EFFECT OF PUMPING ON GROUND-WATER FLOW

The effect that pumping has on ground-water flow in the Lansdale area is described at local and regional scales. Local-scale effects are identified primarily from borehole logging and aquifer-test data. Regional-scale effects are identified from simulation of regional ground-water flow under different pumping scenarios.

Local Ground-Water Flow

Local ground-water flow on a scale that ranges from within a single borehole to distances of 1,000 ft (300 m) or more can be affected by pumping. Effects of pumping within a borehole include change in the rates or directions of flow in and near the borehole. In Lansdale, such changes were observed while measuring vertical flow with a heatpulse flowmeter in a pumping well (Conger, 1999). Nearby pumping can have a similar effect of changing the rate or direction of borehole flow in a nonpumping well, if that well is hydraulically connected to the pumping well. For example, water levels in well Mg-1441 fluctuated rapidly (fig. 13) in response to nearby pumping. The downward borehole flow measured in well Mg-1441 reflects the difference in depths between the producing fracture at 108 ft (32.9 m) and the receiving fracture at 128 ft (39 m), which apparently is hydraulically connected to the pumping well.

Drawdown and changes in ground-water flow on a local scale near a pumping well can be highly variable because of aquifer heterogeneity. Results of aquifer tests indicate transmissivity differs in both vertical and horizontal directions. The extent of hydraulic connection between water-bearing fractures is not necessarily related to distance but may be related to geologic structure. For example, wells with water-bearing zones located in the projected bed of the pumped interval responded to pumping in aquifer tests described in the section, “Multiple-Well Tests.”

Regional Ground-Water Flow Under Different Pumping Conditions

The calibrated flow model is used to simulate ground-water flow and hydraulic heads under three scenarios with different pumping conditions. The first scenario, no pumping, represents unstressed ground-water conditions with all recharge to the saturated zone discharging to streams as base flow. The second scenario, 1994, represents periods with high pumping rates in the Lansdale area. The third scenario, 1997, represents periods with moderate to high pumping rates that are less than those in the 1994 scenario, particularly for wells in the Borough of Lansdale. Between 1994 and 1997, several public-supply wells were removed from service because a surface-water supply became available to NPWA, and several industrial wells were shut down because of plant closure. It is assumed that the flow in a semi-confined aquifer system responds relatively quickly to changes in pumping rates; hence, a steady-state model is used.

Particle tracking using MODPATH (Pollock, 1994) illustrates the paths of ground-water flow simulated by the numerical flow model. On the basis of the calibrated anisotropic transmissivities and vertical hydraulic conductivity and the computed three-dimensional hydraulic gradients, particles of water are tracked through the flow system from recharge to discharge locations in streams or wells. Particles are introduced at the center of each model cell at the top of the modeled domain, which represents recharge across the water table. Maps of capture zones for streams and wells are generated by assigning a discharge location (color coded in figure) to each cell. However, not all of the recharge in that cell necessarily discharges to the same location. This procedure can yield discontinuous colors for cells at the boundaries between different capture zones. Recharge along a ground-water divide may flow deep through the system, beneath the three-dimensional capture zone of a nearby stream, and discharge to a more-distant regional boundary. A more-detailed delineation of capture zones could be generated by tracking more than one particle for each recharge cell, but this level of detail is considered to be unwarranted, given the uncertainties in model parameters and boundary conditions. Individual flowpaths were tracked from areas of known soil contamination (table 19).

Table 19. *Selected sites and main volatile organic compounds where soil contamination or probable sources of ground-water contamination have been identified in Lansdale, Pa. [Source of data: Black & Veatch Waste Science, Inc. 1994; Greg Ham, U.S. Environmental Protection Agency, written commun., 1997]*

[TCE, trichloroethylene; PCE, tetrachloroethylene; VC, vinyl chloride]

Site code	Site name	Primary volatile organic compound(s) on site
A	Keystone Hydraulics	TCE, PCE, VC
B	Westside Industries	TCE, VC
C	J.W. Rex Co.	TCE, PCE, VC
D	John Evans and Sons	TCE, PCE
E	Royal Cleaners	PCE
F	Electra Products	PCE
G	Precision Rebuilding	TCE
H	Rogers Mechanical[1]	TCE

[1] Formerly the Tate Andale property.

No Pumping

The no-pumping scenario corresponds to natural flow conditions in the absence of pumping (fig. 55). It is unlikely that ground-water pumping will cease in the Lansdale area, but this scenario serves as a base case to which alternative pumping conditions can be compared. This limiting-case scenario illustrates the maximum increases in stream discharge possible through reduction in pumping rates.

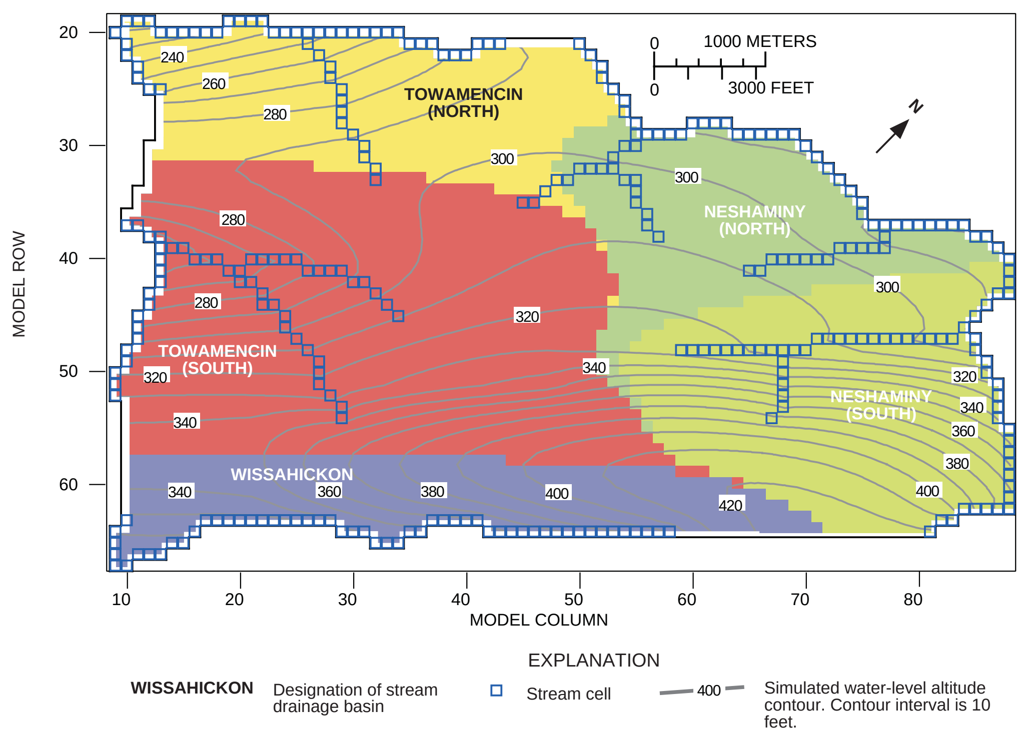

Figure 55. Simulated hydraulic head in model layer 2 representing the upper 328 feet of unweathered, fractured bedrock in and near Lansdale, Pa., and stream capture zones for “No Pumping” scenario. Simulated recharge within a colored capture zone discharges to the indicated stream.

In the no-pumping scenario, all discharge from the aquifer system is to streams (table 20). The sum of discharge from the ground-water system to the stream cells that correspond to the different stream segments in table 20 correspond to the ground-water base flow contributed to these streams from the modeled area. Over one-half of the discharge from the aquifer system is to the Towamencin Creek. The surface-drainage-basin area for the Towamencin Creek occupies a large part of the modeled area. In addition, the streambed altitudes along the Towamencin Creek are much lower than the altitudes along other creeks. Discharge to the West Branch Neshaminy Creek is approximately 35 percent of the total discharge, and discharge to the Wissahickon Creek is about 13 percent of total discharge. The relatively low discharge to Wissahickon Creek is partly the result of relatively low permeability of the Lockatong Formation.

Table 20. *Simulated ground-water discharges to wells and the Towamencin, West Branch Neshaminy, and Wissahickon Creek stream segments in and near Lansdale, Pa., under no-pumping, 1994, and 1997 conditions*

[ft^3/s, cubic feet per second; %, percent]

Discharge location	No pumping		1994		1996 (Calibration)		1997	
	(ft^3/s)	%	(ft^3/s)	%	(ft^3/s)	%	(ft^3/s)	%
Towamencin (N)	1.23	17	1.02	14	1.16	16	1.10	15
Towamencin (S)	2.51	35	1.37	19	1.55	22	1.54	22
Neshaminy (N)	1.07	15	.57	8	.80	11	.78	11
Neshaminy (S)	1.43	20	.55	8	.69	10	.74	10
Wissahickon	.90	13	0	0	0	0	0	0
Wells	0	0	3.66	51	2.96	41	3.00	42

1994 Conditions

The 1994 scenario is representative of conditions of intensive ground-water pumping in the Lansdale area. Pumping rates were relatively high during and prior to 1994 (table 4). Ground-water use has decreased since 1994 because use of surface water from outside the local area has increased and because industrial water use has decreased. Although surface water requires filtration treatment, local ground water is contaminated and, hence, also requires treatment. The cost of ground-water treatment has made use of surface-water resources more economically attractive. Wells pumping in 1994 included well Mg-67 (NPWA well L-8), which is near a known source of contamination and was pumped to help limit the spread of ground-water contamination in the area and protect other downgradient public-supply wells, and four industrial wells (Mg-153, Mg-620, Mg-621, and Mg-1045) at a manufacturing facility.

Simulation of intensive pumping of ground water in the area of Lansdale in the 1994 scenario has a major effect on the regional water balance (table 20) and flowpaths (fig. 56). Slightly more than one-half of recharge to the aquifer system is captured by wells. Streamflow is decreased throughout the entire modeled area, and all the ground water that discharges to the Wissahickon Creek under no-pumping conditions is captured by wells.

Numerical simulation using the calibrated-model parameters and 1994 pumping rates indicates that well Mg-67 (NPWA well L-8) may have captured ground water that recharged in an area that includes sources of soil contamination shown as sites A and B in figure 15. Simulated recharge from site C is captured by the adjacent industrial pumping well Mg-625. Simulated ground-water recharge near site D is captured by industrial wells Mg-153 and Mg-1045. Public-supply well Mg-69 (NPWA well L-10) may have captured water from areas of soil contamination shown as sites F and G (fig. 15). Simulated recharge from site H discharges to industrial pumping well Mg-140.

Some ground water recharged near soil-contamination site E (fig. 15) flows near well Mg-1418 and is partly drawn toward industrial well Mg-620. However, the anisotropy of the calibrated model contributes to the model result that flowpaths from source E flow primarily in the strike direction. A fraction of recharge in the area of site E is captured by public-supply well Mg-1125 (NPWA well NP-61) (fig. 56).

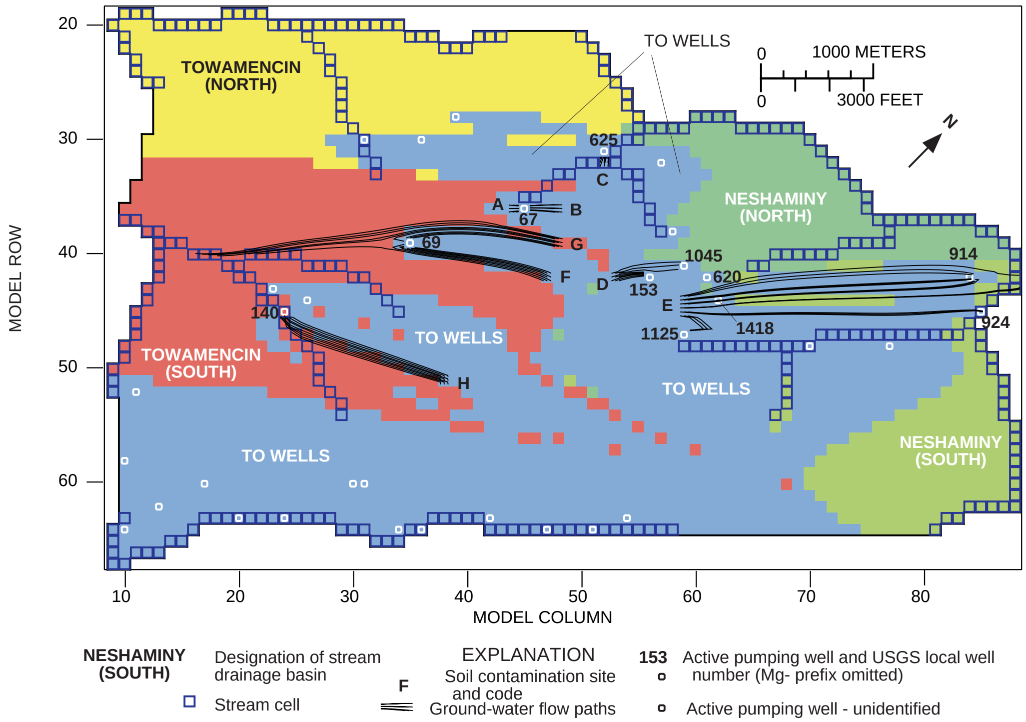

Figure 56. Simulated stream and well capture zones and flowpaths from potential source areas in Lansdale, Pa., and vicinity for “1994” scenario. Potential source areas are designated by letter. See table 19 for site names. Simulated recharge within a colored capture zone discharges to the indicated stream or pumping wells.

To illustrate the sensitivity of flowpaths to the hydraulic properties of the model layers, the 1994 pumping scenario was simulated with modified hydraulic properties. The anisotropy ratio ANI23 was changed from 0.09 to 0.119 (an increase of about 30 percent), and the hydraulic conductivity of the top model layer, representing overburden and weathered rock, was changed from 0.16 to 1.97 ft/d (0.049 to 0.6 m/d) (an increase of slightly more than one order of magnitude). These parameter values are near the limit of the linear, independent confidence intervals (table 7). The selection of these particular parameter changes is somewhat arbitrary but is meant to illustrate the sensitivity of flowpaths to these two model parameters. All other model parameters are identical to the calibrated-model values. These changes in the hydraulic properties result in readily apparent changes in flowpaths (fig. 57). Compared to the flow paths from the calibrated-model simulation, these flowpaths span more of the dip direction, because of the increased hydraulic conductivity in the dip direction. A fraction of the flowpaths from source E are captured by pumping at industrial well Mg-620, whereas none of the flowpaths from source E were captured by this well for the calibrated-model simulation. Public-supply well Mg-67 captures flowpaths from sources A and B, as in the calibrated-model simulation, but also captures at least some of the flowpaths from sources D and G. These results illustrate that simulated flowpaths are sensitive to changes in model parameters that are within the linear confidence intervals.

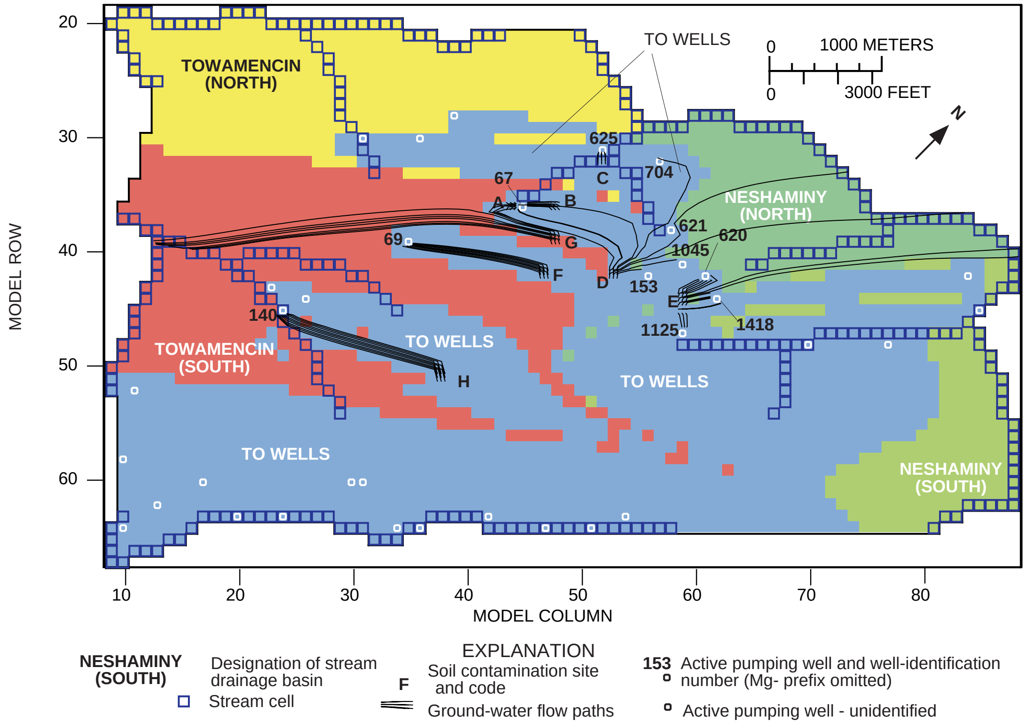

Figure 57. Simulated stream and well capture zones and flowpaths from potential source areas in Lansdale, Pa., and vicinity for 1994 scenario with modified anisotropy ratio (from 0.09 to 0.119) and layer 1 hydraulic conductivity [0.16 to 1.97 feet/day (0.049 to 0.6 meters/day)]. Potential source sites are designated by letter. See table 19 for sites names. Simulated recharge within a colored capture zone discharges to the indicated stream or pumping wells.

1997 Conditions

In fall 1995, the pump in public-supply well Mg-67 (NPWA well L-8) malfunctioned and pumping of the well ceased. In April 1996, manufacturing at an industrial facility ended, and pumping at three of four industrial wells (Mg-620, Mg-621, and Mg-1045) was stopped and greatly reduced in the remaining production well (Mg-153). Other wells in the area continued to be pumped at rates similar to historical rates (table 15). Overall pumping is a smaller fraction of average recharge (average ground-water discharge) in 1997 than in 1994 (table 20). Flowpaths and capture zones for the 1996 simulation are shown in figure 58.

The directions of ground-water flow, as simulated by the model (fig. 58), reflect the changes in the pumping regime. Well Mg-67 is not pumping and does not capture ground water that recharged near sites A and B. The capture zones for public-supply wells Mg-593 (NPWA well L-25) and Mg-69 (NPWA well L-10) shift towards contamination sources A and B, although the simulated flowpaths from these sources discharge to the Towamencin Creek. Ground water recharged near site D is no longer captured by industrial wells at the manufacturing facility, as discussed in section “1994 Conditions,” but moves to the west and southwest. Ground water recharged near site E no longer moves toward industrial wells at the manufacturing facility but instead moves to the northeast flowing directly by well Mg-1418. Other flowpaths from source E are intercepted to a smaller degree than in 1994 by public-supply well Mg-1125 (NP-61). As shown in the section on “1994 Conditions,” the uncertainty in hydraulic properties causes uncertainty in flowpaths. Simulations using other values of hydraulic properties within the linear confidence intervals

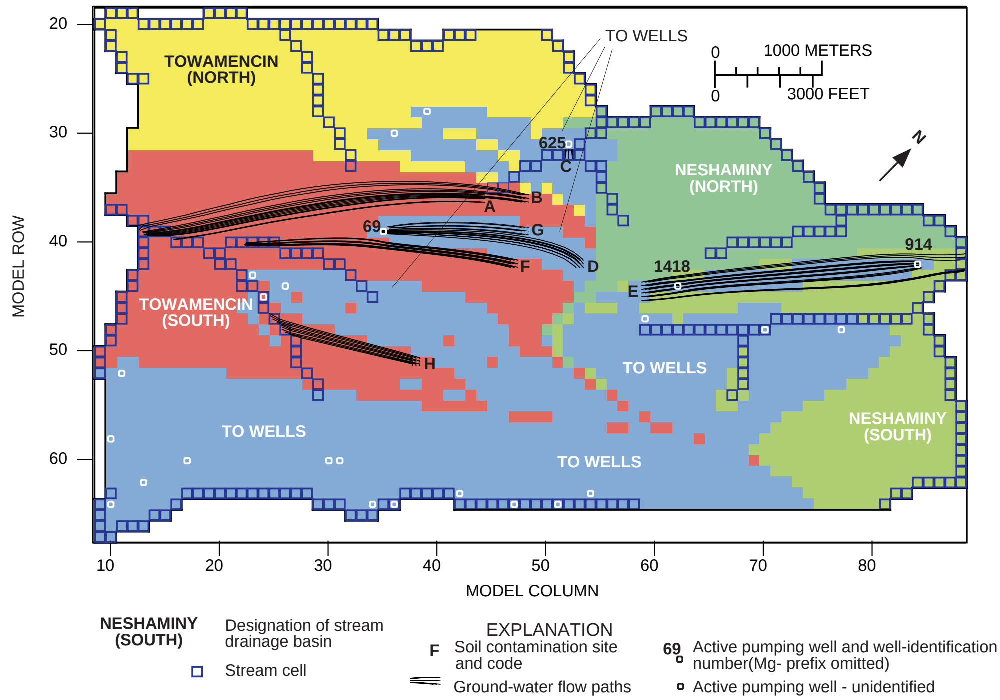

Figure 58. Simulated stream and well captures zones from potential source areas in Lansdale, Pa., and vicinity for 1997 scenario. Potential source areas are designated by letter. See table 19 for site names. Simulated recharge within a colored capture zone discharges to the indicated stream or pumping wells.

could yield different flowpaths. The flowpath for recharge from sites F and H discharges to streams under 1997 conditions rather than to wells as under 1994 conditions. Simulated recharge from site C discharges to the same locations under 1997 conditions as under 1994 conditions.

Relation Between Simulated Ground-Water Flow Directions and Ground-Water Contamination

Contaminants dissolved in ground water generally travel in the direction of ground-water flow. The rate of contaminant transport can be less than that of ground water because of degradation reactions or adsorption on surfaces within the aquifer. Diffusion of contaminants from high-permeability fractures into low-permeability rock matrix also can retard migration. Contaminants with a density different than water can move in directions other than that of ground-water flow in response to gravity. In addition, chemical gradients can differ from hydraulic gradients.

Changes in measured concentrations of some contaminants in samples from wells have corresponded to changes in pumpage in the Lansdale area. Concentrations of TCE and PCE measured in water from selected wells sampled in 1995, 1996, and 1997 are listed in table 21 (Black & Veatch Waste Science, Inc., 1998). Since 1995, concentrations of PCE decreased in samples from industrial wells Mg-153 and Mg-620 and observation well Mg-618 and increased in samples from well Mg-1418. Industrial wells Mg-153, Mg-620, Mg-621, and Mg-1045 were pumping during sampling in 1995 and 1996. PCE is the main contaminant detected in soils at site D, whereas TCE and PCE have been detected at elevated concentrations in soils at site D (Black & Veatch Waste Science, Inc., 1994). Site D may be a source for TCE contamination observed in wells at the manufacturing facility.

Table 21. *Concentrations of trichloroethylene and tetrachloroethylene in water samples from selected wells in and near Lansdale, Pa., spring 1995, winter 1996, and fall 1997*

[µg/L, micrograms per liter; --, no data; ND, not detected]

U.S. Geological Survey local well number Mg-	Owner	Owner well name	Trichloroethylene (µg/L)			Tetrachloroethylene (µg/L)		
			1995	1996	1997	1995	1996	1997
67	North Penn Water Authority	L-8	390	1,680	84.6	72	35.4	31
69	North Penn Water Authority	L-10	25	27.8	32.3	17	21.2	25.7
593	North Penn Water Authority	L-25	17	20	11.3	2	3.7	ND
1418	Ziegler & Sons	1	--	ND	ND	--	.3	128
618	North Penn Feed	--	22	13.3	8.5	130	90	7.6
153	American Olean Tile Co.	PW2	120	96.3	183	130	102	17.4
620	American Olean Tile Co.	PW3	28	27.4	77	110	186	37
621	American Olean Tile Co.	PW4	2	4.6	8.5	ND	.4	.5
1045	American Olean Tile Co.	PW5	17	30.1	--	4	6.5	--

If site E were the source of PCE detected in samples from these wells, the trend in concentrations of PCE in samples from wells Mg-620 and Mg-1418 is consistent with predicted ground-water flow directions. The simulation of flow under reduced 1997 pumping conditions (fig. 58) indicates the contaminants from site E would migrate almost directly to the northeast towards well Mg-1418 and beyond. Under the more intensive 1994 pumping conditions, transport is still in the same general direction, but several flowpaths are diverted from site E north and south towards other nearby pumping wells (fig. 56). The simulations illustrate changes in pumping rates at wells near source E can change flow directions from source E. Because of the uncertainty in the model parameters, and because the model is calibrated to regional hydraulic heads and streamflow, the actual flowpaths probably are more complex than the simulated flowpaths. When modeling steady-state ground-water flow directions, it is assumed the boundary conditions and recharge are constant during the entire time required for movement of water (and possibly contaminants) from the source area to the discharge boundary or pumping well.

Some public-supply wells, including Mg-69 (NPWA L-10) and Mg-593 (NPWA L-25) are equipped with air strippers, and in 1995, water from these wells was slightly contaminated (table 21). Since 1995, concentrations of contaminants have increased in water from well Mg-69 (table 21). The increase in TCE and PCE concentrations in well Mg-69 is consistent with simulated ground-water flow directions that show, in 1997, well Mg-69 captured ground water recharged near source G. Under increased 1994 pumping conditions, recharge near source G was captured by well Mg-67 (fig. 56). Although the model indicates the public-supply well Mg-593 should also capture more contaminants under 1997 pumping conditions, the sampling data from 1995 through 1997 do not show an increase in contamination (table 21).

Traveltime of ground-water flow paths cannot be simulated without specifying effective porosity values. To date (1998), these values have not been measured in the Lansdale area. However, the relatively rapid changes in measured concentrations of contaminants in ground water indicate the effective porosity is low in the formations that underlie the Lansdale area.