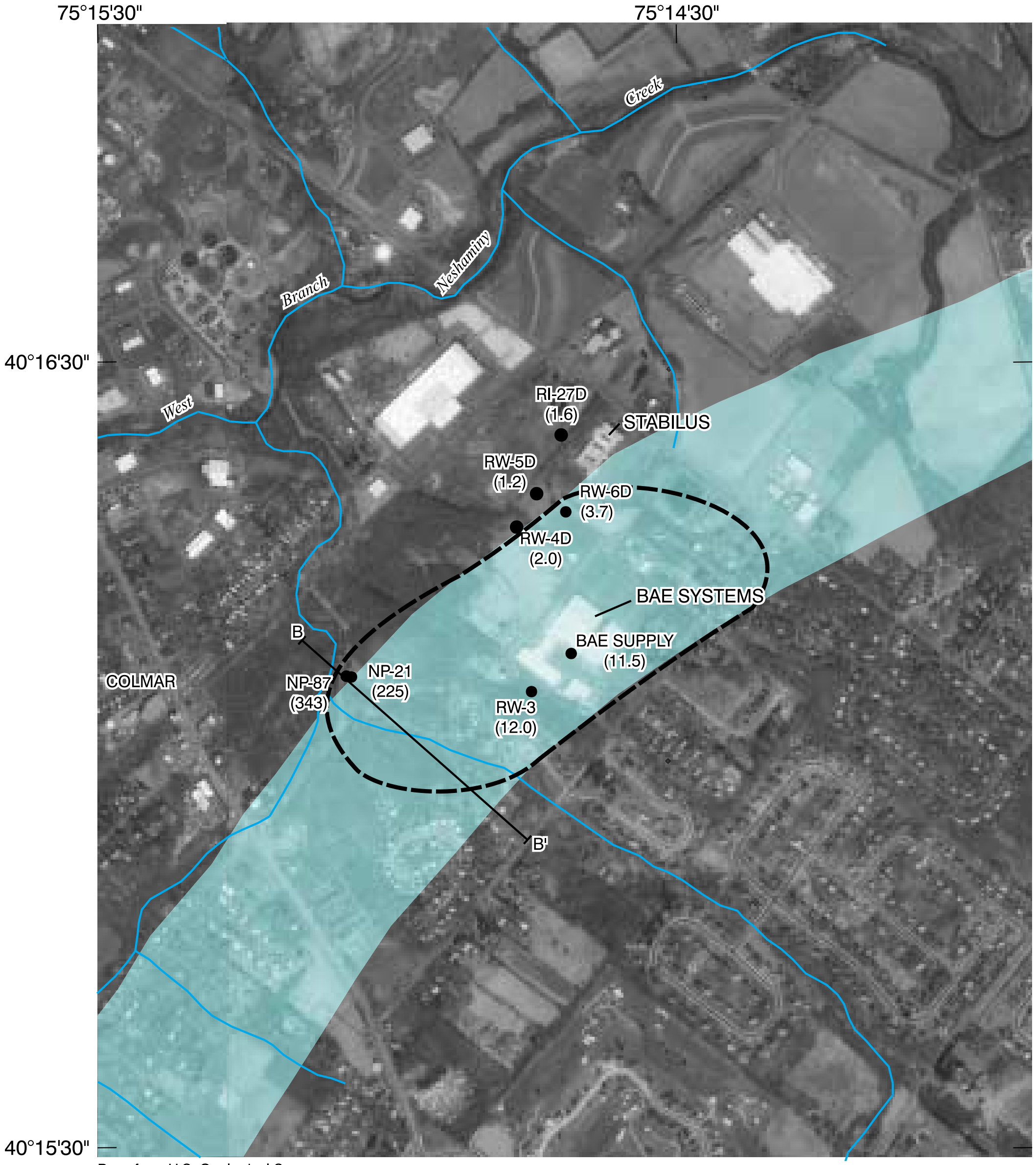
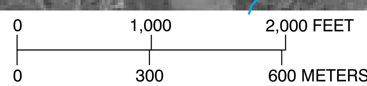


Figure 18. Drawdown in shallow wells (less than 100 feet deep) after 3 days of pumping from well NP–87 during the May 2002 aquifer test, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.



Base from U.S. Geological Survey,
Telford S.E. and Doylestown SW Digital Orthophoto Quadrangles



EXPLANATION

B——B' TRACE OF SECTION SHOWN IN FIGURE 20

— — LINE BOUNDING AREA OF DRAWDOWN GREATER THAN 3 FEET

● W-17 WELL AND IDENTIFIER -- Number is drawdown, in feet, in wells 200 feet deep or greater.

Figure 19. Drawdown in deep wells (at least 200 feet) after 3 days of pumping from well NP–87 during the May 2002 aquifer test, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

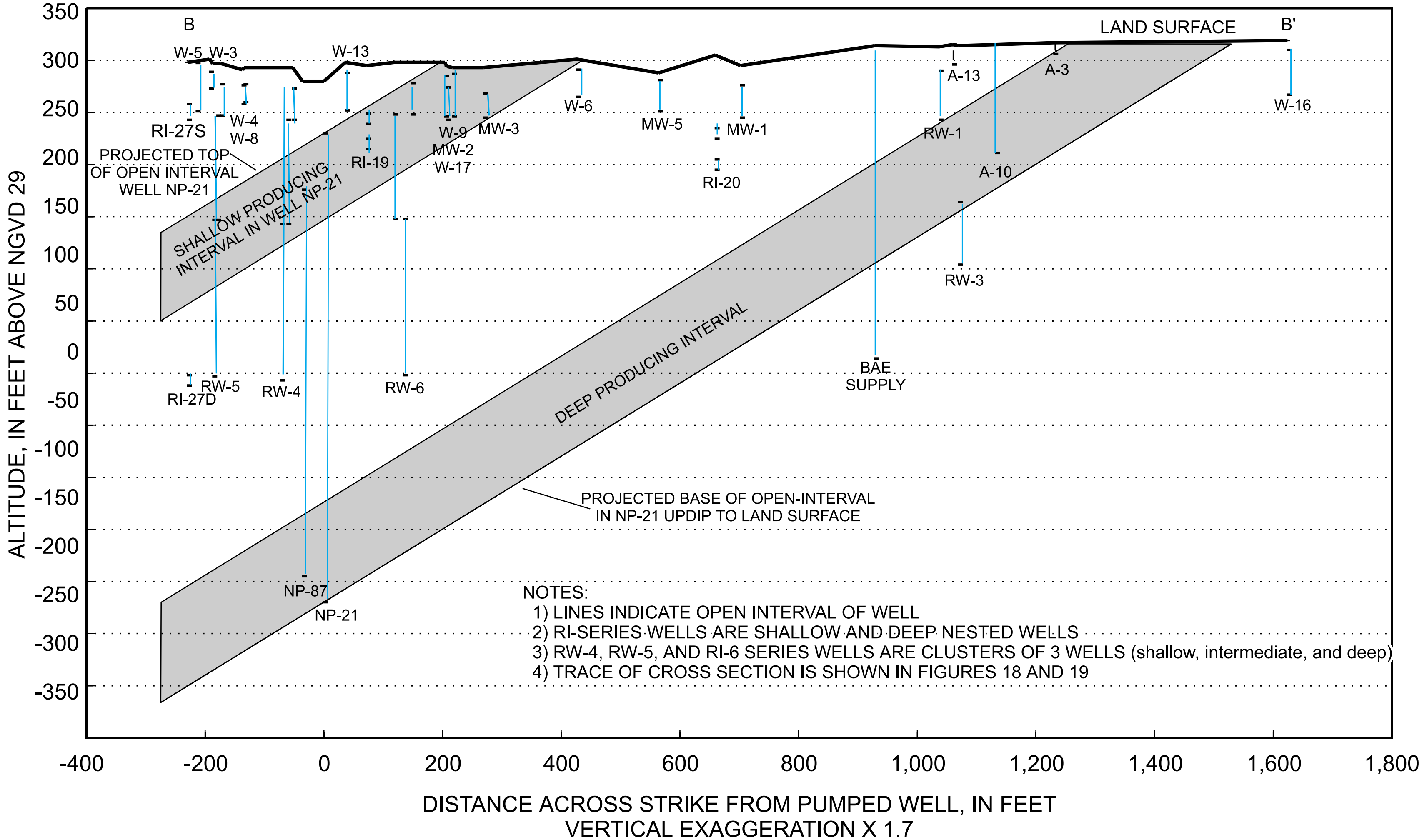
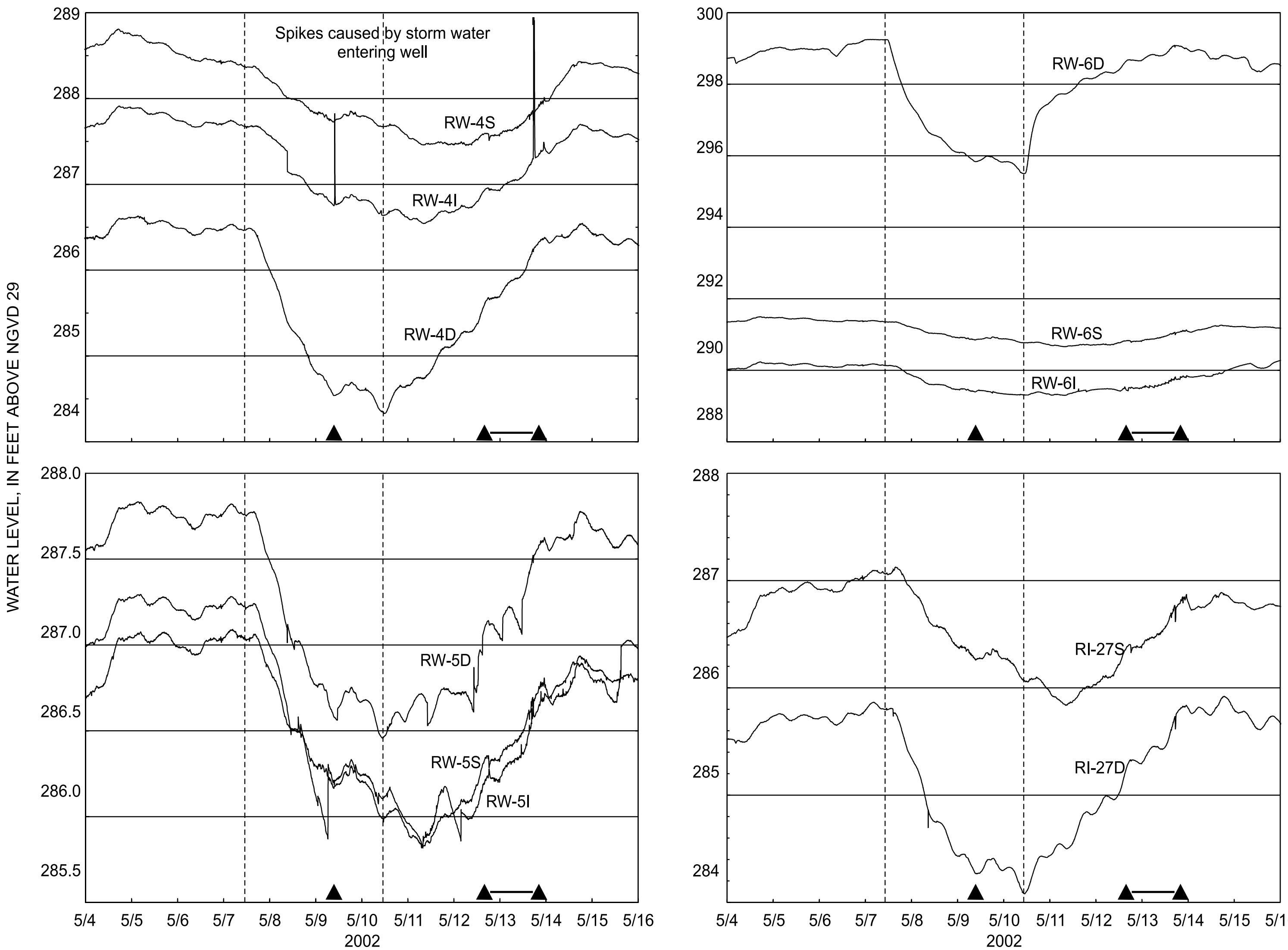
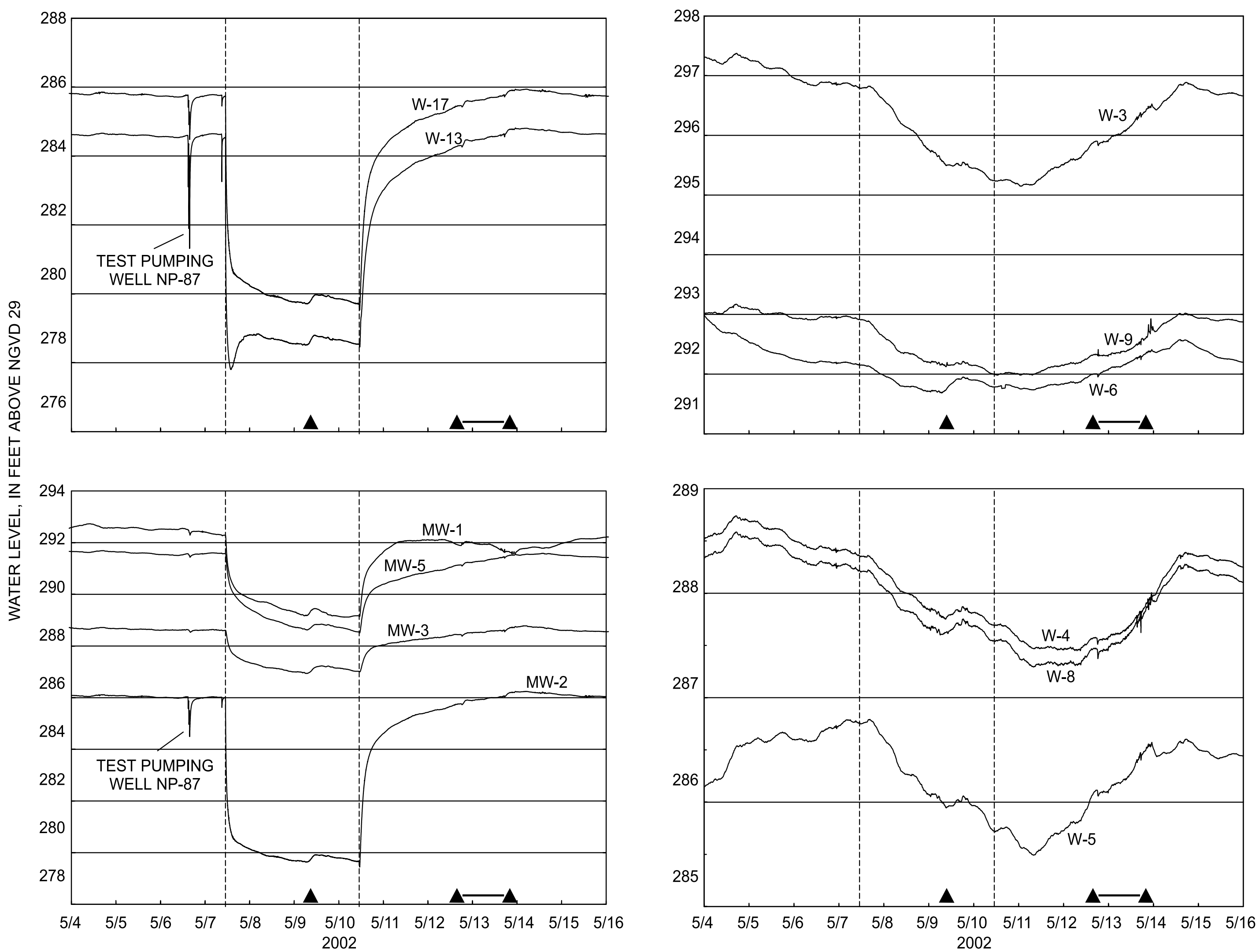


Figure 20. Cross section showing pumped well NP–87 and observation wells monitored during the May 2002 aquifer test, Colmar study area, Bucks and Montgomery Counties, Pennsylvania. (Blue lines indicate wells where drawdown was observed.)



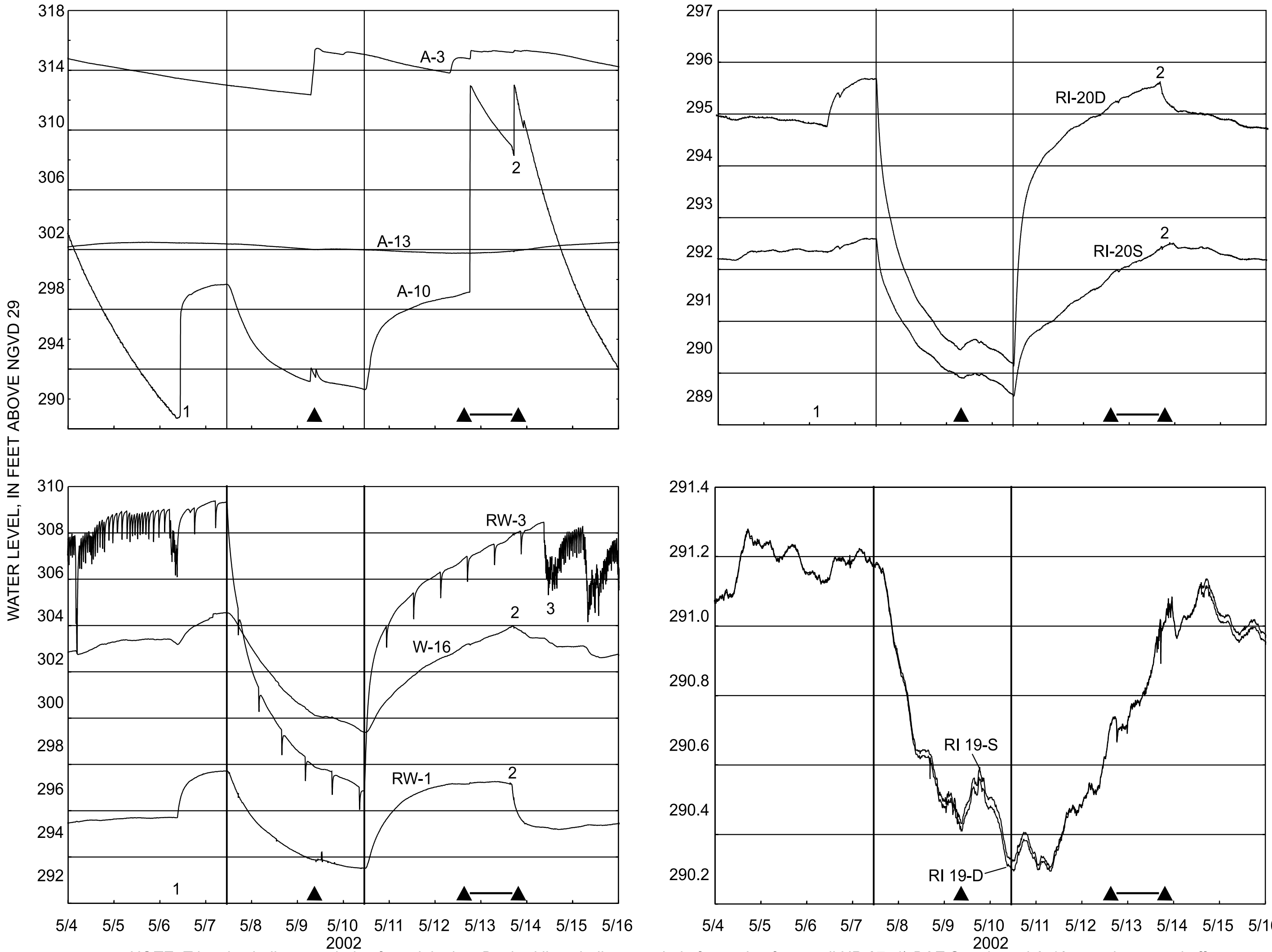
NOTE: Triangles indicate periods of precipitation; Dashed lines indicate period of pumping from well NP-87

Figure 21. Water levels in wells where drawdown was monitored during the May 2002 aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.



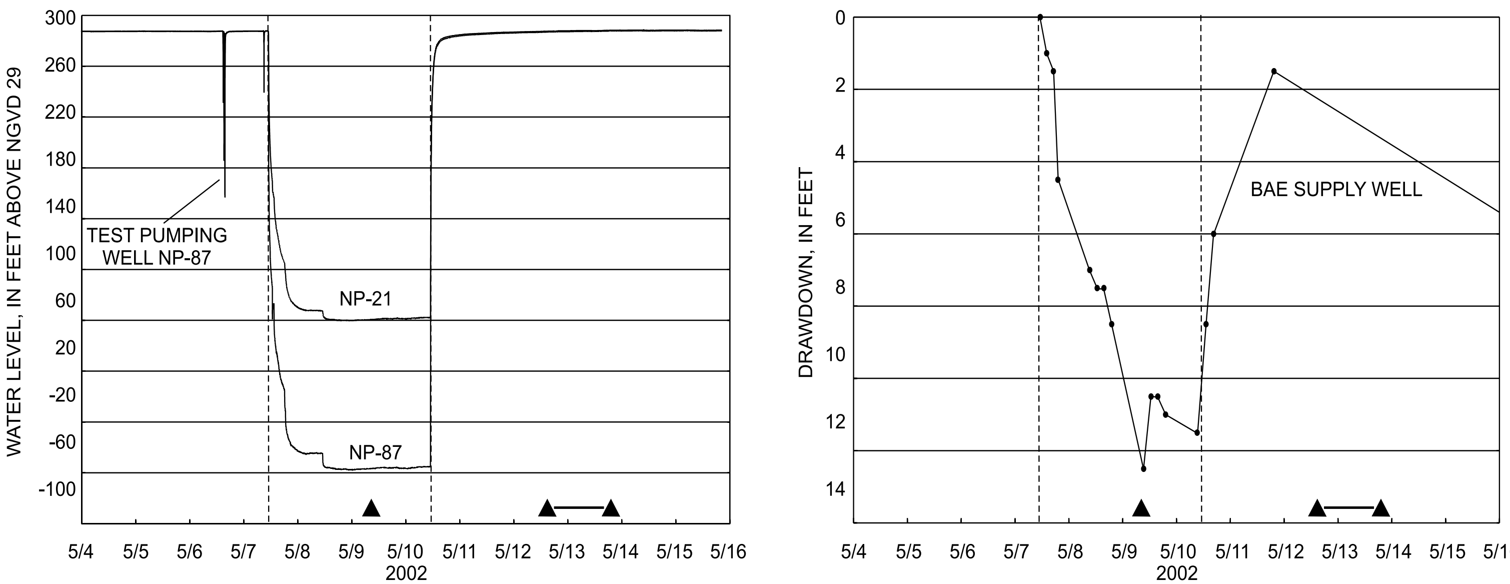
NOTE: Triangles indicate periods of precipitation; Dashed lines indicate period of pumping from well NP-87

Figure 21. Water levels in wells where drawdown was monitored during the May 2002 aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.



NOTE: Triangles indicate periods of precipitation; Dashed lines indicate period of pumping from well NP-87; 1) BAE Supply and A-10 pumping turned off; 2) A-10 restarted; 3) BAE Supply restarted.

Figure 21. Water levels in wells where drawdown was monitored during the May 2002 aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.



NOTE: Triangles indicate periods of precipitation; Dashed lines indicate period of pumping from well NP-87

Figure 21. Water levels in wells where drawdown was monitored during the May 2002 aquifer test at well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania—Continued.

Changes in atmospheric pressure

During the 3-day period when NP–87 was pumping, the atmospheric pressure changed a maximum of about 0.25 ft of water (fig. 22). Thus, as in the NP–21 test, only in wells where drawdown was small (generally less than 1 ft) did adjustments for atmospheric pressure make much difference. Some of the water-level rise measured in wells following the precipitation on May 9 could have been attributed to the 0.2-ft decline in atmospheric pressure associated with the storm. The major effect of atmospheric pressure was after the pumping stopped on May 10. The rise in pressure from about 33.8 to 34.2 ft after the pump was shut off at 11 a.m on May 10 may have caused water levels to continue to decline instead of begin to recover. A hydrograph of RI–27S shows both the measured drawdown and drawdown that was adjusted assuming a 70-percent barometric efficiency (fig. 23). The adjustment makes it more apparent that the water level began to recover shortly after the pumping of NP–87 ceased. The adjusted water-level data show partial recovery of

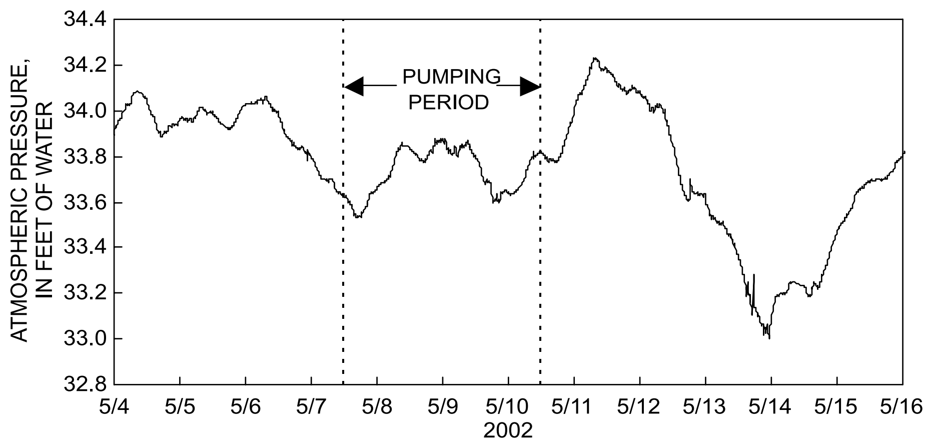


Figure 22. Atmospheric pressure during the May 2002 aquifer test of well NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

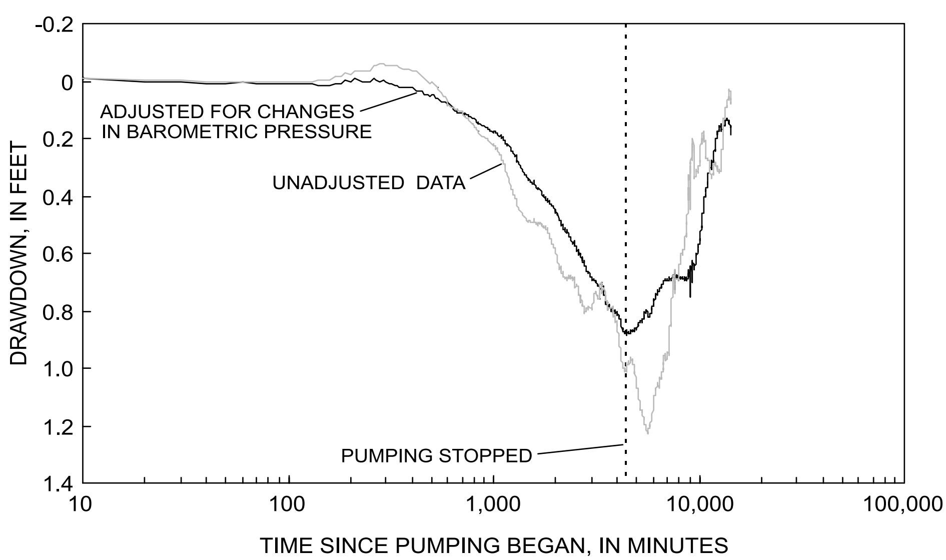


Figure 23. Drawdown in observation well RI–27S showing adjustments for changes in atmospheric pressure during and after the May 2002 aquifer test at NP–87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

about 0.2 ft from the time that pumping stopped (4,320 minutes) to about 7,000 minutes (fig. 23). Water levels did not return to pre-test levels until after the area received precipitation on May 13 (about 9,000 minutes after the pumping began).

Pre-test trends

Pre-test water-level measurements indicated that 9 of the 35 observation wells showed a clearly defined trend (table 4). The slight upward trend in wells RW–1 and W–16 was caused by cessation of pumping from the nearby BAE Systems remediation and supply wells about 24 hours prior to the start of the aquifer test on May 7, 2002. The slight downward pre-test trend in water levels measured in A–3, A–13, MW–1, RW–4S, W–4, W–6, and W–8 is probably the natural ground-water recession. An adjustment of drawdown for a pre-test water-level trend was not made for any of the wells because the trends were so slight.

Withdrawals from other wells

Significant drawdown caused by withdrawals from wells other than NP–87 was not observed during the May 2002 aquifer test. A slight effect was the upward pre-test water-level trend at wells RW–1 and W–16 attributed to cessation of pumping from the BAE Systems supply and remediation wells (fig. 21). The BAE Systems supply well was off from May 6 at 9 a.m. to May 14 at 9:05 a.m. except for about twice a day when it pumped for less than 5 minutes to refill a pressure tank. Those small pumping episodes show up on the hydrograph of RW–3 (fig. 21) but are not a significant influence compared to the drawdown caused by the pumping of NP–87. The BAE Systems recovery well (A–10) was off from May 6 at 10:40 a.m. to May 13 at 4:05 p.m., and NWWA–22 was not in operation from May 3 to 13, 2002.

Drawdown from Pumping NP–87

Pumping of well NP–87 at 402 gal / min for 3 days caused measurable drawdown in all 34 of the observation wells monitored during the aquifer test except A–3 and A–13. Drawdown at the end of 3 days of pumping from well NP–87 was 343 ft in the pumped well and 225 ft in NP–21. Drawdown in the other observation wells ranged from about 0.5 to 12.0 ft. Drawdown is shown for shallow wells (less than 100 ft) and deep wells (at least 200 ft) in figures 18 and 19. At the same location, drawdown is greater in deep wells than shallow wells because the major water-yielding zone was encountered at 400 ft below land surface in NP–21 and NP–87.

The test of NP–87 confirmed the general pattern of drawdown observed during the test of well NP–21; however, water-level declines were observed further to the northeast near the former Stabilus facility because of the greater pumping rate and availability of additional observation wells (clusters at RW–4, RW–5, RW–6, and nested wells at RI–27). Outside of the immediate area of the NP–87 well field, the greatest drawdowns (7-12 ft) were observed near the BAE Systems facility in wells A–10, RW–3, and the BAE Systems supply well. The drawdown confirms the existence of a good hydraulic connection between NP–87 and wells completed within the deepest part of the geologic units penetrated by the pumped well. These units correspond to water-yielding zones encountered below 400 ft in NP–21 and NP–87 (fig. 20).

Near the former Stabilus facility, drawdown was indicated most clearly in deep wells RI–27D, RW–4D, RW–5D, and RW–6D. The greatest drawdown in that area (3.7 ft) was measured in the deepest well in the RW–6 cluster, which is the well farthest updip and completed most closely to the deep water-producing zone penetrated by well NP–87 as shown in figure 20. The shallow wells less than 50 ft deep in the area of the former Stabilus facility probably showed some drawdown from the pumping of NP–87, but the response was indicated less clearly than for the deep wells. After pumping ceased from NP–87, the water-level recovery in shallow wells RI–27S, RW–4S, RW–5S, RW–6S, W–3, W–4, W–5, W–6, W–8, and W–9 was slow. The small apparent drawdown and poor recovery indicate that the pumping has less effect on water levels and direction of ground-water flow in the shallow part of the aquifer than the deep part, at least for the duration of the pumping test.

Streamflow in the tributary of the West Branch Neshaminy Creek near NP–87 appeared to be affected by pumping from NP–87 during the aquifer test. Measurements of stream stage show a downward deflection of the hydrograph recession slope corresponding to the start of pumping from NP–87 at 11 a.m. on May 7, 2002 (fig. 24). The change in recession slope could be interpreted as a capture of ground-water discharge to the stream or induced infiltration of stream water caused by the pumping. Although streamflow measurements were not sufficient to construct a relation between stage and streamflow, miscellaneous measurements showed that streamflow decreased during the aquifer test from 380 to 170 gal / min between May 7 at 1 p.m. to May 8 at 7 p.m. However, it is not clear how much of the decrease was caused by the pumping and how much was part of the natural streamflow recession because precipitation during the morning of May 9 caused the stream to rise, masking any increase in streamflow that might have been noted when the pumping ceased on May 10. The hydrograph from nearby USGS gaging station Little Neshaminy Creek at Valley Road (station 01464907), located about 5 mi southeast of the Colmar area, shows a similar recession prior to the start of pumping (fig. 24) but does not show a downward deflection of the recession slope on May 7 at 11 a.m., which provides evidence that streamflow in the tributary near NP–87 may have been affected by pumping.

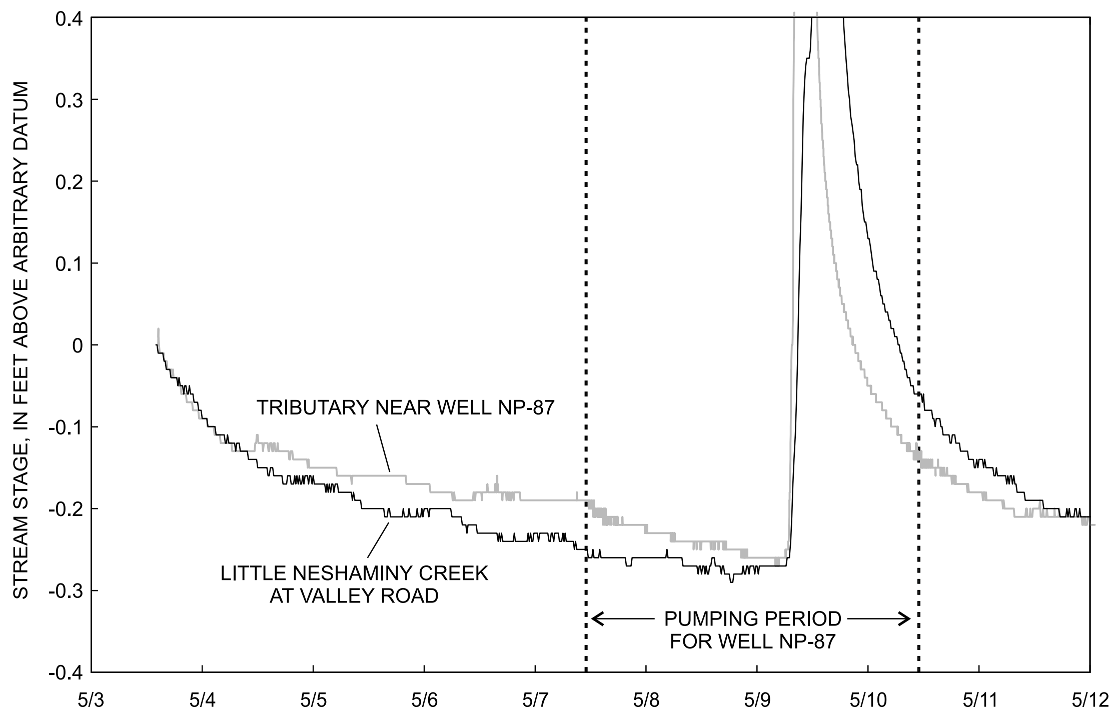


Figure 24. Stream stage in a tributary to the West Branch Neshaminy Creek near well NP–87 and in the Little Neshaminy Creek at Valley Road, monitored during the May 2002 aquifer test at well NP-87, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

SIMULATION OF GROUND-WATER FLOW

A numerical model was developed to simulate ground-water flow in the Colmar area. The model was constructed with dipping layers to characterize the dipping geologic units in the vicinity of wells NP–21 and NP–87. Specifically, the model was used to evaluate (1) ground-water-flow paths under current (2000) conditions and (2) flow paths and areas contributing recharge to wells for hypothetical pumping scenarios that include withdrawals from well NP–21 or NP–87.

Model simulations were conducted under steady-state and transient conditions. Simulations to estimate ground-water-flow paths and contributing areas were conducted under steady-state conditions. Steady-state simulations give results that represent the average position of flow paths and contributing areas on the basis of the values of average annual ground-water recharge and pumping assigned to the model. Changes caused by seasonal variations in recharge or operational variability in pumping were not simulated. Transient model runs simulated the drawdown caused by pumping during the aquifer test of NP–87, which helped guide adjustments of hydraulic properties used in the model, but transient simulations of flow paths and contributing areas were not made.

Description of the Model

A 3-dimensional, finite-difference model was used to simulate steady-state and transient ground-water flow for a region of about 12 mi^2, which is much larger than the area of interest in the Colmar area (fig. 25). This large area was simulated to assure that significant effects from pumping in the Colmar area would not reach model boundaries that define the limits of the model domain. The numerical model constructed for the Colmar area was based partially on the MODFLOW model developed by Senior and Goode (1999), which simulated regional ground-water flow in the Lansdale area. The Lansdale regional model included the headwaters of the West Branch Neshaminy Creek and extended into the Colmar area (fig. 25). Withdrawals from NP–21 were included in that model on its northeastern boundary. For this study of the Colmar area, the regional model of Senior and Goode (1999) was extended to the northeast to include the area of interest in this study; the area outside of the Neshaminy Creek watershed was excluded. The regional model was further modified by adding dipping layers to incorporate more detail about the local-scale geologic structure in the vicinity of wells NP–21 and NP–87.

The 3-dimensional, finite-difference computer code MODFLOW–2000 (Harbaugh and others, 2000) was used with the particle-tracking program MODPATH (Pollock, 1994) to compute ground-water-flow paths and contributing areas. A graphical user interface linked to Argus Numerical Environments was used for pre- and post-processing of data (Winston, 2000).

Finite-Difference Grid and Model Structure

The modeled area was divided into a finite-difference grid with 80 rows and 123 columns (fig. 25). The horizontal dimensions of the cells were varied so that small cells were in the Colmar area, which is the focus of the study. The smallest cells, 66 ft by 66 ft, surround wells NP–21 and NP–87 where the largest effects of pumping were expected; maximum cell size was 328 ft by 328 ft in horizontal dimension. The model grid was oriented N. 62° E. to align with the strike of beds in the Colmar area as determined by orientation of bedding-plane partings interpreted from acoustic-televiewer surveys (Bird and Conger, 2002, p. 24). The orientation of the grid along bedding strike is important because the assumed principle direction of horizontal hydraulic conductivity is along the strike of beds, which was simulated as 11 times greater than across strike in the Lansdale-area model of Senior and Goode (1999).

The bottom of the model is set at 736 ft below land surface everywhere, which is assumed to be the depth below which very little ground-water movement occurs. The depth at which flow becomes negligible is not well known, but Senior and Goode (1999) used 696 ft for the base of their model. In this study, the base of the model was initially set at 696 ft below land surface, but 40 ft was added to the thickness of the uppermost model layer during the process of model adjustment, which lowered the bottom of the model to 736 ft everywhere.

The vertical structure of the model consists of eight layers as shown in figure 26. Layers 1, 2, and 8 are horizontal layers and layers 3, 4, 5, 6, and 7 are dipping layers. Layer 1 represents the weathered part of the aquifer that drapes over the area and layers 2 and 8 represent the regional extent of the aquifer. Layers 3 through 7 represent dipping geologic units in the vicinity of wells NP–21 and

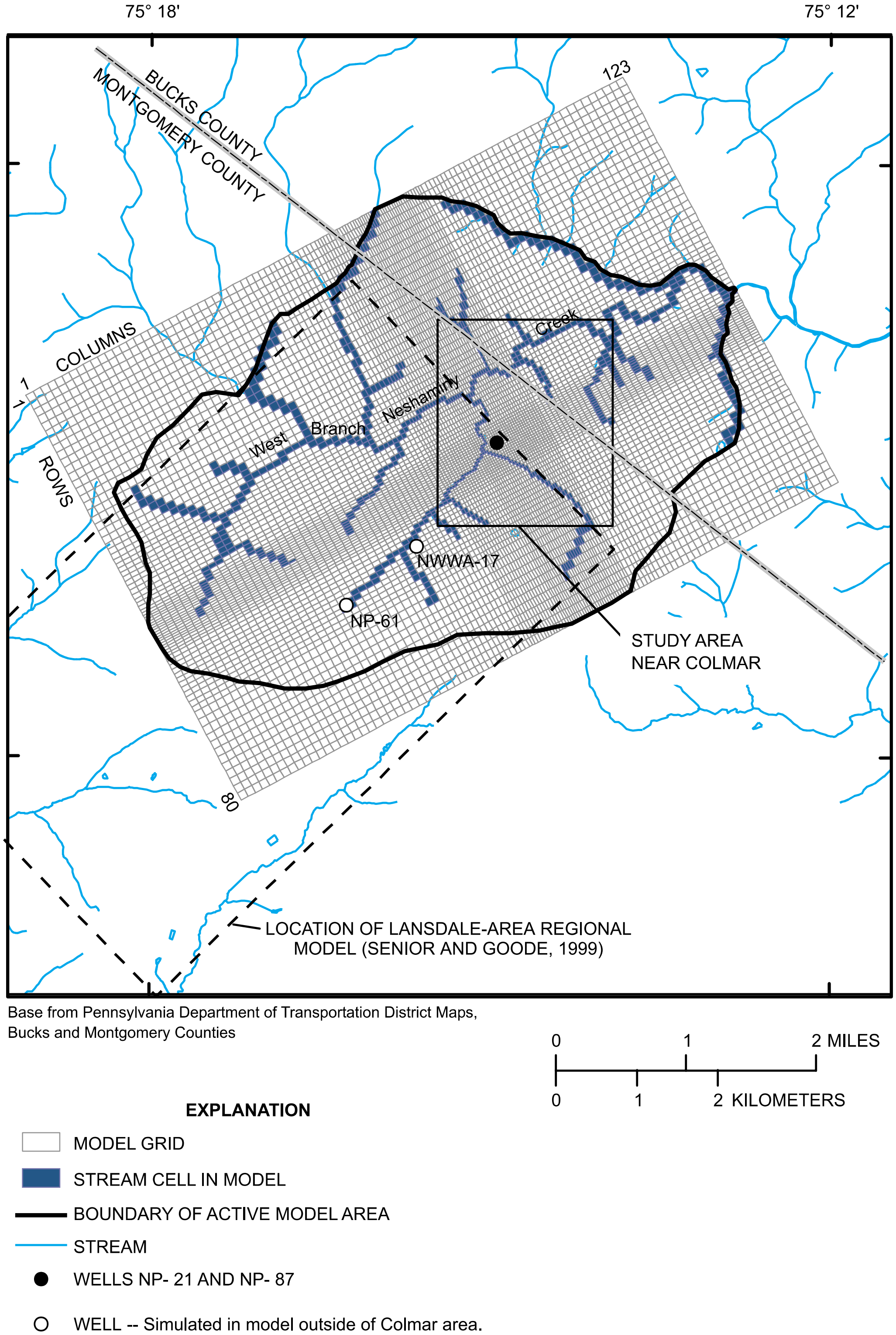
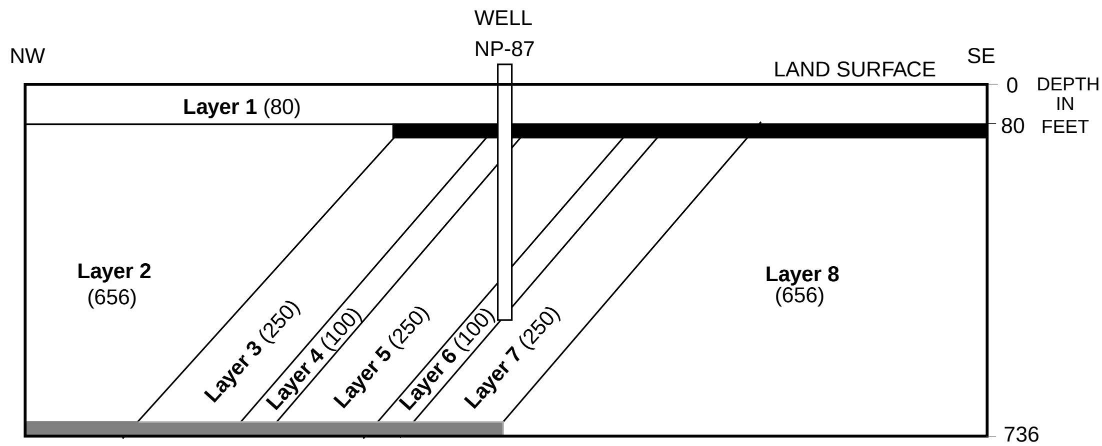


Figure 25. Modeled area showing finite-difference grid, domain boundary, stream cells, and location of Lansdale-area model of Senior and Goode (1999), Bucks and Montgomery Counties, Pennsylvania.



EXPLANATION

1 (80) LAYER NUMBER AND THICKNESS—Number in bold is model layer number; maximum thickness, in feet, is in parentheses.

PSEUDO-ACTIVE ZONE—Layers 2-7 are 0.01-foot thick in this area.

INACTIVE ZONE—Layers 3-8 are 0.1-foot thick in this area; hydraulic conductivity is 0.

ACTIVE ZONE—All of layer 1 and parts of layers 2-8.

Figure 26. Schematic cross section along the model column through well NP–87 showing model layers and thickness.

NP–87. To simulate the dipping units, the model layers were assigned three zones—active zone, inactive zone, and pseudo-active zone. The active zone is the part of the layer representing the geologic unit where it is present beneath layer 1 until its downdip extent reaches the base of the model (736 ft). The inactive zone of the layer represents the geologic unit where it extends below 736 ft. The pseudo-active zone represents the geologic unit where it extends above the base of layer 1. Pseudo-active zones are present in layers 2-7. The geologic unit is not physically present where the pseudo-active zone exists, but the unit needs to be included in the model so that continuity exists between layer 1 and deeper layers; thus, the pseudo-active zone consists of thin cells (0.01 ft thick) that are assigned a horizontal hydraulic conductivity of 0.1 ft/d and a vertical hydraulic conductivity of 100 ft/d, allowing water to pass vertically from model layer 1 to the model layer representing the geologic unit physically present beneath layer 1.

Layer 1 is 80 ft thick and represents the uppermost weathered part of the aquifer. The top of layer 1 is land surface and the bottom is 80 ft below land surface everywhere. Layer 1 is simulated as a confined aquifer; thus, transmissivity does not vary as the saturated thickness of the layer changes. Because most of the water-yielding fractures are in the lower 40 ft of the layer, dewatering of the upper part of the layer probably does not affect transmissivity greatly. In addition, the clayey regolith in the upper 40 ft of the layer partially confines water in the weathered zone.

Layers 2 and 8 are horizontal layers that represent the regional aquifer. These layers have a maximum thickness of 656 ft but become thinner where they truncate into the sequence of dipping layers (layers 3 through 7).

Layers 3 through 7 are dipping layers that represent the dipping structure intercepting wells NP–87 and NP–21. Dipping layers 4 and 6 are a maximum of 100 ft thick and represent the two major water-yielding zones intercepted by NP–21 and NP–87 (fig. 11). Layers 3, 5, and 7 each have a maximum thickness of 250 ft. The top and bottom of each dipping layer is tied to the structure-contour surface shown in figure 27. This surface is an estimate of the altitude of an arbitrary horizon within the sequence of rocks that strike 35 to 70° NE. and dip 10 to 30° NW. The top of the horizon was established to pass through the top of the open interval in NP–21, 50 ft below land surface. The horizon represents the top of layer 4 in the model. Where the horizon is projected above land surface, layer 4 does not exist but the elevation of the horizon is used to compute the top and bottom elevations of lower layers 3 through 7.

Model Boundaries

The lateral extent of the model area is defined by an impermeable boundary represented in each layer by inactive cells or limit of the model grid (fig. 25). The southern and western boundaries of the model extend to the surface-water divide of the West Branch Neshaminy Creek. The northern and most of the eastern boundary follow the main stem or tributaries of Neshaminy Creek. All of these boundaries are far removed from the Colmar area to assure that simulated pumping of NP–21 or NP–87 has little effect on ground-water levels near model boundaries and that simulated contributing areas are totally within the model area. The base of the model, 736 ft below land surface everywhere, is simulated as an impermeable boundary.

Streams

Streams are simulated in the model by use of the stream package (Prudic, 1989) as modified for MODFLOW–2000. The stream package allows simulated streams to gain or lose water and accounts for the flow in each stream cell so that losses cannot exceed the simulated base flow of the stream. The altitude of the stream bottom was assigned from altitudes estimated from 7.5-minute topographic maps. Stream stage was assigned an altitude 1 ft higher than the streambed and thickness of the streambed was assumed to be 1 ft. Stream width was assigned a value that increased from 10 to 30 ft depending on the position of the stream in the watershed. First-order and second-order headwater streams are 10 ft wide, mid-basin streams are 20 ft wide, and near the confluence of the West Branch and main branch Neshaminy Creek, streams are 30 ft wide. The hydraulic conductivity of the streambed was assigned a value of 0.16 ft/d. This is the value of the upper 40 ft of regolith used in the Lansdale area regional model. It represents the clayey and relatively impermeable weathered rock near land surface. The location of stream cells is shown in figure 25.

Recharge

Recharge to the model is added as a constant flux to the top of each active cell in layer 1. An average, annual recharge rate of 8.3 in/yr estimated by Senior and Goode (1999) for the Lansdale area also was used in this model of the Colmar area. Recharge was not varied spatially according to differences in land use or topography.

Wells

Ground-water withdrawals from wells are represented by a constant flux of water removed from the model using the well package in MODFLOW–2000. Withdrawals from each well were assigned to the model layer representing the geologic unit yielding water to the well. In cases where a well receives water from more than one model layer, the total withdrawal is apportioned to each layer according to estimates from drillers records, flowmeter surveys, or isolated-interval testing. Where yield information is not available, the apportionment was arbitrarily divided equally between layers. Location and pumping rates of wells used in model simulations are listed in later sections of this report where the results of simulations are discussed.

Aquifer Properties

Initial estimates of aquifer properties used in the model were taken from the regional modeling study of the Lansdale area by Senior and Goode (1999); the values subsequently were changed during the model-adjustment procedure described in the following section. In the Lansdale area model, the hydraulic conductivity along model rows was 5.35 ft/d and the Lockatong Formation was 1.12 ft/d. The hydraulic conductivity of both formations was 11 times greater along rows than across rows. A hydraulic-conductivity value of 0.16 ft/d was used to represent a relatively impermeable weathered zone in the upper 40 ft of both Lockatong and Brunswick Formations. Specific storage was assumed to be 0.000001 per foot of aquifer thickness. Initial values for the Lansdale area model are listed in table 5.

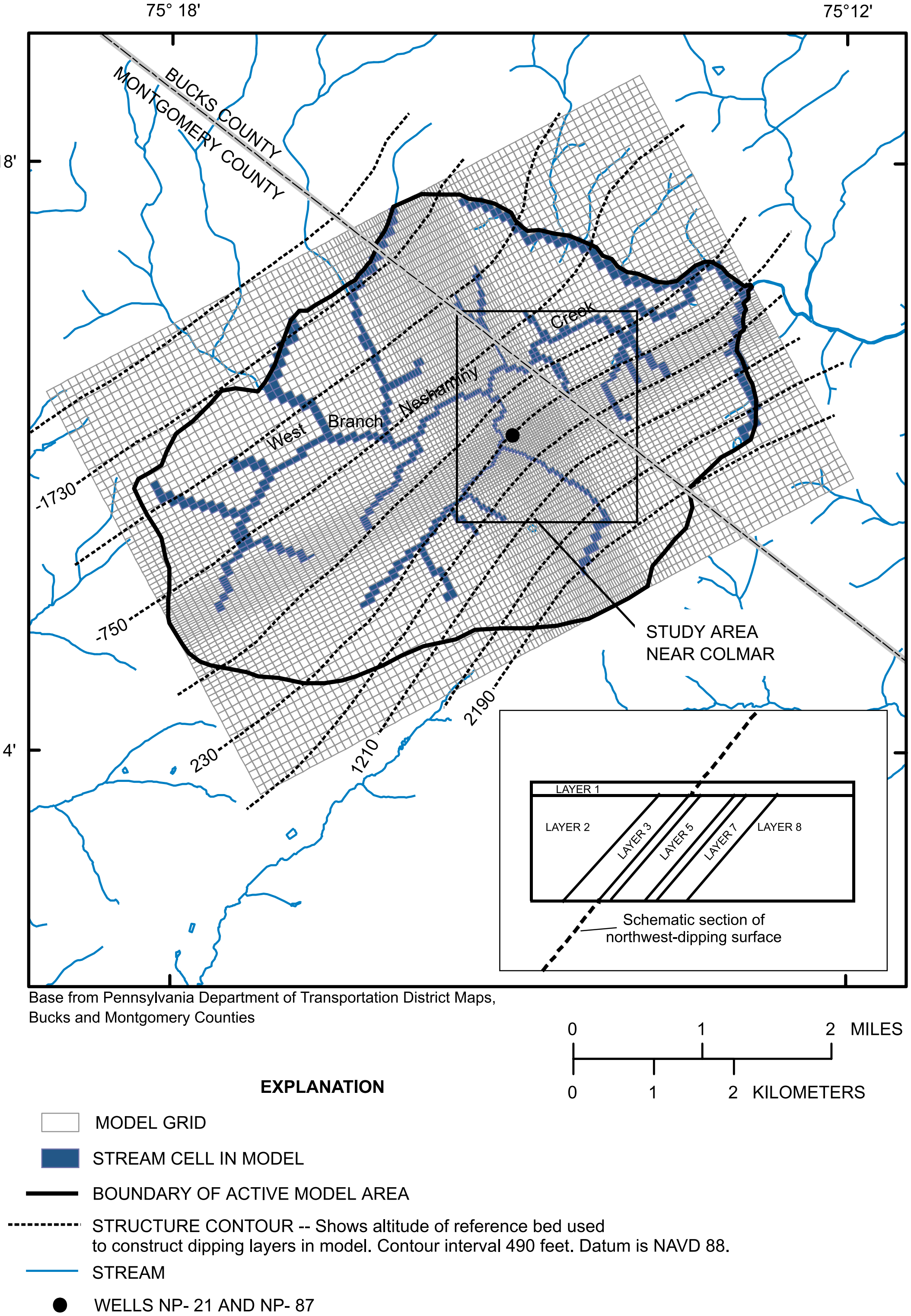


Figure 27. Structure-contour map of northwest-dipping surface representing top of model layer 4, Colmar study area, Bucks and Montgomery Counties, Pennsylvania.

Table 5. *Initial estimates of aquifer properties for the model of ground-water flow in the Colmar study area, Bucks and Montgomery Counties, Pennsylvania*

Model Layer	Geologic unit	Hydraulic conductivity in direction of strike of beds (feet per day)	Geometric mean hydraulic conductivity (feet per day)	Horizontal anisotropy (ratio of hydraulic conductivity along model columns to along rows)	Vertical anisotropy (ratio of hydraulic conductivity in the horizontal direction to the value in the vertical direction)	Specific storage (1/foot)
1	Weathered Zone	0.16	0.16	1	1	0.000001
2	Brunswick Formation	5.35	1.16	.09	1	.000001
3	Brunswick Formation	5.35	1.16	.09	1	.000001
4	Brunswick Formation	5.35	1.16	.09	1	.000001
5	Lockatong Formation	1.12	.34	.09	1	.000001
6	Lockatong Formation	1.12	.34	.09	1	.000001
7	Lockatong Formation	1.12	.34	.09	1	.000001
8	Lockatong Formation	1.12	.34	.09	1	.000001

Model Adjustments

Model adjustment is a process in which aquifer properties are changed until the model adequately simulates the measured response of the physical hydrologic system. This process commonly is called model calibration, but it is not intended to establish with certainty the accuracy or precision of model predictions. Rather, the process is used to refine concepts until an adjusted model is constructed that can reproduce observed conditions in the real hydrologic system. The model of the Colmar area was adjusted by matching as closely as possible the water levels in monitoring wells during (1) average, non-pumping, steady-state conditions and (2) transient pumping of well NP–87 during the May 2002 aquifer test.

Method and Data Used for Model Adjustments

The aquifer properties in the model were adjusted by use of the parameter-estimation program that is integrated into MODFLOW–2000 (Hill and others, 2000). The parameter-estimation program adjusts aquifer properties in the model to optimum values that minimize the difference between simulated and measured steady-state water levels and transient drawdown in wells. Water-level altitudes from 54 wells representing the average, non-pumping, steady-state conditions and drawdown measured in 30 wells during the 3-day aquifer test of NP–87 were used by the parameter-estimation program to adjust aquifer properties. Drawdown data from the NP–87 aquifer test were used (instead of the NP–21 aquifer test) because (1) the greater pumping rate during the NP–87 test made it easier to differentiate drawdown from natural trends, (2) drawdown caused by pumping from other wells in the area was not significant, (3) rainfall during the NP–87 test caused less ground-water recharge than during the NP–21 test, and (4) the pumping rate of NP–87 was monitored more closely than that of NP–21.

Water levels used to adjust the model for steady-state non-pumping conditions need to represent the average annual position of the water table to the best extent possible. Water-level measurements made prior to the aquifer test of well NP–21 during June 2000 probably are fairly representative of average conditions based on long-term water-level fluctuations at the USGS observation well MG–917 in Hatfield, about 4 mi northwest of

Colmar (fig. 28). The water level in MG–917 during the period of the June 2000 aquifer test was near the 3-year median water level for that well; the water level during the May 2002 test was about 1 ft higher. Thus, water levels measured prior to the aquifer test from June 19–20, 2000, were used to calibrate the model under steady-state nonpumping conditions.

Some wells monitored during the May 2002 aquifer test of NP–87 were not drilled until after the June 2000 test was conducted, so average, steady-state water levels were estimated for those wells on the basis of the water level measured prior to the May 2002 test and an adjustment factor, determined by comparing water levels in other wells that were monitored during both periods. Water levels measured in May 2002 in the MW–series wells were adjusted by lowering them 0.8 ft on the basis of the water levels measured in nearby wells W–13 and W–17 during both periods. Water levels in the RW–4, RW–5, and RW–6 well clusters and RI–27 nested well pair measured in May 2002 (but not in June 2000) were lowered 1.4 ft on the basis of the average difference in 14 wells monitored during both periods. The final set of water levels used for model adjustments is shown in table 6. All values, measured and adjusted, were considered to be known with the same degree of accuracy for purposes of parameter estimation.

The drawdown values used for model adjustment are listed in table 6. Drawdown values from 30 monitor wells were determined after 1, 4, 10, 24, and 43 hours of pumping well NP–87 from May 7–8, 2002. Drawdown values from 43 to 72 hours of pumping were affected to varying degrees by the rainstorm and were not used for calibration. Drawdown was computed after adjusting the water-level measurements for transducer drift and changes in atmospheric pressure.

Aquifer properties that were adjusted were the horizontal hydraulic conductivity, horizontal anisotropy, vertical anisotropy, and specific storage of the active parts of all model layers. The inactive parts of model layers 3 through 8 at the base of the model were assigned a hydraulic conductivity of 0; thus, cells in the inactive parts are not used in model computations.

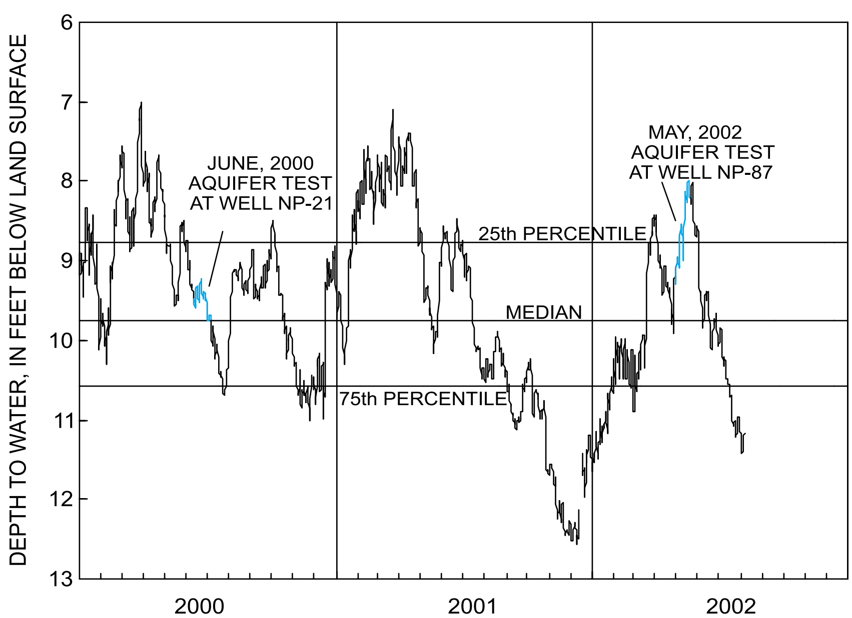


Figure 28. Water-level fluctuations, January 2000 through July 2002 in U.S. Geological Survey observation well MG–917, 4 miles northwest of Colmar, Pennsylvania.

Table 6. *Steady-state water-level altitude and drawdown used for calibration of the ground-water-flow model in the Colmar area, Bucks and Montgomery Counties, Pennsylvania*

[—, not measured; NGVD 29, National Geodetic Vertical Datum of 1929]

Well	Steady-state water-level altitude (feet above NGVD 29)	Drawdown in feet, after pumping from NP–87				
		1 Hour	4 Hours	10 Hours	24 Hours	43 Hours
A–10	298.27	0.04	1.00	2.97	5.27	6.49
A–18	303.21	—	—	—	—	—
BAE Production	298.27	.50	1.20	5.00	7.20	12.50
MW–1	291.48	1.01	1.90	2.33	2.64	3.10
MW–2	285.20	4.00	5.37	5.75	6.13	6.36
MW–3	287.80	.34	.90	1.18	1.45	1.67
MW–5	290.78	.60	1.49	1.99	2.55	2.93
NP–75	260.20	—	—	—	—	—
R&B–2	267.90	—	—	—	—	—
R&B–3	266.69	—	—	—	—	—
RI–1S	263.88	—	—	—	—	—
RI–2S	297.25	—	—	—	—	—
RI–4S	330.13	—	—	—	—	—
RI–5S	291.74	—	—	—	—	—
RI–6S	280.75	—	—	—	—	—
RI–7S	290.17	—	—	—	—	—
RI–8D	273.19	—	—	—	—	—
RI–9S	262.04	—	—	—	—	—
RI–10D	256.04	—	—	—	—	—
RI–11S	267.45	—	—	—	—	—
RI–12D	263.29	—	—	—	—	—
RI–13D	263.74	—	—	—	—	—
RI–15D	259.02	—	—	—	—	—
RI–16D	256.96	—	—	—	—	—
RI–18D	287.42	—	—	—	—	—
RI–19D	290.09	.00	.04	.21	.45	.62
RI–19S	289.93	.00	.05	.20	.43	.62
RI–20D	294.12	.59	1.98	3.11	4.39	5.20
RI–20S	291.72	.28	.84	1.35	2.13	2.65
RI–23	275.02	—	—	—	—	—
RI–27D	284.40	.01	.08	.34	.89	1.28
RI–27S	285.66	.01	.00	.09	.33	.61
RW–1	295.10	.04	.61	1.57	2.81	3.76
RW–3	304.88	1.09	3.61	6.24	9.23	11.23
RW–4D	285.06	-.01	.02	.30	1.03	1.69
RW–4I	286.41	.02	.03	.06	.44	.74
RW–4S	286.97	.01	.04	.12	.27	.50
RW–5D	286.36	.01	.02	.18	.61	.95
RW–5I	285.83	.01	.02	.15	.63	1.24
RW–5S	285.95	.01	.02	.12	.42	.69
RW–6D	297.84	.00	.56	1.51	2.64	3.27
RW–6I	288.73	.01	.02	.19	.53	.68
RW–6S	289.95	.01	.02	.10	.27	.43
W–3	295.40	.01	.03	.13	.49	1.04
W–4	286.03	.01	.04	.11	.25	.47
W–5	285.36	.01	.02	.08	.38	.63
W–6	291.77	.01	.05	.14	.25	.36
W–8	286.41	.04	.06	.15	.33	.55
W–9	290.05	.01	.04	.21	.52	.70
W–10	286.91	—	—	—	—	—
W–12	290.58	—	—	—	—	—
W–13	283.77	—	—	—	—	—
W–14	290.16	—	—	—	—	—
W–16	303.30	.01	.25	1.09	2.71	4.22

Model Parameters

Fifteen parameters were used in MODFLOW–2000 to represent hydraulic properties of the active parts of layers 1 through 8. The parameters are described in table 7. Each parameter was assigned a value or it was optimized by the parameter-estimation process in MODFLOW–2000. The decision of which parameters to allow the program to optimize was based on the sensitivity of simulated hydraulic head to changes in each parameter. The composite-scaled sensitivity of the 15 parameters is shown in figure 29. The composite-scaled sensitivity is computed as defined by Hill (1998, p. 15). It can be interpreted as the average amount that the simulated head or drawdown will change, expressed as a percent of the standard deviation of the measurement error, if the parameter value changes 1 percent. In general, a change in a parameter with a large composite sensitivity causes a greater proportional change in simulated water level than a change in a parameter with smaller sensitivity. Thus, aquifer properties for five of the seven most sensitive parameters [K(1), K(dip), K(4&6), SS(1), SS(23578)] were optimized (black bars in figure 29) and the properties of the other parameters were assigned a value (white and grey bars in figure 29). The value of the parameter with the largest normalized sensitivity, VANI(dip), was assigned because it was highly correlated with parameter K(dip). Because of the correlation, many combinations of VANI(dip) and K(dip) could produce essentially the same results, so only the value of K(dip) was optimized.

Final values of aquifer properties used in the model are shown in table 8. The model-adjustment procedure used to arrive at the values for aquifer properties indicated that, given the dipping bed structure, the two producing intervals (layers 4 and 6) must be separated by geologic units (layers 3, 5, and 7) with much lower hydraulic conductivity than the units supplying water to the well. The low hydraulic conductivity is needed to prevent drawdown from the deep-producing interval from propagating to shallower units where little drawdown was observed. However, the low hydraulic conductivity units represented by K(dip), which were layers 3, 5, and 7, restrict simulated regional ground-water flow so that simulated steady-state water levels are higher than observed. From the parameter-estimation process in MODFLOW, the

Table 7. *Definition of parameters used to represent aquifer properties in the ground-water-flow model of the Colmar area, Bucks and Montgomery Counties, Pennsylvania*

Parameter name	Description of model characteristic represented by parameter		
	Aquifer property	Active part of model layer(s)	Geologic unit
K(1)	Horizontal hydraulic conductivity along model rows	1	Weathered zone
K(brun)	Horizontal hydraulic conductivity along model rows	2	Brunswick Formation
K(dip)	Horizontal hydraulic conductivity along model rows	Dipping layers 3, 5, and 7	Brunswick and Lockatong Formations
K(4&6)	Horizontal hydraulic conductivity along model rows	Dipping layers 4 and 6	Shallow and deep water-producing zones in wells NP–21 and NP–87
K(lock)	Horizontal hydraulic conductivity along model rows	8	Lockatong Formation
HANI(1)	Ratio of hydraulic conductivity along model columns to along rows	1	Weathered zone
HANI(2&8)	Ratio of hydraulic conductivity along model columns to along rows	2 and 8	Brunswick and Lockatong Formations
HANI(dip)	Ratio of hydraulic conductivity along model columns to along rows	Dipping layers 3, 4, 5, 6, and 7	Brunswick and Lockatong Formations
VANI(1)	Ratio of horizontal to vertical hydraulic conductivity	1	Weathered zone
VANI(2&8)	Ratio of horizontal to vertical hydraulic conductivity	2 and 8	Brunswick and Lockatong Formations
VANI(dip)	Ratio of horizontal to vertical hydraulic conductivity	Dipping layers 3, 4, 5, 6, and 7	Brunswick and Lockatong Formations
SS(1)	Specific storage	1	Weathered zone
SS(23578)	Specific storage	2, 3, 5, 7 and 8	Brunswick and Lockatong Formations
SS(4)	Specific storage	Dipping layer 4	Shallow water-producing zones in wells NP–21 and NP–87
SS(6)	Specific storage	Dipping layer 6	Deep water-producing zone in wells NP–21 and NP–87

optimum hydraulic conductivity for the weathered zone was 7.4 ft / d along model rows (geometric mean of 3.3 ft / d), which is larger than previously thought reasonable. Because of this modeling result, slug tests were conducted at eight shallow observation wells (MW–1, MW–2, MW–5, RI–2S, RI–5S, RI–9S, W–3, and W–17) completed to depths of less than 50 ft to provide an estimate of hydraulic conductivity of the weathered zone. Hydraulic conductivity from slug tests ranged from 1.6 to 68 ft / d; the median was 7.7 ft / d, and geometric mean was 8.4 ft / d. This small testing effort shows that the hydraulic conductivity is highly variable, but the value of 7.4 ft / d determined from the parameter optimization procedure may be reasonable.

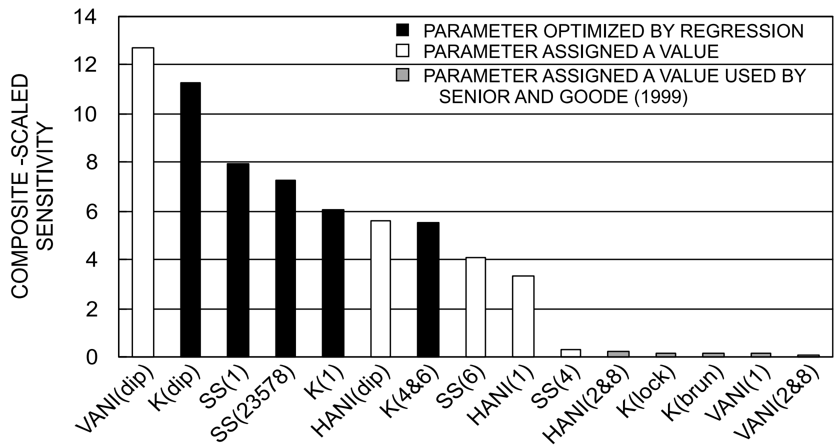


Figure 29. Composite-scaled sensitivity of hydraulic parameters used in the ground-water-flow model. (See table 7 for definition of parameters.)

Table 8. *Final aquifer-property values used for predictive simulations with the ground-water-flow model of the Colmar area, Bucks and Montgomery Counties, Pennsylvania*

[Shading pattern indicates method that parameter was assigned; dark shading, value estimated using parameter-estimation program; medium shading, value assigned from Lansdale area model of Senior and Goode (1999); no shading, parameter set at reasonable assumed value]

Layer	Parameter name and value			
	Hydraulic conductivity in direction of strike of beds (feet per day)	Horizontal anisotropy (ratio of hydraulic conductivity in the direction of dip to the value in the direction of strike)	Vertical anisotropy (ratio of hydraulic conductivity in the horizontal direction to the value in the vertical direction)	Specific storage (per foot)
1	K(1) 7.4	HANI(1) 0.2	VANI(1) 1	SS(1) 0.000012
2	K(brun) 5.2	HANI(2&8) .09	VANI(2&8) 1	SS(2,3,5,7,8) .0000039
3	K(dip) .081	HANI(dip) .2	VANI (dip) 10	SS(2,3,5,7,8) .0000039
4	K(4&6) 5.3	HANI(dip) .2	VANI (dip) 10	SS(4) .00000031
5	K(dip) .081	HANI(dip) .2	VANI (dip) 10	SS(2,3,5,7,8) .0000039
6	K(4&6) 5.3	HANI(dip) .2	VANI (dip) 10	SS(6) .00000031
7	K(dip) .081	HANI(dip) .2	VANI (dip) 10	SS(2,3,5,7,8) .0000039
8	K(lock) 1.1	HANI(2&8) .09	VANI(2&8) 1	SS(2,3,5,7,8) .0000039

Adjusted Model Results

The ability of the adjusted model to simulate steady-state water-level altitude is illustrated in figures 30A and 31. The model-simulated steady-state water levels are compared to levels measured in observation wells in figure 30A. The difference between simulated and observed steady-state water levels at 54 wells ranged from -12.66 to 14.9 ft. The largest differences were at wells RI–1S, RI–11S, and W–3 (table 9). The root-mean-square difference between simulated and observed steady-state water levels was 5.0 ft.

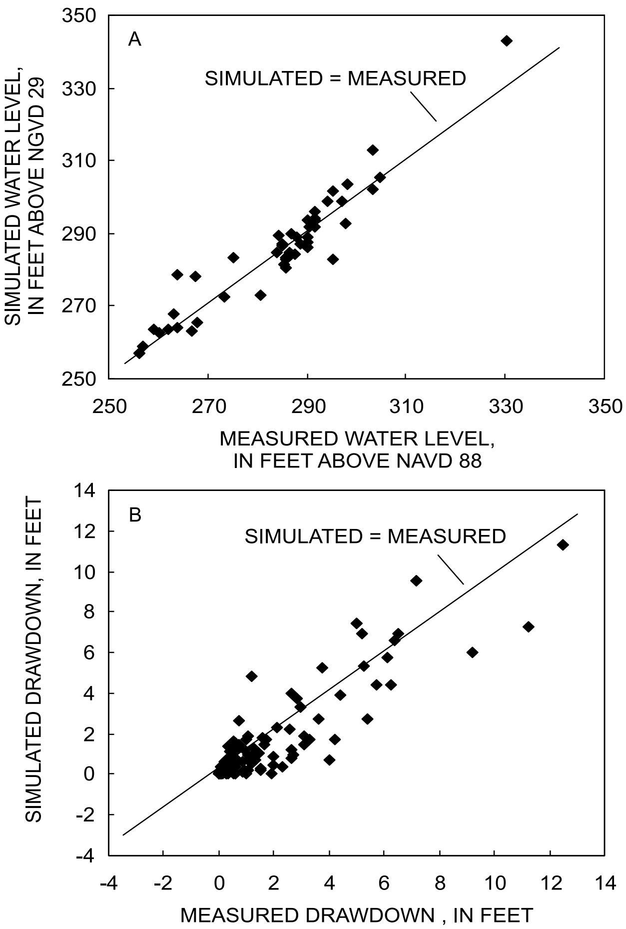
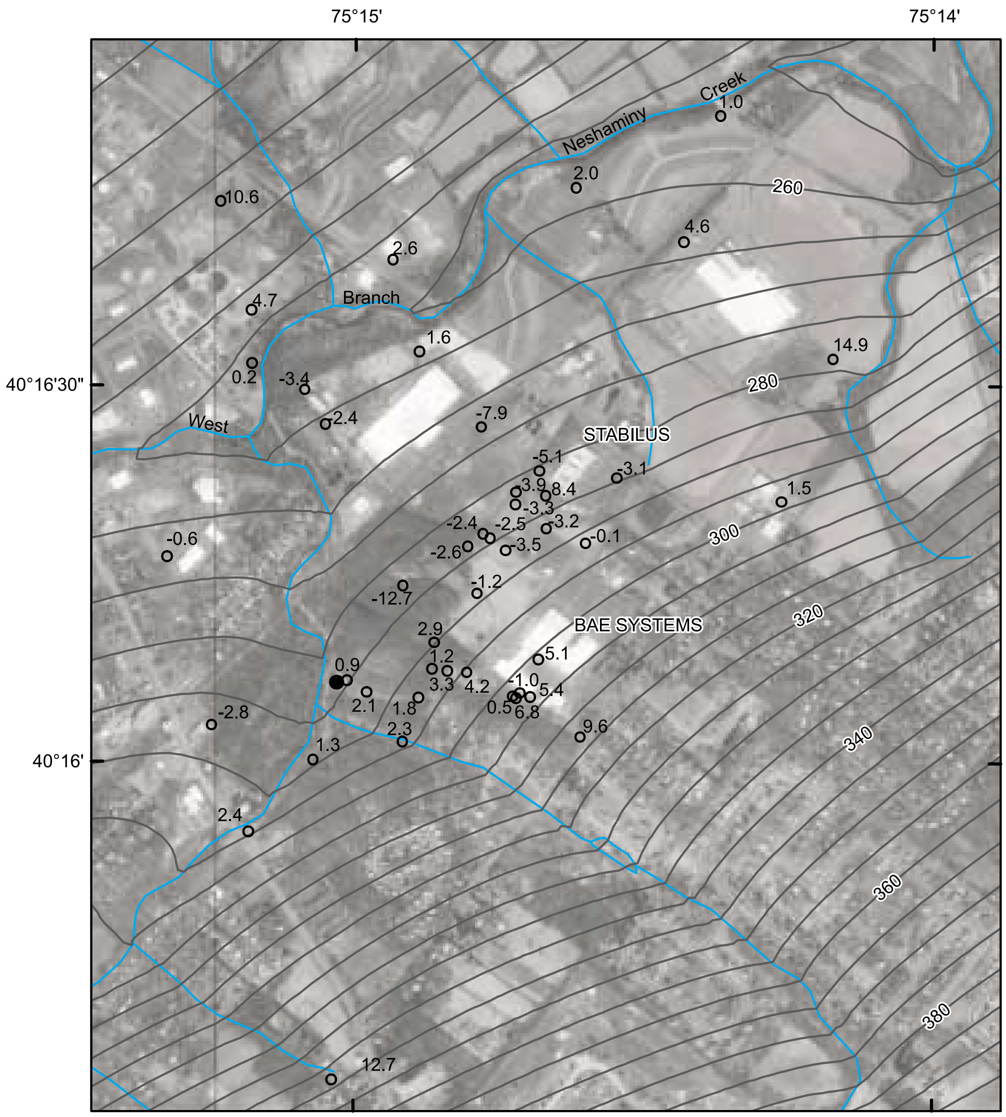


Figure 30. Observed values of (A) water-level altitude and (B) drawdown in relation to values simulated by the ground-water-flow model.

The relations between simulated and measured drawdown and time since pumping began show the degree to which the model can simulate drawdown and the shape of the drawdown curves at selected observation wells (fig. 30B and 32). In general, the drawdown curves are reasonably reproduced except for the MW–series wells and some of the W–series wells. The MW–series wells are near NP–87 and tributary streams to West Branch Neshaminy Creek. The reason for the poor simulation of measured drawdown may be attributed to an inaccurately simulated hydraulic connection between the stream and aquifer. In addition, lowering the specific storage of layer 1 produced a better simulation of measured drawdown in the MW–series wells but produced too much drawdown in other wells.

The ability of the adjusted model to simulate drawdown at the end of the 3-day aquifer test of NP–87 is shown in figure 33. The spatial pattern of simulated and measured drawdown at the end of 3 days pumping is reasonably simulated with the model. The model structure of dipping beds striking to the northeast produced a pattern of drawdown in the shallow part of the aquifer system that was similar to that observed in observation wells. The east-west trend of maximum observed drawdown between the pumping well and BAE Systems (shown for both the June 2000 aquifer test of NP–21 and the May 2002 test of NP–87 in figures 12 and 18) was simulated fairly well. The simulated area of 5 to 7 ft of drawdown in the BAE Systems area occurs because the deep producing zone in wells NP–21 and NP–87 crops out in that vicinity. The area of largest drawdown extending from the pumped well to the BAE area appears to be the result of east-west anisotropy but can be produced from a model constructed with the NE-SW trending structure of dipping beds.



Base from U.S. Geological Survey,
Telford S.E. and Doylestown S.W. Digital Orthophoto Quadrangles

0 1,000 2,000 FEET

0 300 600 METERS

EXPLANATION

—380— POTENTIOMETRIC CONTOUR - Shows equal simulated head in model layer 1. Contour interval is 5 feet; datum is NAVD 88

STREAM

● WELL NP- 87

1.3 ○ OBSERVATION WELL AND SIMULATED RESIDUAL - Residual is simulated minus measured water level at well location, in feet. At clusters or nested wells, value is for shallowest well. (See table 9 for residuals for all wells used in calibration).

Figure 31. Simulated steady-state water-level altitude in model layer 1 and residual between simulated and observed values.

Table 9. *Measured and simulated steady-state water levels from the ground-water-flow model of the Colmar area, Bucks and Montgomery Counties, Pennsylvania*

[NGVD 29, National Geodetic Vertical Datum of 1929]

Well identifier	Measured[1] steady-state water level, in feet above NGVD 29	Simulated steady-state water level, in feet above NGVD 29	Residual, simulated minus observed, in feet
A–10	298.27	303.66	5.39
A–18	303.21	302.21	-1.00
BAE Supply	303.37	298.27	5.10
R&B–2	267.90	265.46	-2.44
R&B–3	266.69	263.34	-3.35
MW–1	291.48	293.78	2.30
MW–2	285.20	287.25	2.05
MW–3	287.80	289.08	1.28
MW–5	290.78	292.57	1.79
NP–75	260.20	262.84	2.64
RI–1S	263.88	278.78	14.90
RI–2S	297.25	298.70	1.45
RI–4S	330.13	342.83	12.70
RI–5S	291.74	294.19	2.45
RI–6S	280.75	272.83	-7.92
RI–7S	290.17	287.40	-2.77
RI–8D	273.19	272.62	-.57
RI–9S	262.04	263.68	1.64
RI–10D	256.04	257.05	1.01
RI–11S	267.45	278.09	10.64
RI–12D	263.29	268.02	4.73
RI–13D	263.74	263.98	.24
RI–15D	259.02	263.62	4.60
RI–16D	256.96	258.99	2.03
RI–18D	287.42	284.33	-3.09
RI–19D	290.09	286.30	-3.79
RI–19S	289.92	286.44	-3.48
RI–20D	294.12	298.65	4.53
RI–20S	291.72	295.93	4.21
RI–23	275.02	283.38	8.36
RI–27D	284.40	289.31	4.91
RI–27S	285.66	280.59	-5.07
RW–1	295.10	301.87	6.77
RW– 3	304.88	305.36	.48
RW–4D	285.07	286.45	1.38
RW–4I	286.41	284.70	-1.71
RW–4S	286.98	284.45	-2.53
RW–5D	286.36	284.41	-1.95
RW–5I	285.83	283.14	-2.69
RW–5S	285.95	282.65	-3.30
RW–6D	297.84	292.53	-5.31
RW–6I	288.73	287.27	-1.46
RW–6S	289.95	286.72	-3.23
W–3	295.40	282.74	-12.66
W–4	286.03	283.63	-2.40
W–5	285.36	281.50	-3.86
W–6	291.77	291.63	-.14
W–8	286.41	283.85	-2.56
W–9	290.05	288.88	-1.17
W–10	286.91	289.79	2.88
W–12	290.58	291.82	1.24
W–13	283.77	284.71	.94
W–14	290.16	293.45	3.29
W–16	303.30	312.95	9.65

[1] Some water levels were adjusted as described on page 50.

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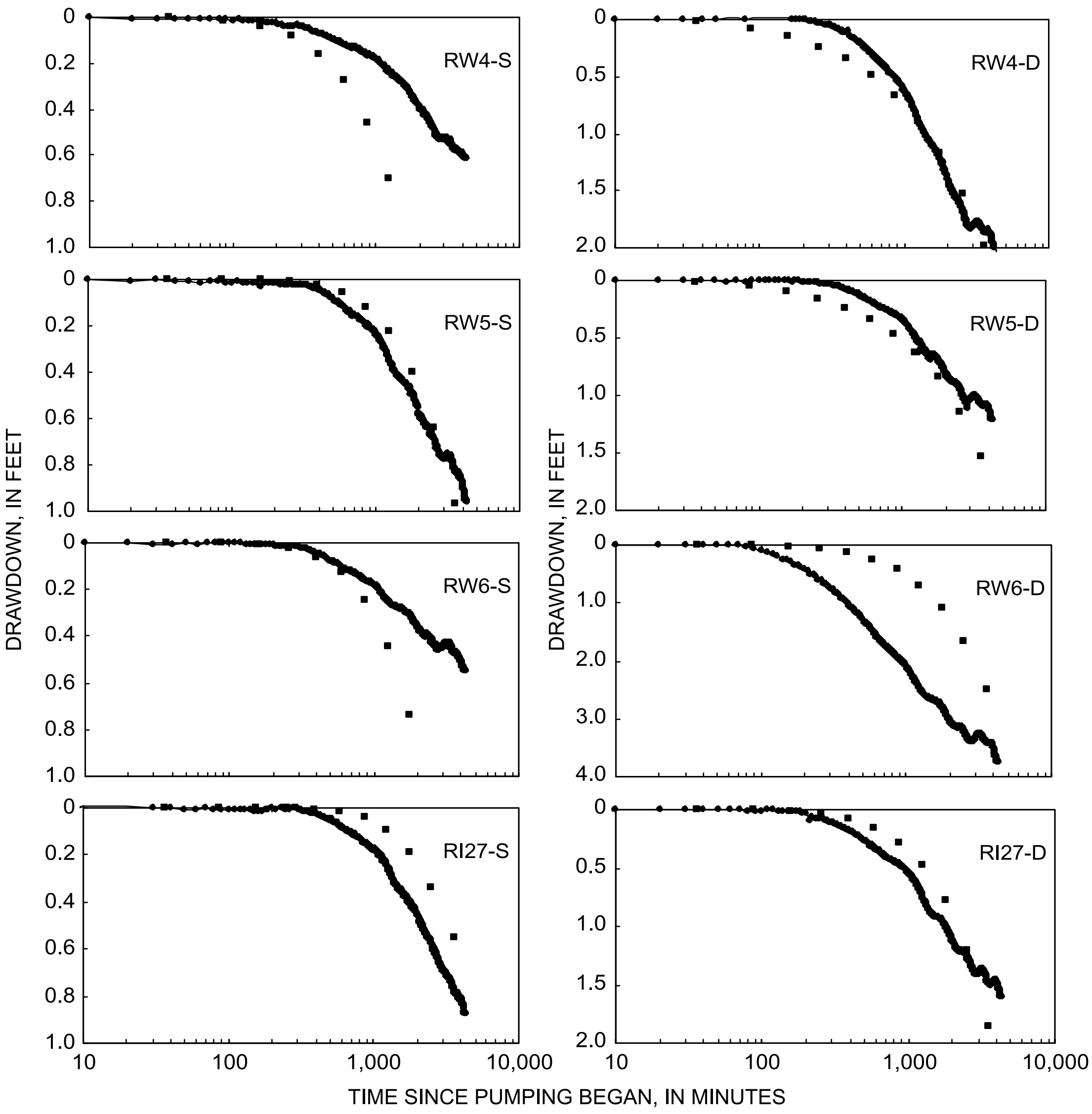


Figure 32. Hydrographs comparing observed drawdown (solid line) in selected observation wells to drawdown simulated (points) by the ground-water-flow model.

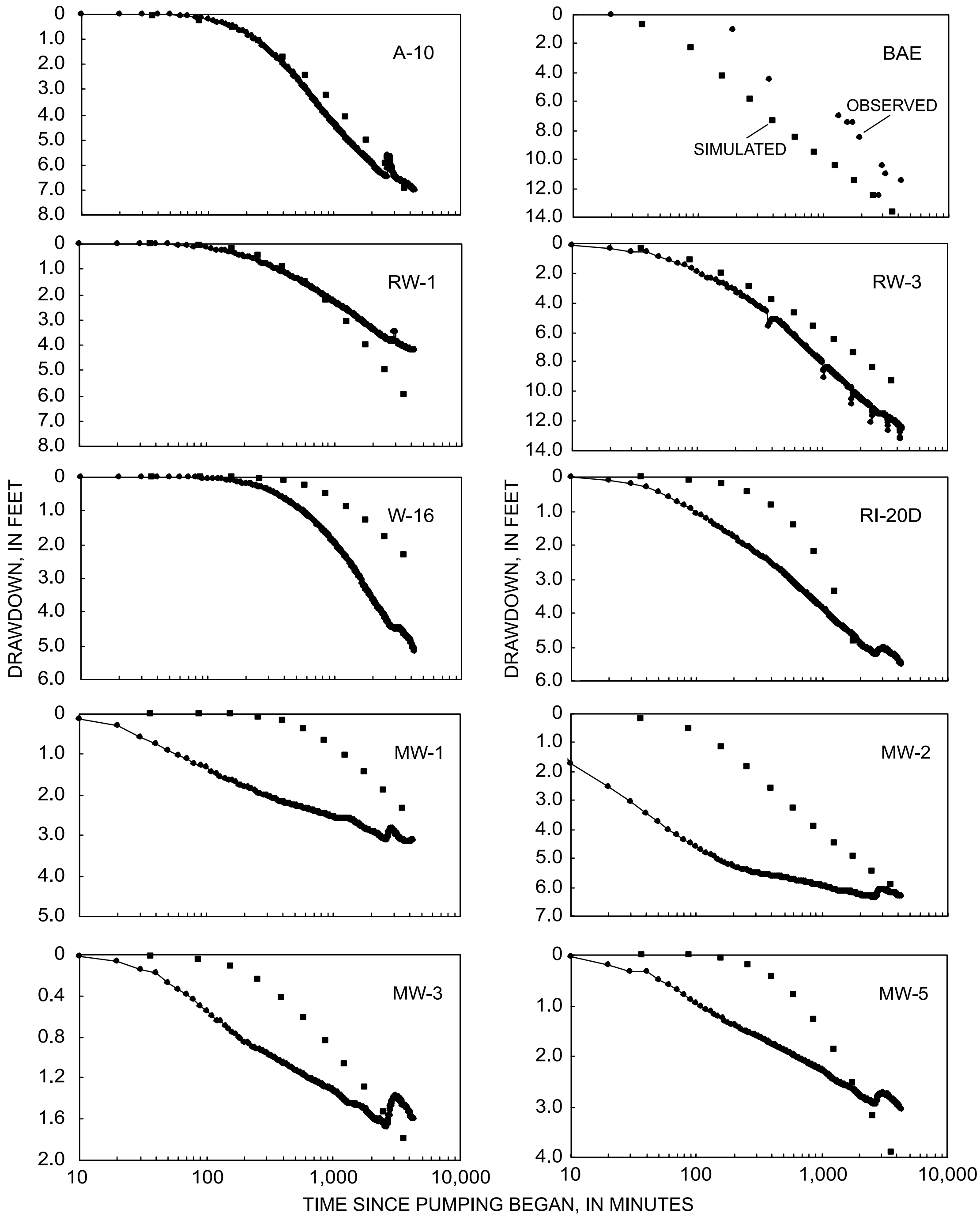


Figure 32. Hydrographs comparing observed drawdown (solid line) in selected observation wells to drawdown simulated (points) by the ground-water-flow model—Continued.

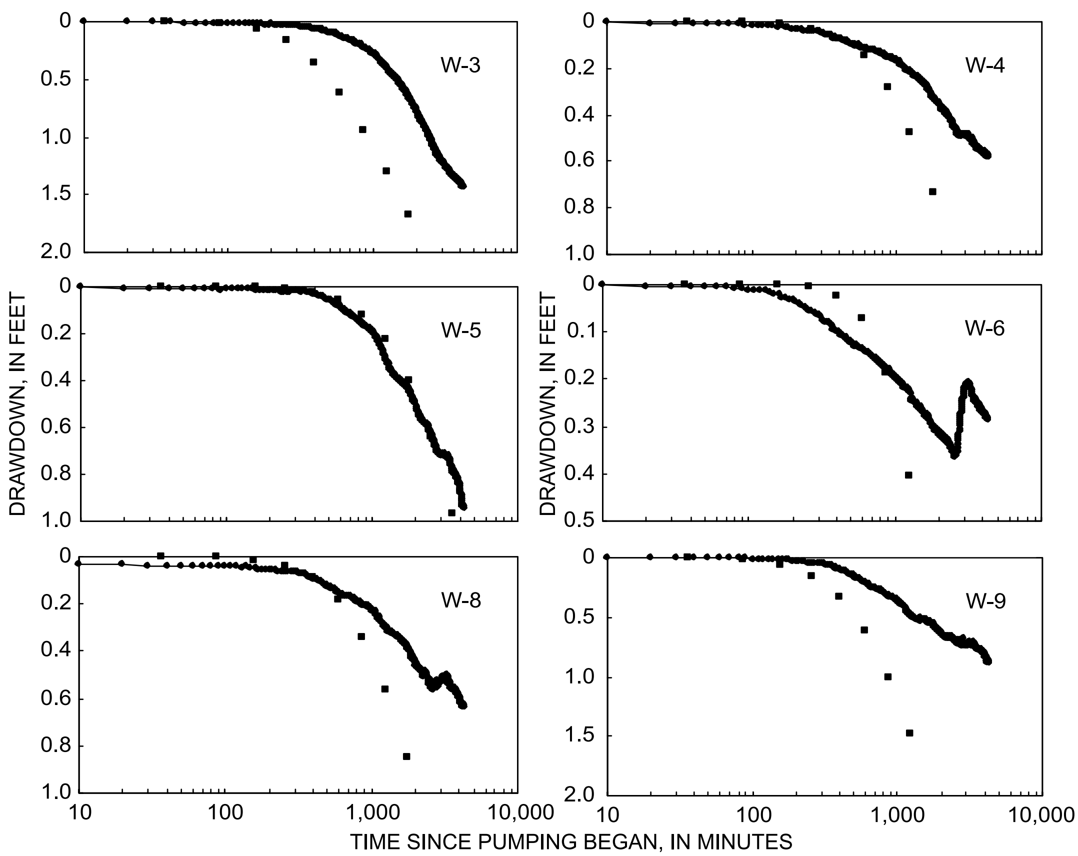
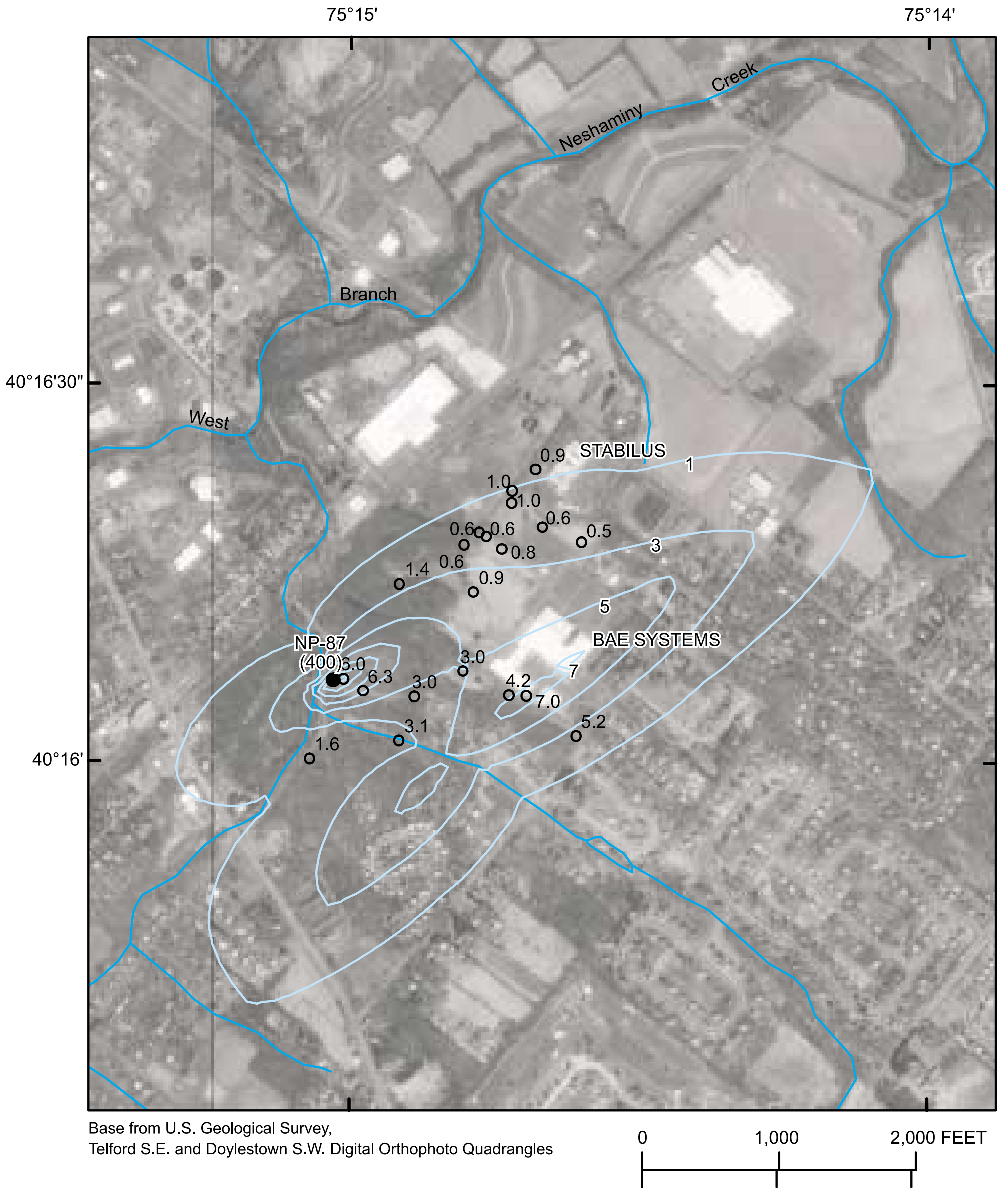


Figure 32. Hydrographs comparing observed drawdown (solid line) in selected observation wells to drawdown simulated (points) by the ground-water-flow model—Continued.



EXPLANATION

LINE OF EQUAL SIMULATED DRAWDOWN IN MODEL LAYER 1 - Contour interval is 2 feet.

STREAM

WELL NP-87 AND PUMPING RATE, IN GALLONS PER MINUTE

3.1 MEASURED DRAWDOWN, IN FEET

Figure 33. Simulated drawdown in model layer 1 after 72 hours of pumping well NP–87 at 400 gallons per minute and measured drawdown in observation wells less than 100 feet deep.

Model Assumptions and Limitations

The ground-water flow model is based on a generalized conceptualization of ground-water flow in a heterogeneous, dipping, fractured, bedrock aquifer. Some of the major assumptions and limitations of the model are discussed below:

- The fractured bedrock is modeled as an equivalent porous medium. This approach assumes that the hydraulic properties of fractures can be represented by an equivalent set of hydraulic properties representing a continuous porous medium. The approach is usually adequate if fractures are numerous but may be invalid at the local scale if a few discrete fractures control ground-water flow paths. In the vicinity of well NP-21 and NP-87, fractures intercepted by the wells at depths of 50 to 140 feet and below 400 feet below land surface contribute the majority of the water to the wells and probably have a strong local effect on ground-water flow. Therefore, these fractures were simulated in the model as layers of high hydraulic conductivity separated by layers of low hydraulic conductivity.
- The interbedded, dipping, geologic units are assumed to be laterally extensive in the model and were simulated as layers having uniform hydraulic properties. In reality, units of shale and siltstone interfinger and pinch out, undoubtedly causing considerable variability of hydraulic properties within a layer.
- Recharge to the ground-water system was assumed to be spatially and temporally uniform. Ground-water recharge rates probably vary in this urban area because of impermeable surface cover, detention basins, and sewers.
- The model simulates only the advective flow of ground water. In addition to advective flow, the transport of a contaminant in the ground-water system also may be affected by the density of the contaminant. TCE, the principal contaminant in the study area, has a specific gravity of 1.6, and could move as a non-aqueous phase in a direction different than the advective flow of ground water. In addition, the effects of dispersion, diffusion, dilution, chemical reactions, and biological transformations are not simulated.
- Given the simplifying assumptions noted above, undoubtedly ground-water flow within the fractured-bedrock aquifer is more complex than shown by illustrations of simulated flow paths and areas contributing recharge to wells. The simulated areas contributing recharge are approximations that are useful for comparing the potential effects of alternative pumping scenarios and general characteristics of areas contributing recharge to pumping wells.

Simulated Flow Paths and Area Contributing Recharge to Wells

The ground-water-flow model was used to simulate flow paths and to determine the area contributing recharge to wells for pumping conditions in the Colmar area in 2000 and for hypothetical situations of pumping suggested by USEPA in the proposed plan for North Penn Area 5, dated July 2002, that might be employed to limit contaminant migration (U.S. Environmental Protection Agency, 2002). The focus was on the northern area of contamination near the former Stabilus facility and the southern area of contamination near the BAE Systems facility. Ground-water withdrawals were simulated from the wells listed in table 10. Withdrawals from wells NP–61, NWWA–17, and NWWA–22 were included in all simulation scenarios because those wells represent existing withdrawals for public supply. NP–61 and NWWA–17 are outside of the Colmar area but within the model area. Their locations are shown in figure 25. Withdrawals from the other wells in table 10 were simulated only in scenarios used to illustrate the effect of adding that pumpage.

The area contributing recharge was determined by using the forward-tracking option in MODPATH (Pollock, 1994). One particle was placed at the center of the top face of each cell in model layer 1 and tracked to its discharge location. The starting location of each particle that terminated in a cell representing a pumping well was then plotted on a map. Particles were allowed to pass through weak sinks, where a simulated stream does not discharge at a rate large enough to remove all the water entering a model cell, if 40 percent ar less of the flow entering the cell was discharged to the sink. The location of the plotted particles represents the land area contributing recharge to the aquifer that is captured by the pumping well. The particles are shown as open circles to allow the features of the base map to be visible beneath the area contributing recharge.

Table 10. *Wells and withdrawal rates in 2000 simulated in the ground-water-flow model of the Colmar area, Bucks and Montgomery Counties, Pennsylvania*

Well	Well status (existing or hypothetical)	Model cell			Simulated withdrawal rate (gallons per minute)
		Layer	Row	Column	
Wells included in all simulation scenarios					
NP–61	Existing	1	64	23	28.5
		4	64	23	28.5
NWWA–17	Existing	4	60	35	5.5
		6	60	35	5.5
NWWA–22	Existing	1	58	45	10
		6	58	45	10
Wells simulated only in scenarios to illustrate effect of that withdrawal					
NP–87	Existing	4	43	65	100
		6	43	65	300
BAE supply	Existing	6	49	80	13
BAE Recovery (A–10)	Existing	1	51	78	15
New BAE Recovery (80 feet deep)	Hypothetical	1	47	73	8
New Stabilus Recovery (80 feet deep)	Hypothetical	1	36	88	15
New Stabilus Recovery (80 feet deep)	Hypothetical	1	38	87	15

Conditions in 2000

Current (2000) ground-water-flow conditions in the Colmar area were simulated by including pumping from the BAE Systems supply well and recovery well A–10 and from NP–61, NWWA–17, and NWWA–22 at the rates shown in table 10. The area contributing recharge to BAE Systems supply well and recovery well (A–10) within the study area is shown in figure 34. The contributing area does not surround the BAE supply well because the withdrawal was simulated from layer 6, which is 130 to 230 ft below land surface. The simulated capture zone extends to the east slightly outside of the study area in a long, narrow band because of the steep hydraulic gradients in this area.

Ground-water-flow paths were tracked from land surface in the northern and southern areas of contamination to discharge locations. Flow paths were simulated by placing particles on the top face of cells in layer 1 and using the forward-tracking flow-path option in MODPATH (Pollock, 1994). Simulations indicate that ground water near BAE Systems moves west and discharges to a tributary of West Branch Neshaminy Creek (fig. 34). Ground water in the northern area of contamination moves north and west to discharge in West Branch Neshaminy Creek and tributaries. The wide range of flow paths taken by the ground water originating from the northern area is partially a result of the anisotropy with respect to hydraulic conductivity (fig. 34).

Simulated flow paths shown on figure 34 do not correlate very well with the distribution of ground-water contamination found in the vicinity of the northern area of contamination near the former Stabilus facility. Simulated flow paths show that contaminated ground water should be moving northwest toward West Branch Neshaminy Creek, but contamination was not found in downgradient wells RI–6S, RI–6D, RI–9S, and RI–9D (see figure 2 for well locations). Flow paths do show, however, that contamination potentially could move northward to well RI–17, where TCE has been detected in ground water at concentrations greater than 300 µg/L. The apparent lack of contamination along simulated flow paths could be partly the result of past large-scale pumping in the Colmar area for public supply. Supply well NP–21 was in service until 1995 and supply well NWWA–16 was in service until 1994. Withdrawals from each of those wells, southwest and southeast of the former Stabilus facility (fig. 2), probably would have inhibited the northwestern movement of ground water from the northern area of contamination. Another possibility is that the ground-water model does not adequately incorporate the aquifer heter-

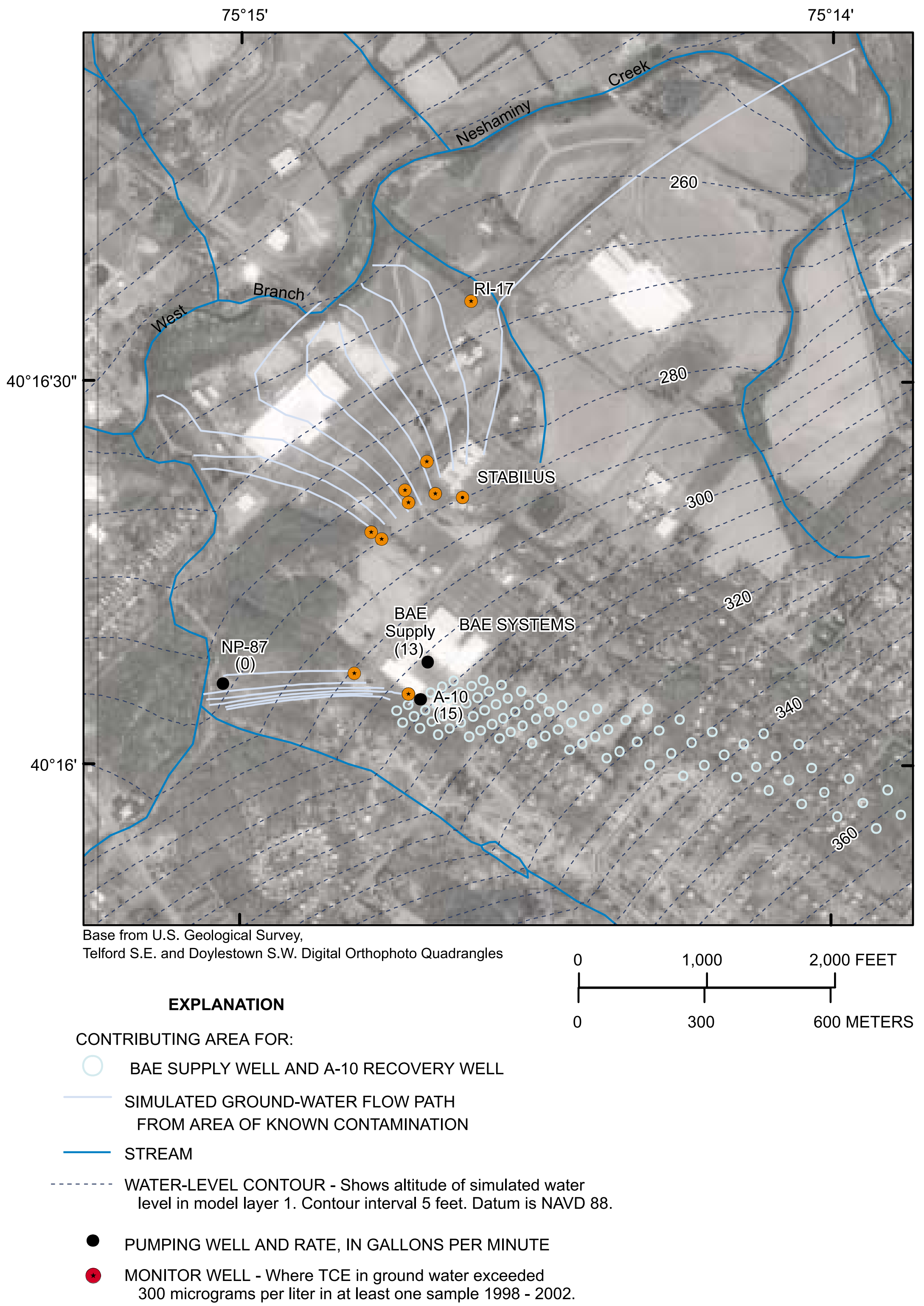


Figure 34. Simulated ground-water-flow paths and areas contributing recharge to wells, near Colmar, Pa., for pumping conditions in 2000. (NP–87, no pumping; BAE supply well, 13 gal/min; A–10, 15 gal/min)

ogeneity caused by the fractured, dipping siltstone and shale. Use of a more extreme value of horizontal anisotropy in the model, stipulating that hydraulic conductivity be even larger along the strike of beds than along the dip direction, would cause the flow paths to all align in a more northerly direction toward well RI–17 but would allow much more drawdown in the vicinity of the northern area of contamination than was observed during either aquifer test.

Pumping from NP–87

Ground-water flow in the Colmar area was simulated for current conditions with the hypothetical addition of pumping NP–87 at 400 gal / min. Pumping was simulated from the BAE Systems supply well and recovery well A–10, NP–87, NP–61, NWWA–17, and NWWA–22 at the rates shown in table 10. The areas contributing recharge to NP–87 and the two wells at BAE Systems are shown in figure 35. The simulation indicates that pumping from NP–87 is likely to capture recharge from the southern area of ground-water contamination but is less likely to capture recharge from the northern area of contamination.

Simulated ground-water-flow paths are shown in figure 35 that represent water entering well NP–87 from the deep water-yielding zone 400-500 ft below land surface represented in the model by layer 6. Flow paths were simulated by placing particles on the four lateral faces of the model cell in layer 6 representing pumping from well NP–87 and using the backward-tracking flowpath option in MODPATH (Pollock, 1994). The flow paths show that the surface area contributing recharge to the deep water-bearing zone in NP–87 is likely not coincident with the subsurface extent through which ground water moves to the well. Thus, if contaminants occurred at depths of several hundred feet in the northern area of contamination, they could be captured by the NP–87 pumping.

New Recovery Well in Southern Area of Ground-Water Contamination

Ground-water flow in the Colmar area was simulated for current conditions with the hypothetical addition of one new recovery well pumping 8 gal / min from the southern area of contamination. Pumping also was simulated from the BAE Systems supply and recovery well, NP–87, NP–61, NWWA–17, and NWWA–22 at the rates shown in table 10. The area contributing recharge to the three wells is shown in figure 36. The simulation indicates that an additional recovery well situated west of the existing recovery well (A–10) would likely improve the chances of capturing the contamination.

Ground-water flow was simulated for the conditions shown in figure 36 with the hypothetical addition of NP–87 pumping at 400 gal / min. The contributing areas to the two wells at BAE Systems, the hypothetical new recovery well, and NP–87 are shown in figure 37. The simulation indicates that the new recovery well would probably capture recharge from the southern area of contamination where TCE concentrations exceed 300 µg / L, and NP–87 would capture recharge in the surrounding area. Recharge from the northern area of contamination is less likely to be captured.

New Recovery Wells in the Northern Area of Ground-Water Contamination

Ground-water flow in the Colmar area was simulated for the hypothetical addition of two new recovery wells, each pumping 15 gal / min from the northern area of contamination. Pumping also was simulated from wells NP–61, NWWA–17, and NWWA–22 at the rates shown in table 10. The area contributing recharge to the two hypothetical new wells in the northern area of contamination is shown in figure 38. The simulation indicates that pumping from the two wells would capture recharge from the northern area of contamination near the former Stabilus facility where TCE in excess of 3,000 µg / L has been found in ground-water samples. Contamination at RI–17 would not be captured because it is too far downgradient from the contributing area.

Ground-water flow was simulated for the conditions shown in figure 38 with the hypothetical addition of NP–87 pumping at 400 gal / min. The contributing areas for hypothetical pumping from the two new recovery wells near the former Stabilus facility and NP–87 are shown in figure 39. The simulation indicates that the pumping from NP–87 probably will make the two new recovery wells more effective at capturing recharge from the northern area of contamination by moving their contributing area to the north. The southern area of contamination is within the area contributing recharge to NP–87.

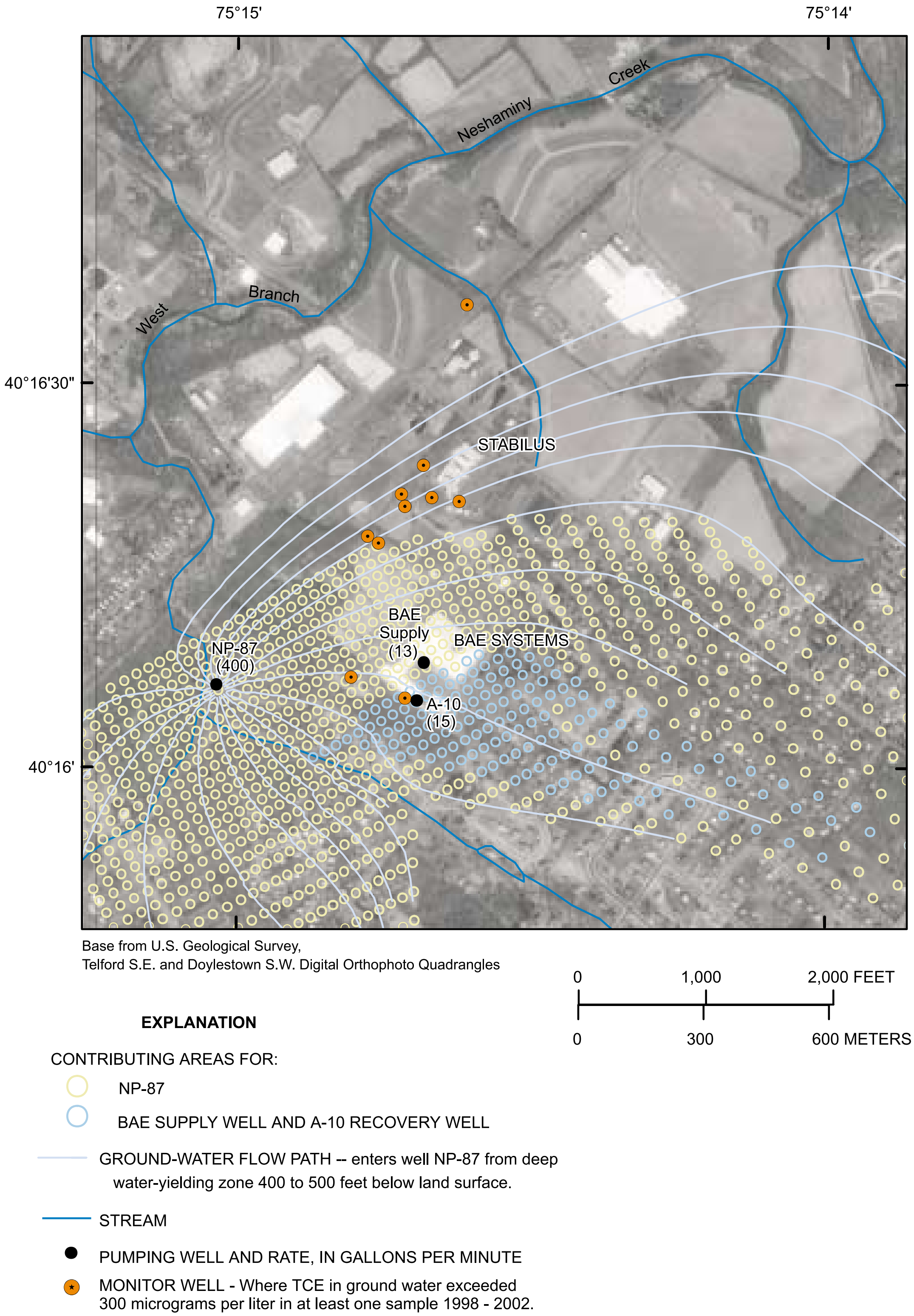


Figure 35. Simulated ground-water-flow paths and area contributing recharge to wells, near Colmar, Pa., for hypothetical pumping from NP–87. (NP–87, 400 gal/min; BAE Supply, 13 gal/min; A–10, 15 gal/min)

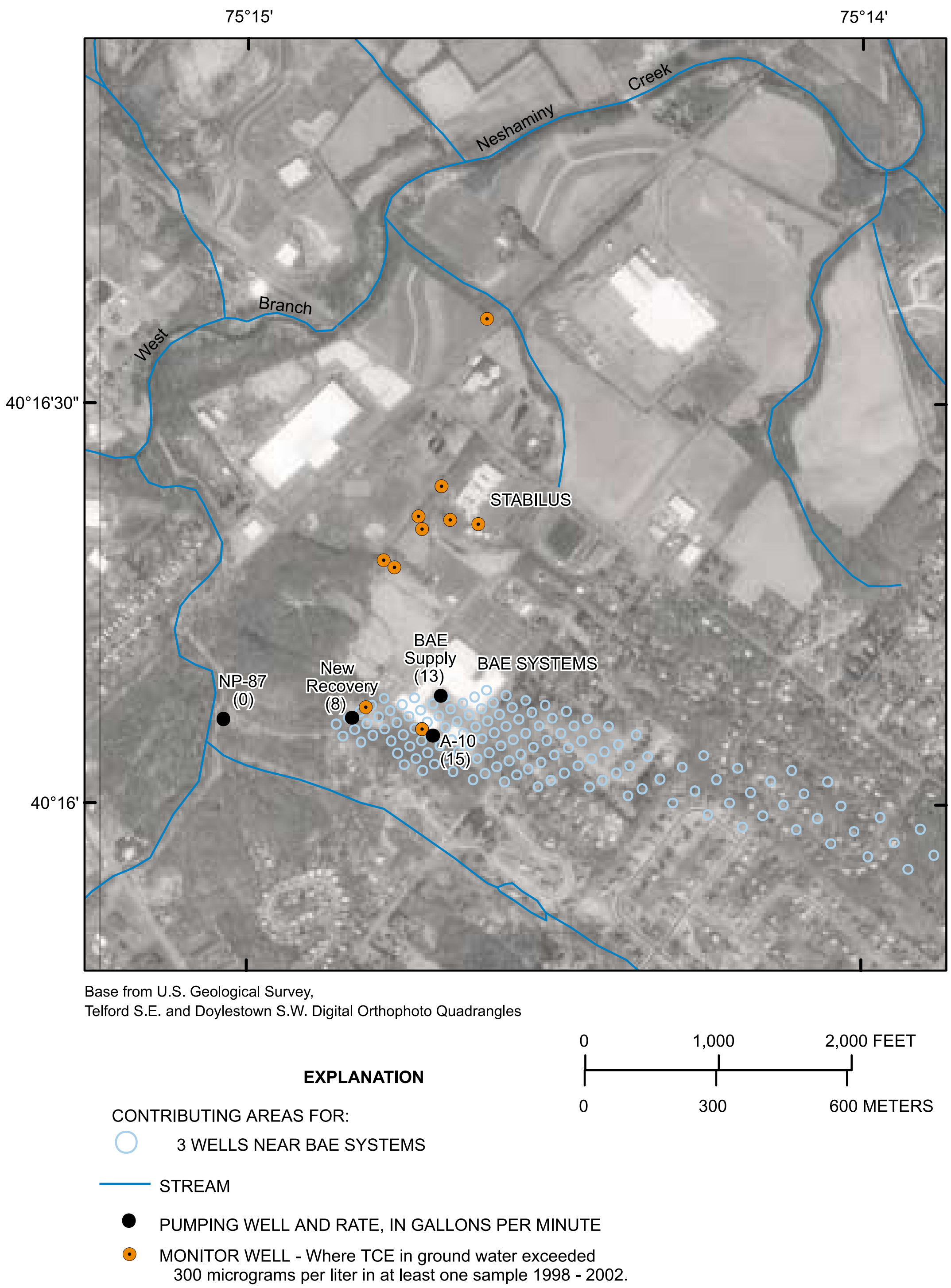
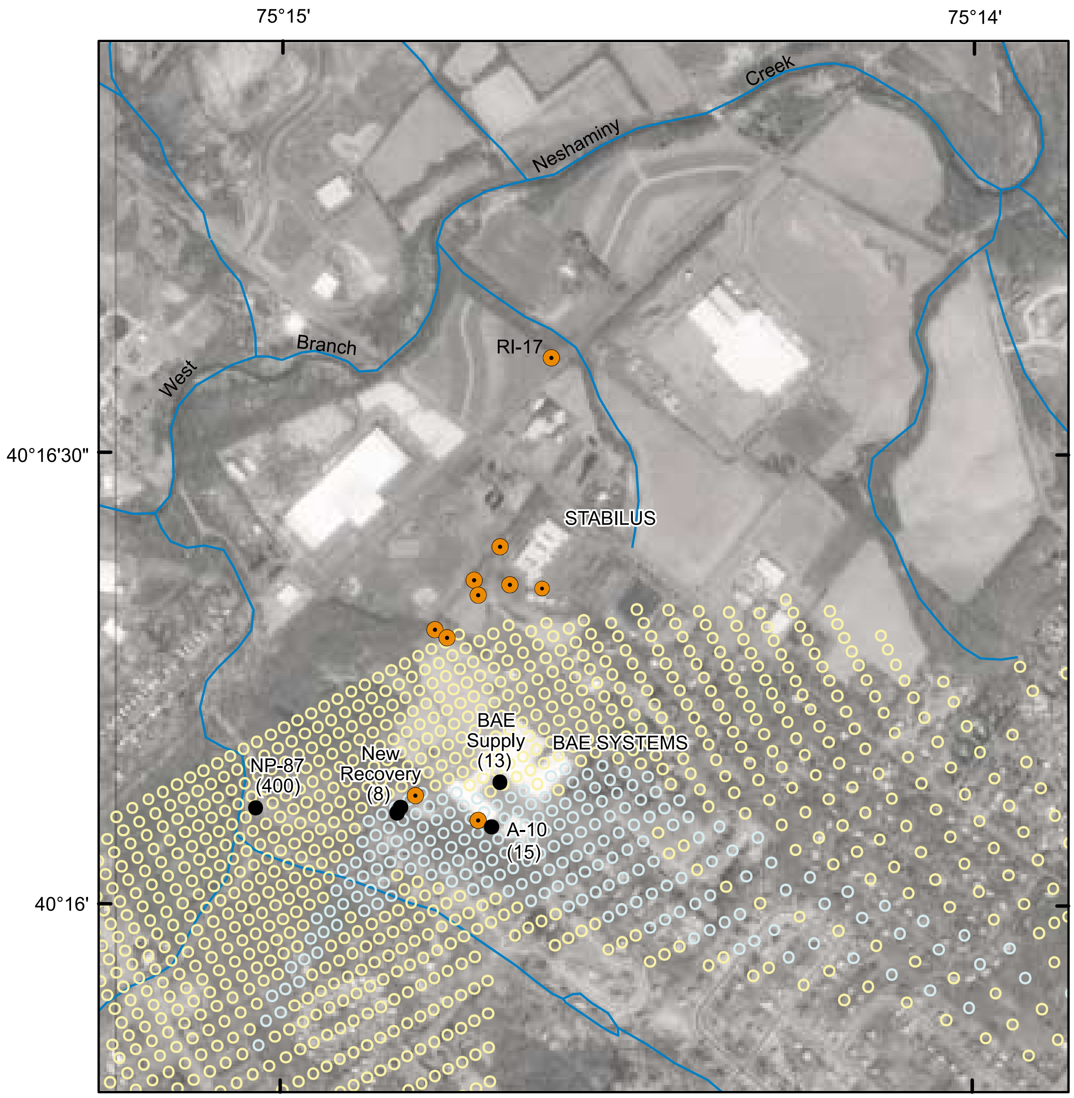


Figure 36. Simulated area contributing recharge to wells near Colmar, Pa., for hypothetical pumping from a new recovery well in the southern area of ground-water contamination. (NP–87, 0 gal/min; BAE Supply, 13 gal/min; A–10, 15 gal/min; new BAE recovery well, 8 gal/min)



Base from U.S. Geological Survey,
Telford S.E. and Doylestown S.W. Digital Orthophoto Quadrangles

0 1,000 2,000 FEET
0 300 600 METERS

EXPLANATION

CONTRIBUTING AREAS FOR:

NP-87

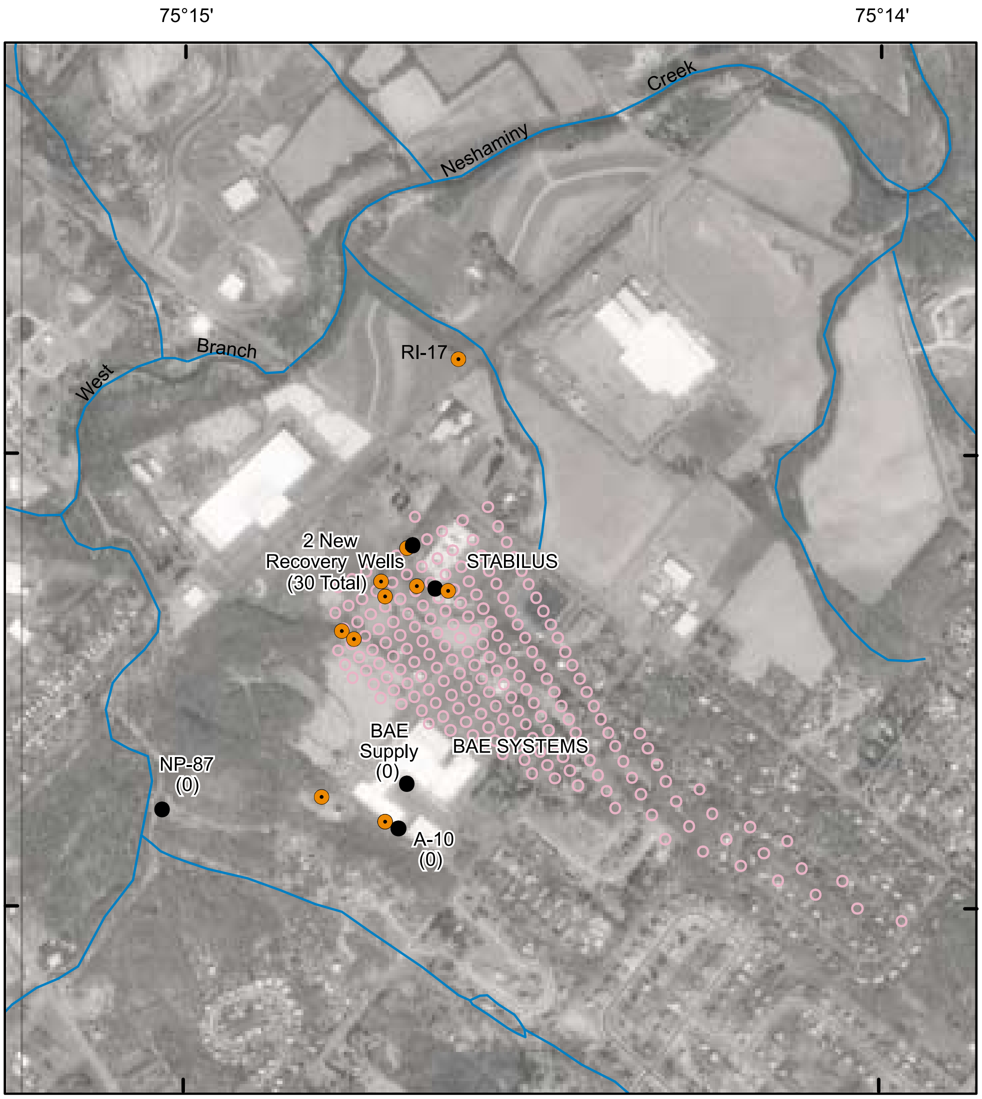
3 WELLS NEAR BAE SYSTEMS

STREAM

PUMPING WELL AND RATE, IN GALLONS PER MINUTE

MONITOR WELL - Where TCE in ground water exceeded 300 micrograms per liter in at least one sample 1998 - 2002.

Figure 37. Simulated area contributing recharge to wells near Colmar, Pa., for hypothetical pumping from a new recovery well in the southern area of ground-water contamination and NP–87. (NP-87, 400 gal/min; BAE Supply, 13 gal/min; A-10, 15 gal/min; new BAE recovery well, 8 gal/min)



Base from U.S. Geological Survey,
Telford S.E. and Doylestown S.W. Digital Orthophoto Quadrangles

0 1,000 2,000 FEET
0 300 600 METERS

EXPLANATION

CONTRIBUTING AREAS FOR:

2 WELLS NEAR STABILUS

STREAM

PUMPING WELL AND RATE, IN GALLONS PER MINUTE

MONITOR WELL - Where TCE in ground water exceeded 300 micrograms per liter in at least one sample 1998 - 2002.

Figure 38. Simulated area contributing recharge to wells, near Colmar, Pa., for hypothetical pumping from two new recovery wells near the former Stabilus facility. (NP-87, 0.0 gal/min; new Stabilus recovery wells, 30 gal/min)

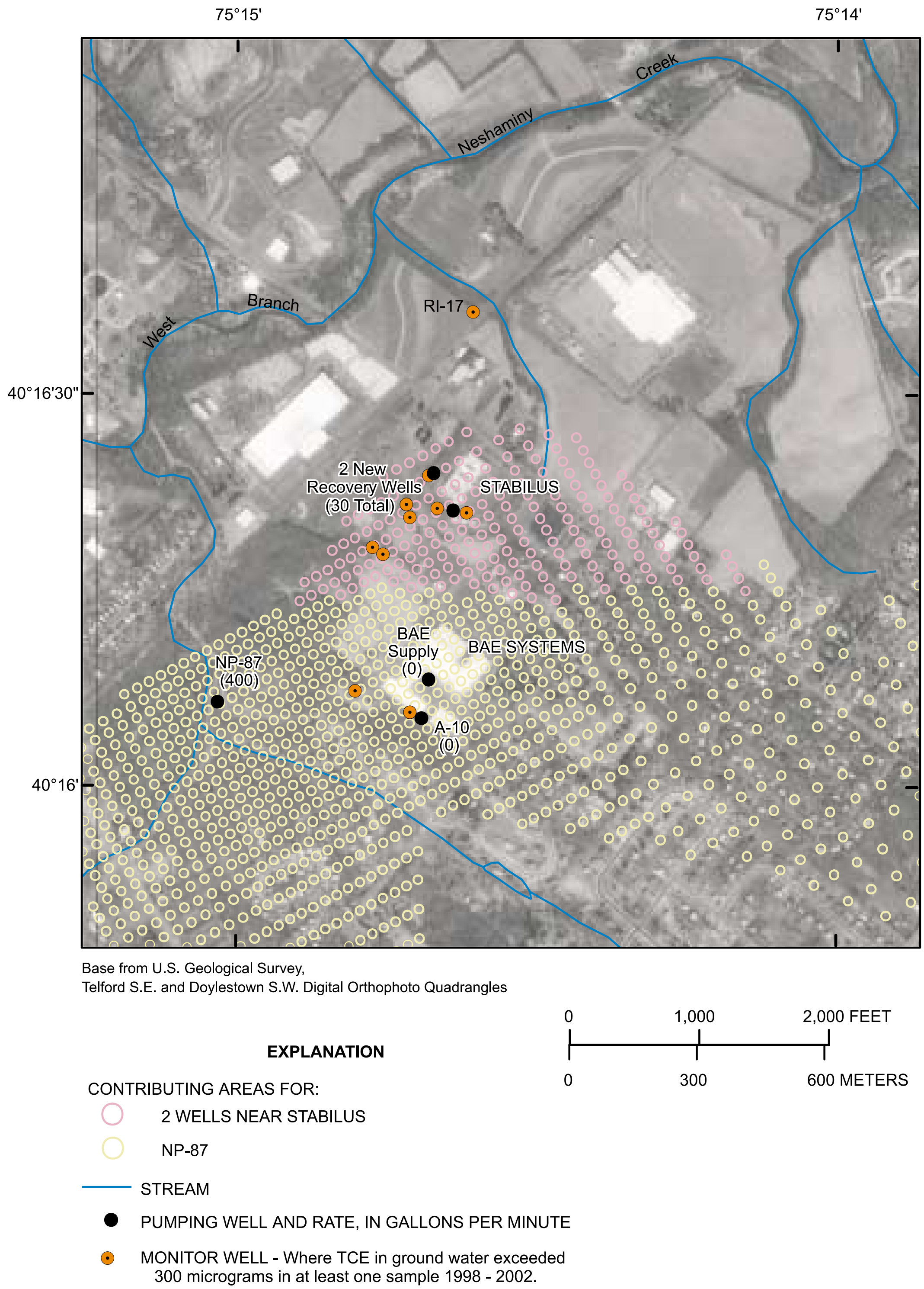


Figure 39. Simulated area contributing recharge to wells, near Colmar, Pa., for hypothetical pumping from two new recovery wells near the former Stabilus facility and NP–87. (NP-87, 400 gal/min; new Stabilus recovery wells, 30 gal/min)

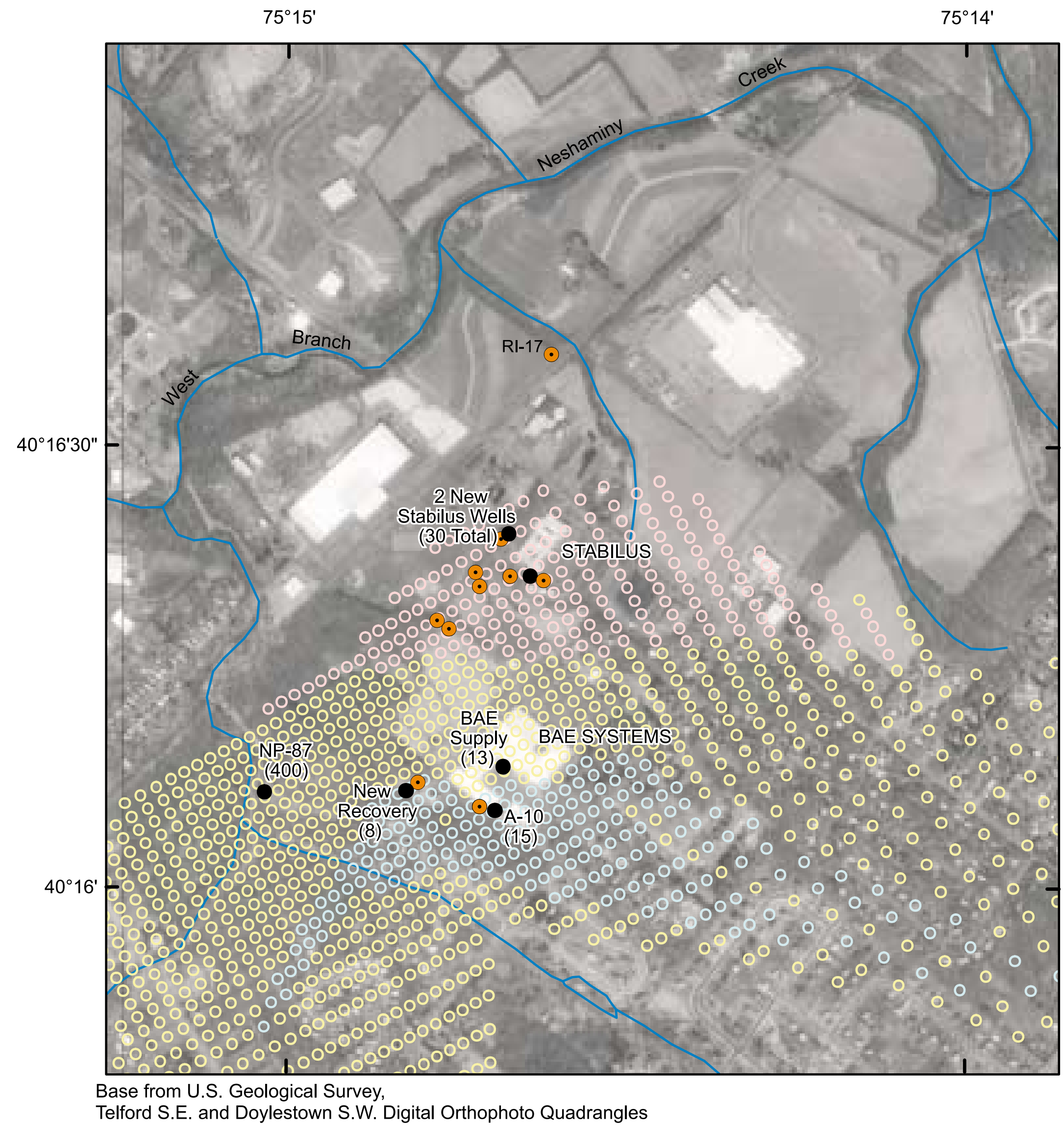


Figure 40. Simulated area contributing recharge to wells, near Colmar, Pa., for hypothetical pumping from new recovery wells near BAE Systems, the former Stabilus facility, and NP–87. (NP-87, 400 gal/min; BAE Supply, 12 gal/min; A-10, 15 gal/min; new BAE recovery well, 8 gal/min; new Stabilus recovery wells, 30 gal/min)

All Remediation Wells and NP–87

Ground-water flow in the Colmar area was simulated to evaluate the combined effect of all the previously described current and hypothetical pumping. The simulation used withdrawals from all nine wells pumping at the rates listed in table 10. The wells in the Colmar area included the hypothetical addition of two new recovery wells in the northern area of contamination, one new recovery well in the southern area, and pumping from NP–87 at 400 gal / min. The areas contributing recharge to the wells are shown in figure 40. The simulation indicates that this hypothetical pumping scenario would capture recharge from both the northern and southern areas of contamination, with the exception of contamination at RI–17.

SUMMARY AND CONCLUSIONS

The U.S. Environmental Protection Agency (USEPA) is in the process of characterizing ground-water contamination and evaluating remediation alternatives for the North Penn Area 5 Superfund Site near Colmar, Pa. This report presents the results of a study by the U.S. Geological Survey in cooperation with USEPA to determine the (1) drawdown caused by separately pumping North Penn Water Authority wells NP–21 and NP–87, (2) probable paths of ground-water flow under present-day (2000) conditions (with NP–21 pumping discontinued), and (3) areas contributing recharge to wells if pumping from NP–21 or NP-87 were restarted and new recovery wells were installed. Drawdown was estimated from water levels measured in observation wells during aquifer tests at supply well NP–21 and NP–87. Ground-water-flow paths and areas contributing recharge were estimated by use of a ground-water-flow model.

Aquifer tests were conducted at wells NP–21 and NP–87 to identify hydraulic connections and to quantify the drawdown caused by pumping these wells. Wells NP–21 and NP–87 are only 40 ft apart and are similar in depth and construction. Aquifer-isolation tests indicated that the wells are connected hydraulically through fractures below 400 ft below land surface. Thus, when one well is pumped, the wells act together as if each were being pumped, so the effect on the aquifer is similar regardless of which well is pumped. Well NP–21 was pumped at the maximum rate possible (average of 257 gal / min) for about 7 days in June 2000. Well NP–87 was pumped at an average rate of 402 gal / min for 3 days in May 2002.

Water-level measurements made during the aquifer test at NP–21 showed that, except at RI–7, ground-water levels declined almost exclusively in observation wells completed within or updip of the geologic units penetrated by the pumped well. Because the geologic units become deeper to the northwest, shallow wells updip to the southeast of the pumped well showed more drawdown than observation wells an equal distance but downdip from the pumping well. A good hydraulic connection (2.4 to 4.0 ft of drawdown) was shown for observation wells updip in the southern area of ground-water contamination near the BAE Systems facility. Shallow wells in the northern area of ground-water contamination (RI–23, RI–25, and RI–17S) near the former Stabilus facility did not appear to be within the influence of well NP–21 after 7 days of pumping at 257 gal / min.

Pumping of supply well NP–87 at 402 gal / min for 3 days confirmed the general pattern of drawdown observed during the test of well NP–21. However, during the pumping of supply well NP-87, water-level declines were observed further to the northeast near the northern area of ground-water contamination because of the greater pumping rate and availability of additional observation wells. Outside of the immediate area of well NP–87, the greatest drawdowns (7-12 ft) were observed near the BAE Systems facility in wells A–10, BAE Systems supply well, and RW–3. The drawdown confirms the existence of a good hydraulic connection between NP–87 and wells completed within the deepest part of the geologic units penetrated by the pumped well. Near the former Stabilus facility, the greatest drawdown (3.7 ft) was measured in RW–6D, which is the well farthest updip and completed most closely in the deep water-producing zone penetrated by well NP–87. After pumping from NP–87 stopped, the water-level recovery in shallow wells RI-27S, RW–4S, RW-5S, RW–6S, W-3, W–4, W–5, W–6, W–8, and W-9 was slow. The small drawdown and poor recovery indicates that the pumping has less effect on water levels and direction of ground-water flow in the shallow part of the aquifer than in the deep part. Streamflow in the tributary of the West Branch Neshaminy Creek near NP–87 appeared to be affected by pumping from NP–87. Miscellaneous measurements showed that streamflow decreased during the aquifer test from 380 to 170 gal / min; however, it is not clear how much of the decrease was caused by the pumping and how much was part of natural streamflow recession.

A 3-dimensional, finite-difference, ground-water-flow model was used to simulate flow paths and contributing areas to wells for current (2000) conditions of pumping in the Colmar area and for hypothetical situations of pumping suggested by USEPA that might be used for remediation. The focus was on principal areas of contamination near the former Stabilus facility (northern area of contamination) and BAE Systems facility (southern area of contamination) where TCE has been detected at concentrations greater than 300 µg/L. The numerical model constructed for the Colmar area was based partially on the MODFLOW model developed to analyze regional ground-water flow in the Lansdale area by Senior and Goode (1999) but was modified by adding dipping layers to incorporate more detail about the local-scale geologic structure in the vicinity of wells NP–21 and NP–87.

Current ground-water-flow conditions simulated by the model in the Colmar area indicate that ground water in the southern area of contamination moves west and discharges to a tributary of West Branch Neshaminy Creek near well NP–21, and ground water in the northern area of contamination moves northwest to discharge to West Branch Neshaminy Creek and tributaries. Model simulations indicate that if NP–21 or NP–87 are pumped at 400 gal/min, ground-water recharge is likely to be captured from the southern area of contamination, but ground-water recharge from the northern area of contamination is less likely to be captured by the pumping. Simulations also indicate that a new recovery well pumping about 8 gal/min near RI–20 and two new recovery wells pumping a total of 30 gal/min near the former Stabilus facility probably would capture ground-water recharge in most of the area where contamination exceeds 300 µg/L.

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