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EFFECTS OF PUMPING ON GROUND-WATER FLOW NEAR WATER-SUPPLY WELLS IN THE LOWER POTOMAC-RARITAN-MAGOTHY AQUIFER, PENNSAUKEN TOWNSHIP, CAMDEN COUNTY, NEW JERSEY

Water-Resources Investigations Report 00-4012

Prepared in cooperation with the

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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West Trenton, New Jersey

2001

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot per year (ft/yr)	0.3048	meter per year
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Water-quality abbreviations:

mg/L - milligrams per liter
µg/L - micrograms per liter

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By Richard L. Walker

ABSTRACT

Since the 1970's, hexavalent chromium has been detected in concentrations as great as 1.0 milligram per liter in wells at the Puchack well field operated by the Camden City Department of Utilities, Water Division (Water Department), forcing the Water Department to progressively remove five of its six wells from service between 1975 and 1988. The wells in the Puchack well field range in depth from 140 to 220 feet and are screened in the Lower Potomac-Raritan-Magothy aquifer. The Water Department has continued to pump Puchack Well 1 to maintain a hydraulic gradient toward the well field in an attempt to limit contaminant migration. In late 1997, concerns about treating the water withdrawn from Puchack Well 1 led water managers to consider temporarily discontinuing the pumping.

In the spring of 1998, the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection, began a preliminary assessment of the potential effects of temporarily removing Puchack Well 1 from service. Water levels in the Lower Potomac-Raritan-Magothy aquifer were measured during both pumping and non-pumping conditions to determine the direction and velocity of ground-water flow and the results were compared.

Data collected in late March and early April 1998 indicate the presence of a ground-water divide between the Puchack well field and the Morris and Delair well fields when Puchack Well 1 was being pumped. A similar divide also was present when the well was not being pumped. The position and persistence of this divide limits the probability that contaminants in the vicinity of the Puchack well field will reach the Delair and Morris well fields during either pumping condition. Another divide southeast of Puchack Well 1 while the well was being pumped was no longer evident when the pumping was stopped and water levels had recovered. Under non-pumping conditions, ground water between Puchack Well 1 and this divide could begin to migrate toward other large pumping centers to the southeast. The average linear ground-water velocity along an arbitrarily selected southeast-trending flow path was estimated to be from 221 to 332 feet per year. This estimate indicates that any contaminated ground water that may be present within the area influenced by pumping at Puchack Well 1 may begin to move toward the pumping centers less than 2 miles to the southeast if Puchack Well 1 is either temporarily or permanently removed from service.

INTRODUCTION

The Camden City Department of utilities, Water Division (Water Department) has oper-

ated wells at the Puchack well field since 1924. The well field, which consists of six water-supply wells (Puchack 1-3 and 5-7), is located in the New Jersey Coastal Plain, along the Puchack Creek in Pennsauken Township, Camden County, N. J. (fig. 1). The wells range in depth from 140 to 220 ft and are screened in the Lower Potomac-Raritan-Magothy aquifer. The wells have a high capacity and historically have provided a significant part of the water supply for the City of Camden. In the 1970's and 1980's, the detection of hexavalent chromium in water from the supply wells forced the Water Department to progressively remove five of the six wells from service between 1975 and 1988, as hexavalent chromium increased to concentrations as great as 1 mg/L (Camp Dresser and McKee, Inc., 1986), much greater than the current New Jersey Department of Environmental Protection (NJDEP) maximum contaminant level for total chromium of 100 µg/L. Since that time, the Water Department has continued to pump Puchack Well 1 to maintain a hydraulic gradient toward the Puchack well field in an attempt to limit contaminant migration toward the large pumping centers southeast of the project area. In 1997, concerns about treating the water withdrawn from Puchack Well 1 led water managers to consider discontinuing pumping of the well (Akshay Parikh, New Jersey Department of Environmental Protection, oral commun., 1998). Therefore, the U.S. Geological Survey (USGS), in cooperation with the NJDEP, conducted a preliminary assessment of the effects of temporarily removing Puchack Well 1 from service on the direction and velocity of ground-water flow in the vicinity of the well (fig. 1). This assessment was conducted as part of a larger on going investigation designed to characterize geohydrology and ground-water quality and simulate ground-water flow and contaminant transport in the study area.

This report describes ground-water levels, flow directions, and flow velocities in the vicinity of Puchack Well 1 during late March and early April 1998. Water levels were measured while Puchack Well 1 was being pumped and after pumping was suspended and water levels had recovered. Potentiometric-surface maps are used to determine and compare the general direction of ground-water flow under pumping and non-pumping conditions and to estimate ground-water flow velocity.

HYDROGEOLOGIC SETTING

The aquifers of the Potomac-Raritan-Magothy aquifer system are the principal source of water supply in northwestern Camden County. The aquifer system is part of a wedge-shaped sequence of sediments composed of gravel and sand aquifers with intervening silt and clay confining units that thicken and dip from the western edge of the Coastal Plain sediments at the Fall Line toward the southeast (Zapecza, 1989). The Potomac-Raritan-Magothy aquifer system can be divided into Upper, Middle, and Lower aquifers in the Camden County area. The three aquifers are separated by confining units of varying thickness and hydraulic properties. The Lower Potomac-Raritan-Magothy aquifer is used for water supply at the Delair, Morris, and Puchack well fields. In this area, the Lower aquifer is confined or semiconfined and lies directly on the weathered-schist bedrock. In some areas near the updip extent of the aquifer system, the aquifer is hydraulically connected to the Delaware River (Navoy and Carleton, 1995). The general direction of regional ground-water flow in the aquifer system in the study area is southeast (Navoy and Carleton, 1995, p. 34).

STUDY METHODS

Ground-water levels, tidal water levels, and local pumping conditions in the vicinity of the Puchack well field were monitored. Water-level data and well information are summarized in table 1. On March 20, 1998, continuous

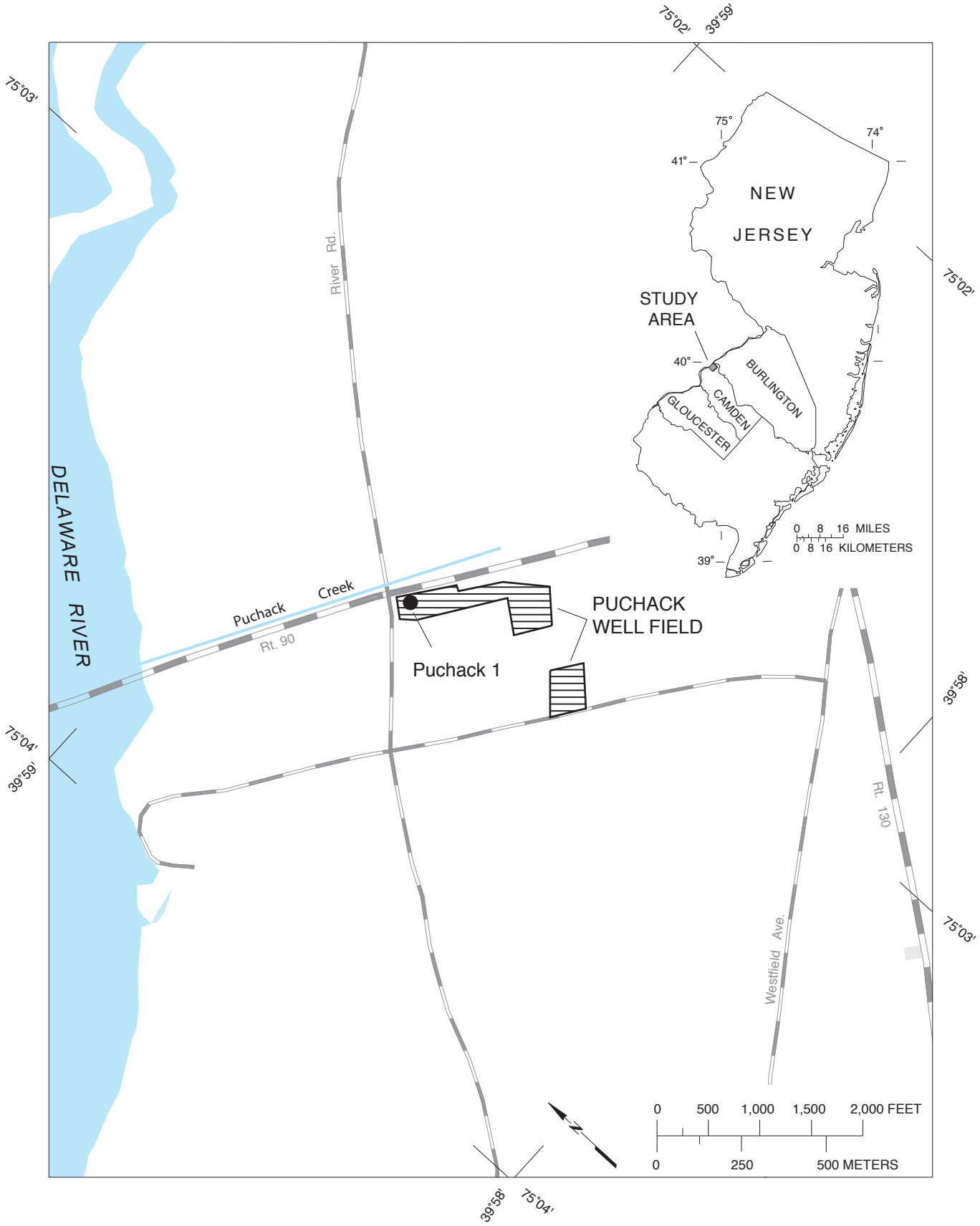

Figure 1. Location of study area, Pennsauken Township, Camden County, New Jersey.

Table 1. Water-level and well data for selected wells screened in the Lower Potomac-Raritan-Magothy aquifer, Pennsauken Township, Camden County, New Jersey, March 23-30, 1998, and April 7, 1998

[*, water level measured in a pumped well during operation; land-surface elevations expressed in tenths of a foot indicate surveyed elevations rounded to the nearest tenth of a foot; --, data unavailable]

Map number (figs. 3 and 4)	U.S. Geological Survey well number	Local identifier	Owner	Land-surface elevation (feet above sea level)	Well depth (feet below land surface)	Depth of well screen (feet below land surface)		Water level				
									March 23-30, 1998		April 7, 1998	
						Top	Bottom	Measuring-point elevation (feet above sea level)	Depth to water (feet below measuring point)	Altitude (feet below sea level)	Depth to water (feet below measuring point)	Altitude (feet below sea level)
1	070851	Camden City MW-1A	Camden City Water Department	73.4	141	131	141	73.29	87.30	-14.01	86.69	-13.30
2	070853	Camden City MW-2A	Camden City Water Department	57.4	174	164	174	57.12	74.53	-17.41	73.76	-16.64
3	070855	Camden City MW-4A	Camden City Water Department	56.7	202	192	202	56.31	72.27	-15.96	70.89	-14.58
4	070368	Delair 1	Camden City Water Department	10	138	106	126	12.1	93.8*	-81.7*	--	--
5	070369	Delair 2	Camden City Water Department	5	146	111	141	6	19.62	-13.62	--	--
6	070370	Delair 3	Camden City Water Department	6	132	87	127	7.2	72.1*	-64.9*	--	--
[1]7	070373	Morris 6	Camden City Water Department	8	138	98	133	--	--	--	--	--
8	070375	Morris 8	Camden City Water Department	6	128	89	124	8.2	78.6*	-70.4*	--	--
9	070374	Morris 9/9N	Camden City Water Department	7	148	89	143	7.7	27.51	-19.81	26.17	-18.47
10	070379	Morris 10	Camden City Water Department	8	118	75	115	9.4	80.46*	-71.06*	--	--
11	070545	Morris 11	Camden City Water Department	15	149	102	144	16.5	34.64	-18.14	33.53	-17.03
12	070586	Morris 12	Camden City Water Department	10	122	86	117	12.5	88.2*	-75.7*	--	--
13	070587	Morris 13	Camden City Water Department	10	135	90	130	12.4	81.8*	-69.4*	--	--
14	070366	Puchack 1	Camden City Water Department	12	140	107	137	14.3	78.7*	-64.4*	--	--
				12	140	107	137	13.6	--	--	29.26	-15.66
15	070363	Puchack 2	Camden City Water Department	14	170	124	164	15	33.06	-18.06	31.40	-16.4
16	070367	Puchack 3/3A	Camden City Water Department	14	176	139	176	14.7	31.78	-17.08	29.88	-15.18
17	070359	Puchack 5/5A	Camden City Water Department	28	208	181	206	28.7	45.15	-16.45	43.57	-14.87
18	070358	Puchack 4R/6-70	Camden City Water Department	48	220	170	220	49.1	64.92	-15.82	63.58	-14.48
19	070528	Puchack 6-75/7	Camden City Water Department	20	180	140	180	22.45	39.63	-17.18	38.22	-15.77

Table 1. Water-level and well data for selected wells screened in the Lower Potomac-Raritan-Magothy aquifer, Pennsauken Township, Camden County, New Jersey, March 23-30, 1998, and April 7, 1998--Continued

Map number (figs. 3 and 4)	U.S. Geological Survey well number	Local identifier	Owner	Land-surface elevation (feet above sea level)	Well depth (feet below land surface)	Depth of well screen (feet below land surface)		Water level				
									March 23-30, 1998		April 7, 1998	
						Top	Bottom	Measuring-point elevation (feet above sea level)	Depth to water (feet below measuring point)	Altitude (feet below sea level)	Depth to water (feet below measuring point)	Altitude (feet below sea level)
20	070536	TW-3-79	Camden City Water Department	10	117	85	115	9.2	31.16	-21.96	--	--
21	070537	TW-4-79	Camden City Water Department	10	128	97	128	11	30.21	-19.21	--	--
22	070538	TW-5-79	Camden City Water Department	10	129	80	110	11.6	35.63	-24.03	--	--
23	070540	TW-7-79	Camden City Water Department	10	141	98	138	12.9	28.45	-15.55	26.94	-14.04
24	070944	KAmw-5D	King Arthur - Warren Stevens	64.6	140	125	140	66.56	79.32	-12.76	--	--
25	070906	Puchack MW-1D	State of NJ - Surface Technologies	39.2	177	162	172	38.90	49.67	-10.77	49.20	-10.30
26	070910	Puchack MW-2D	State of NJ - Pennsauken Township	31.0	155	140	150	30.65	41.55	-10.90	11.22	-10.57
27	070912	Puchack MW-3D	State of NJ - Pennsauken Township	79.3	287	272	282	79.00	95.39	-16.39	94.70	-15.70
28	070915	Puchack MW-4D	State of NJ - World Harvest Christian Center	61.1	260	245	255	60.83	78.15	-17.32	77.30	-16.47
29	070918	Puchack MW-5D	State of NJ - J.J. Maloney Inc.	36.0	190	175	185	35.59	51.41	-15.82	50.27	-14.68
30	070920	Puchack MW-6D	State of NJ - Pennsauken Township	26.8	193	178	188	26.37	42.71	-16.34	41.56	-15.19
31	070921	Puchack MW-7D	State of NJ - Pennsauken Township	58.5	202	187	197	58.00	74.12	-16.12	72.24	-14.24
32	070924	Puchack MW-8D	State of NJ - Pennsauken Township	24.0	165	150	160	23.48	37.45	-13.97	37.39	-13.91
33	070927	Puchack MW-9D	State of NJ - Pennsauken Township	23.7	181	166	176	23.29	40.85	-17.56	39.28	-15.99
34	070929	Puchack MW-10D	State of NJ - Pennsauken Township	43.8	202	187	197	43.54	56.19	-12.65	55.48	-11.94
35	070957	PSLF MW-3D	Pennsauken Solid Waste Management Authority	60.6	177	157	177	62.81	79.1	-16.29	--	--
36	070959	PSLF MW-5D	Pennsauken Solid Waste Management Authority	72.1	187	167	187	74.33	90.37	-16.04	--	--
37	070961	PSLF MW-6D	Pennsauken Solid Waste Management Authority	38.4	149	129	149	40.92	57.55	-16.63	--	--

[1]Pumped well not available for water-level measurement. Location included to estimate the position of the pumping center.

water-level recorders were installed in wells MW-8D and Puchack 3A (figs. 3 and 4, in a following section). The continuous recording equipment was used to monitor water-level fluctuations throughout the period of data collection from March 20, 1998, to April 20, 1998. Concurrent tide-elevation measurements were compiled for the Delaware River at Philadelphia, Pa. (National Oceanographic and Atmospheric Administration, station ID 8545240, preliminary data accessed May 5, 1998, on the World Wide Web at URL http://www.co-ops.nos.noaa.gov, ASCII (text) format). These data were used to evaluate the influence of tides in the river on water levels in the Lower Potomac-Raritan-Magothy aquifer.

Synoptic measurements of water levels were made in 36 wells in the study area during March 23-30, 1998, while Puchack Well 1 was being pumped. On April 4, 1998, Puchack Well 1 was shut off, and water levels were allowed to recover. With Puchack Well 1 not being pumped, follow-up synoptic measurements of water-levels were made in 22 selected wells on April 7, 1998.

Water-level measurements were made with either an electric or a steel tape whenever possible. Water levels in some water-supply wells were measured by using the owner's airline when measurement with a tape was not possible. All water-level measurements were referenced to a fixed measuring point. The elevation of all water levels was determined by subtracting the depth to water below the measuring point from the elevation of the measuring point.

The datum of all elevations in this report is sea level. The elevations in table 1 are those from the USGS Ground-Water Site Inventory (GWSI) File (computerized data file available at the U.S. Geological Survey office in West Trenton, N.J.). Elevations documented for wells in the GWSI File were determined by using various methods. The accuracy of the elevations varies depending on the method used. The GWSI File contains qualifying information on determination method and elevation accuracy. Elevations at many of the monitoring-well locations were determined by means of a leveling survey. Elevations at other well sites were estimated from a 2-ft contour-interval topographic map prepared by professional engineers for the Township of Pennsauken (J.C. Anderson Associates, Pennsauken, New Jersey, unpublished maps, 1990).

For the purpose of this report, land-surface elevations for surveyed wells are rounded to the nearest 0.1 ft, and measuring-point elevations are the actual values determined from a leveling survey, rounded to the nearest 0.01 ft. Land-surface elevations derived by methods other than leveling are rounded to the nearest foot. Elevations of measuring points for non-surveyed wells were determined by calculating the height of the measuring points above or below the elevation determined for the land surface.

EFFECTS OF PUMPING ON GROUND-WATER FLOW

Ground-water flow in the Puchack well-field area is controlled primarily by pumping-induced hydraulic gradients. The water-level hydrographs for the period of data collection for wells MW-8D near the Delair well field and Puchack 3A in the Puchack well field are shown in figure 2a. (The wells' locations are shown in figures 3 and 4, in the following section.) The hydrographs illustrate the response of water levels in the Lower Potomac-Raritan-Magothy aquifer to pumping and to tides in the Delaware River (fig. 2b) superimposed on the general trend in water levels during the period of investigation. Water-level fluctuations due to tides were about 0.2 ft at Puchack 3A and about 0.7 ft at MW-8D, closer to the river. Water levels in wells near the river were not corrected for tidal variations because the tidal influence on water levels there was shown to be less than the

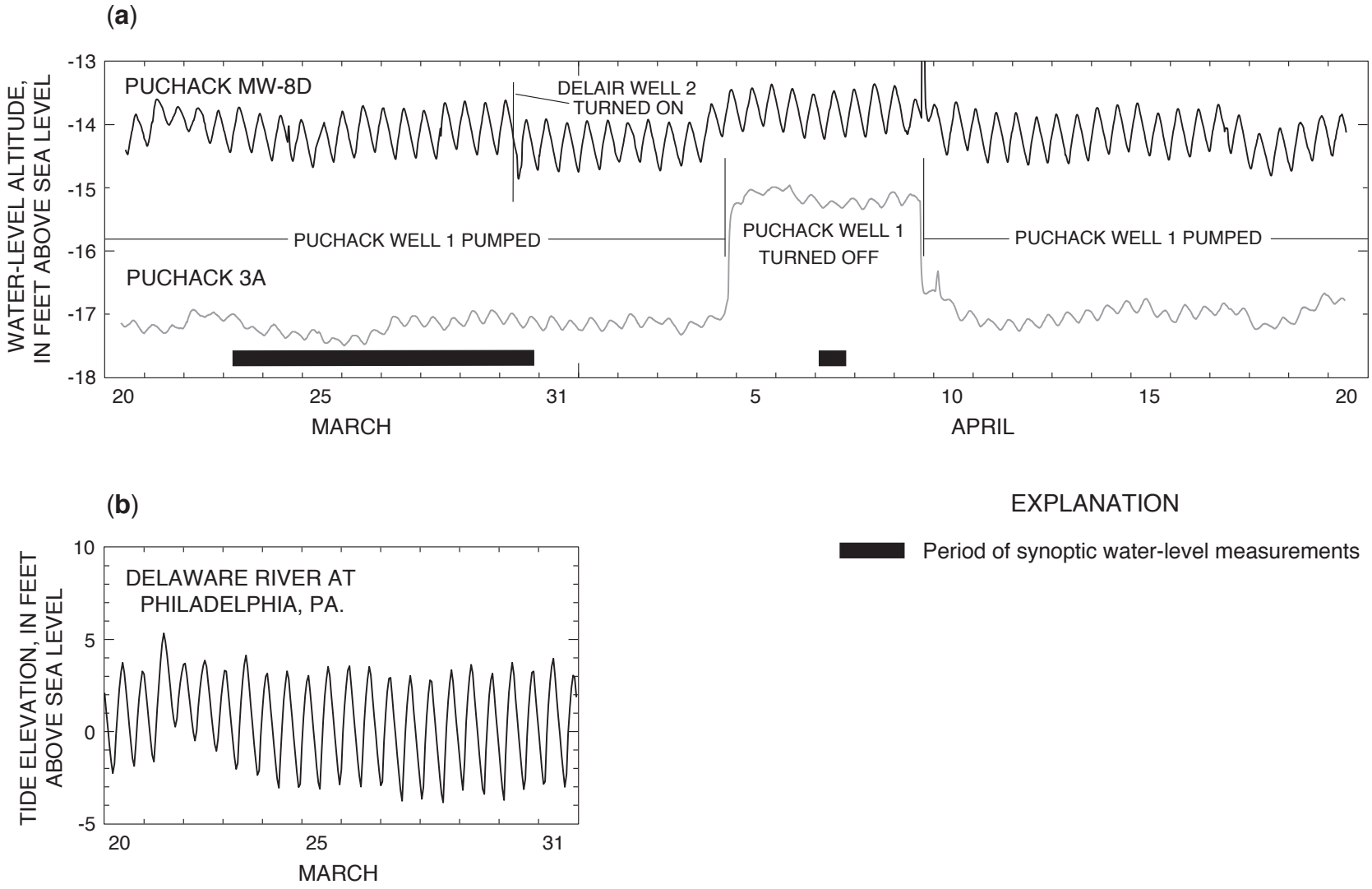

Figure 2. Water levels in (**a**) wells Puchack MW-8D and Puchack 3A, Pennsauken Township, Camden County, New Jersey, March 20-April 20, 1998, and (**b**) the Delaware River at Philadelphia, Pa., March 20-31, 1998.

accuracy of the vertical-control data available for some of the wells. On March 30, 1998, water levels at well MW-8D fell as a result of the start-up of Delair Well 2, which had been out of service during the first synoptic measurement. Water levels at wells MW-8D and Puchack 3A recovered quickly on April 4, 1998, in response to the shutdown of Puchack Well 1 (fig. 2). Except for the tidal variations and pumping effects, the hydrographs show a level trend in water levels that extends throughout both synoptic-measurement periods, indicating that these measurement periods are suitable for comparison.

Ground-Water Levels

A potentiometric-surface map of the Lower Potomac-Raritan-Magothy aquifer in the study area (fig. 3) was prepared from water-level measurements made during March 23-30, 1998, when Puchack Well 1 was pumping (table 1). The pumping rate for Puchack Well 1 was estimated by the Water Department to range from 0.45 to 0.80 Mgal/d (Mike Stevens, Camden City Water Department, oral commun., 1998). Water levels also were measured in selected pumped wells listed in table 1 (locations shown in fig. 3). Water levels measured inside wells while they are being pumped are not representative of water levels in the immediate vicinity of the well because of hydraulic losses at the well screen. These water levels were used qualitatively in conjunction with static (nonpumping) water levels to estimate the position of the cones of depression surrounding the pumped wells. The position of the potentiometric contour surrounding Morris Well 6 was estimated from nearby water levels because no water-level data were available for Well 6 during this period. The potentiometric contours also illustrate the approximate area of the aquifer most influenced by withdrawals at Puchack Well 1. The ground-water divide east of Puchack Well 1 defines the eastern limit of the area in which water levels are controlled by the pumping of Puchack Well 1 (fig. 3). Beyond this divide, ground water flows to the southeast.

A second potentiometric-surface map (fig. 4), prepared from synoptic water-level measurements made on April 7, 1998, shows the interpreted water-level contours and ground-water flow directions after pumping at Puchack Well 1 had stopped and the water levels had recovered for 3 days. The ground-water flow paths shown in figure 4 extend west from the ground-water divide between the Puchack well field and the Morris and Delair well fields toward the Morris and Delair well fields, and southeast toward and through the Puchack well field. The absence of pumping at Puchack Well 1 reversed the local flow directions in the immediate vicinity of the well. These conditions allowed ground water that formerly flowed to Puchack Well 1 to begin migrating along flow paths to the southeast.

Ground-Water Flow Direction

The potentiometric-surface contours and ground-water flow directions illustrated in figures 3 and 4 show that the ground-water divide between the Puchack well field and the Morris and Delair well fields was present under both pumping and non-pumping conditions. The persistence of this ground-water divide appears to minimize the potential for contaminants in the vicinity of the Puchack well field to reach either the Morris or Delair wells under the conditions observed. Any changes in the current pumping stress, however, could change the position of the divide and alter the directions of ground-water flow. When Puchack Well 1 is not in operation, the direction of flow in a small area near the well changes, allowing water that would otherwise be captured by the well to migrate to the southeast.

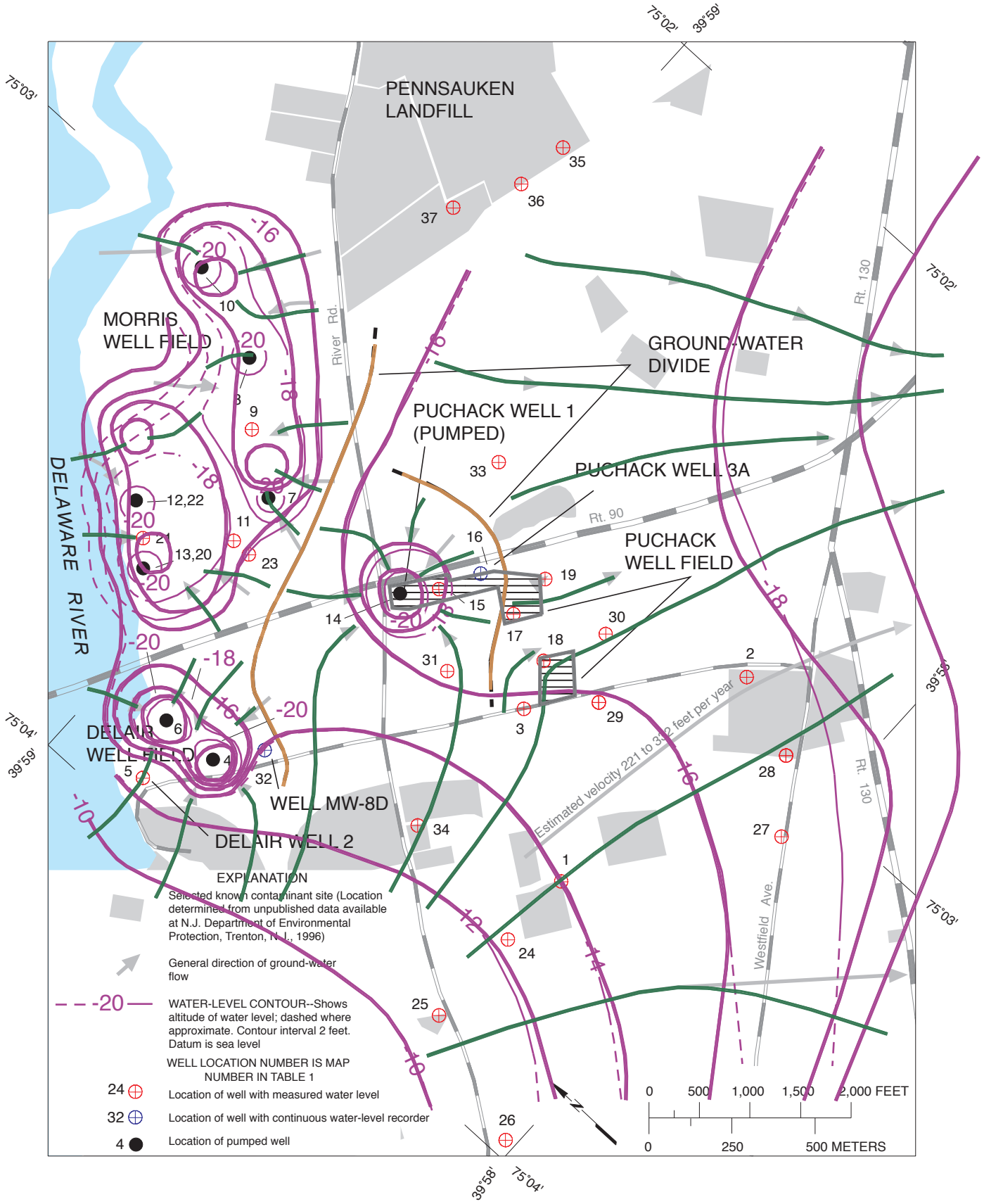

Figure 3. Potentiometric surface of the Lower Potomac-Raritan-Magothy aquifer, Pennsauken Township, Camden County, New Jersey, March 23-30, 1998.

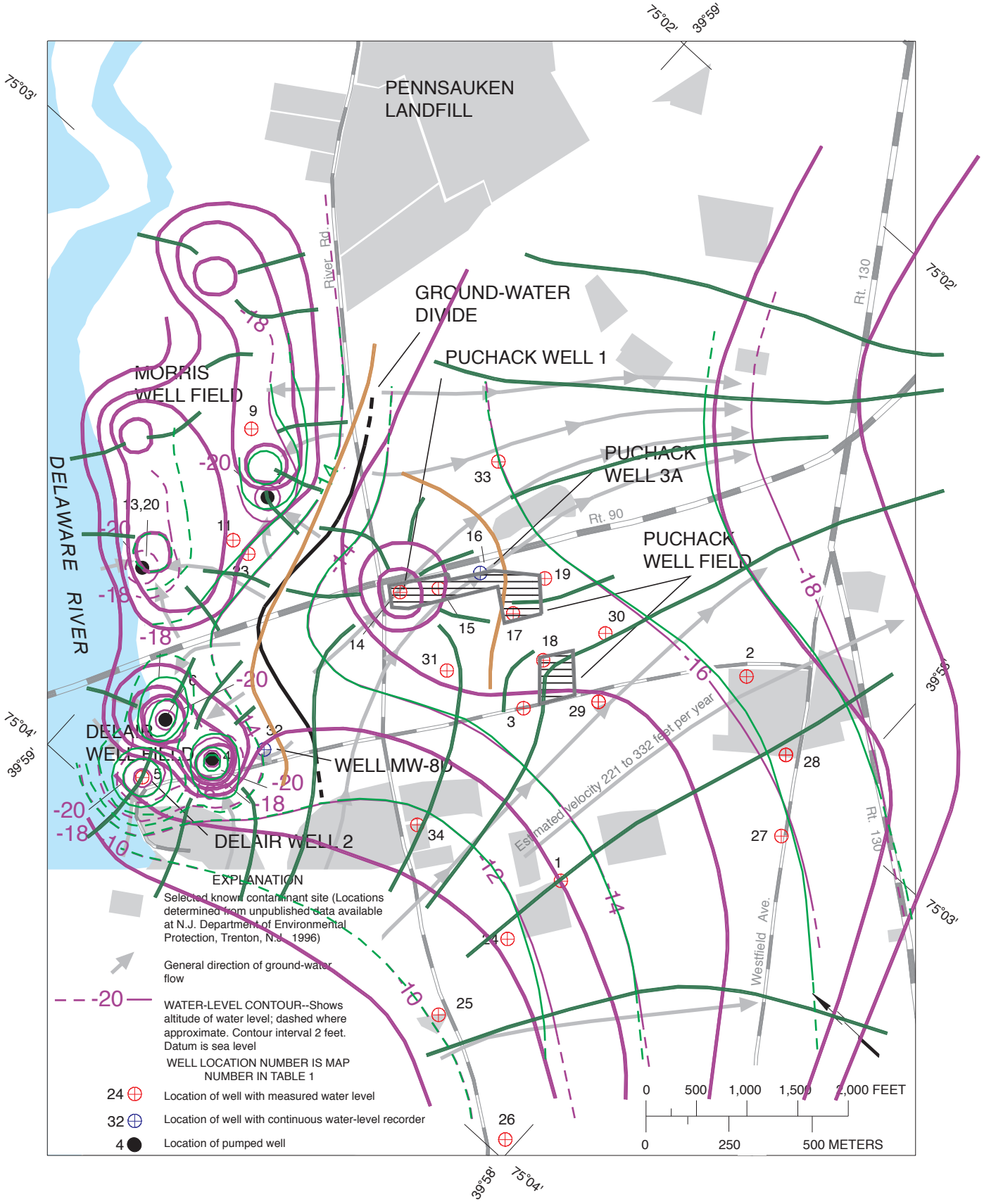

Figure 4. Potentiometric surface of the Lower Potomac-Raritan-Magothy aquifer, Pennsauken Township, Camden County, New Jersey, April 7, 1998.

Estimated Average Linear Ground-Water Flow Velocity

Average linear ground-water flow velocities were estimated to relate ground-water flow rates to the potential for contaminant transport in the study area. Linear ground-water velocities were estimated along an arbitrarily selected southeast-trending flow path by interpreting the horizontal hydraulic gradient from the potentiometric-surface maps (figs. 3 and 4). Although local variations in the hydraulic gradient and velocity may be significant over short distances, the horizontal hydraulic gradient along this flow path does not appear to be affected by the observed pumping from Puchack Well 1.

The velocity of the ground water along the selected southeast-trending flow path was calculated by using the equation

$$V = (K ((h_1 - h_2)/l)) / n ,$$

where

V = average ground-water flow velocity,
K = hydraulic conductivity (130 ft/d),
$((h_1 - h_2)/l)$ = average hydraulic gradient along a typical flow path (0.00140 ft/ft), and
n = effective porosity (estimated to range from 20 to 30 percent).

On the basis of these assumptions, the range of estimated average ground-water flow velocities along the selected flow paths illustrated in figures 3 and 4 is 221 to 332 ft/yr. This estimate provides an approximation of potential transport rates along the specific flow paths at a point in time. No differences in estimated velocity were observed between the two pumping conditions, indicating that the effects of pumping at Puchak Well 1 were localized. The actual rate of contaminant transport is spatially variable and is controlled by several factors including, but not limited to, water levels, the distribution and amount of pumping stress, aquifer characteristics, and contaminant attenuation.

CONCLUSIONS

If Puchack Well 1 is shut off and water levels are allowed to recover, ground water in the immediate vicinity of the well field will begin to move to the southeast, away from the well field and in the direction of regional ground-water flow, at an estimated velocity of 221 to 332 ft/yr. This estimated velocity range indicates that any contaminated ground water that may be present in the vicinity of Puchack Well 1 likely will not pose an immediate threat to the quality of water withdrawn from the pumping centers to the southeast if the well is temporarily removed from service. Water in the lower Potomac-Raritan-Magothy aquifer southeast of the ground-water divide is outside the zone of influence of Puchack Well 1. This water that may be contaminated with hexavalent chromium, probably would continue to migrate to the southeast in the direction of regional ground-water flow whether or not pumping at Puchack Well 1 is suspended.

In late March and early April 1998, a ground-water divide was present between the Puchack well field and the Morris and Delair well fields whether or not Puchack Well 1 was being pumped. The position of this ground-water divide limits the probability that any contaminants that may be present in the vicinity of the Puchack well field would reach either the Morris or Delair wells under the conditions observed. Any changes in the current pumping stress, however, could change the position of the divide and the ground-water flow directions and necessitate additional evaluation.

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