GROUND-WATER SYSTEM

Ground water in the rocks underlying Lansdale and the North Penn Area 6 site originates from infiltration of local precipitation. After infiltrating through soil and saprolite (extensively weathered rock), the water moves through near-vertical and horizontal fractures in the shale and siltstone bedrock. Depth to bedrock is commonly less than 20 ft (6 m) below land surface. The soil, saprolite, and individual beds of the sedimentary bedrock form a layered aquifer, with varying degrees of hydraulic connection between the layers. Hydraulic properties of the soil, saprolite, and individual beds of the underlying sedimentary bedrock differ. Primary porosity, permeability, and storage in the Triassic-age sedimentary bedrock is very low.

Water in the shallowest part of the sedimentary-rock aquifer may be under unconfined (water table) or partially confined conditions; the unconfined part of the aquifer is thin and is difficult to delineate. In some areas, perched water is present at shallow depths [less than 50 ft (15 m)]; in the deeper part of the aquifer, water generally is confined or partially confined, resulting in artesian conditions.

Shallow and deep ground-water-flow systems may be present at the site. Water from the shallow system likely discharges locally to streams and leaks downward to the deep system. Deep and shallow ground water generally flows in a direction similar to the topographic gradient. Deep ground water discharges to streams and to pumping wells. The natural direction of shallow and deep ground-water flow is altered by pumping, and pumping from deep zones may induce downward flow from shallow zones. In the Triassic-age sedimentary rocks of the Brunswick Group and the Lockatong Formation, cones of depression caused by pumping have been observed to extend preferentially along strike of bedding planes or in the direction of fracture orientation (Longwill and Wood, 1965).

The conceptual model of the ground-water system in the study area consists of dipping, layered fractured rocks with ground-water flow within partings developed primarily along bedding planes. Vertical fractures generally do not cut extensively across beds but may provide local routes of ground-water flow or leakage between beds (fig. 7).

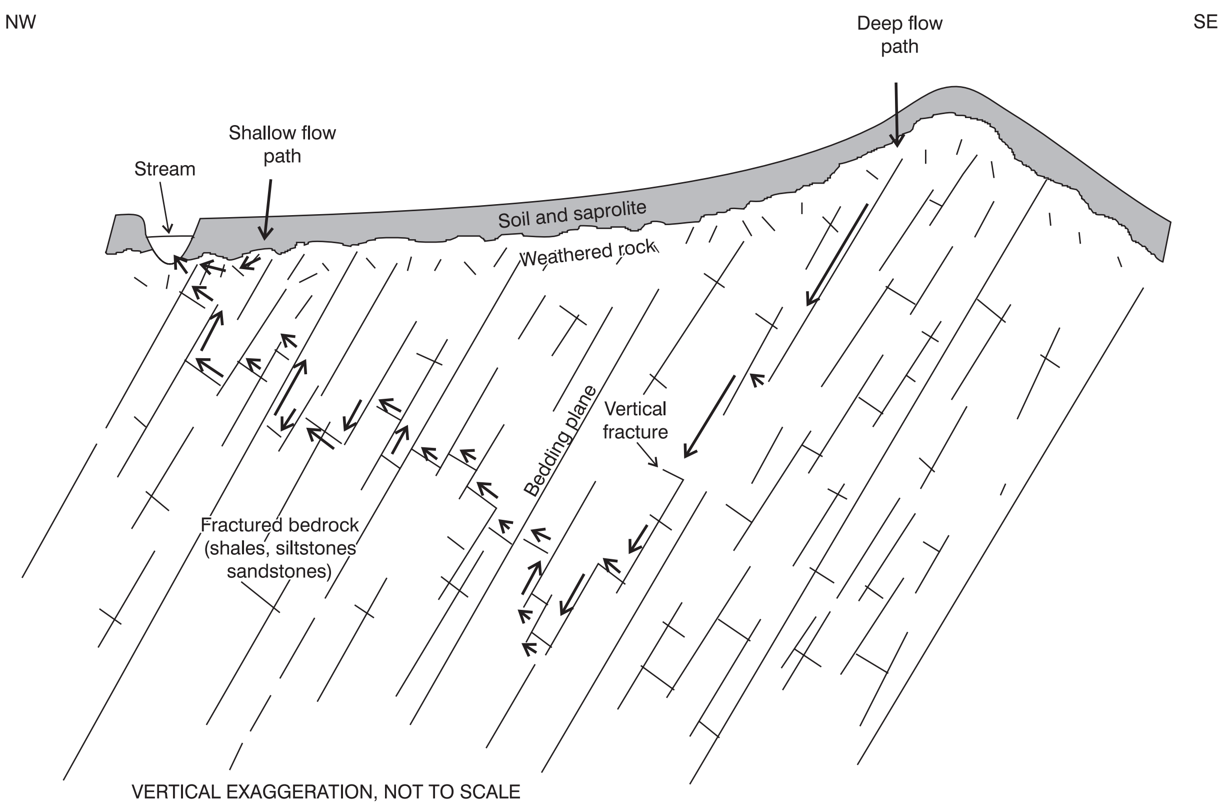


Figure 7. Conceptual ground-water flow system in a fractured sedimentary-rock aquifer with dipping beds.

Recharge

Recharge to areas underlain by shales, siltstones, and sandstones of the Newark Basin tends to be lower than recharge to other areas of the Piedmont in southeastern Pennsylvania. Recharge estimates to areas underlain by the Triassic sedimentary rocks of the Newark Basin range from 6 to 12 in. (153 to 305 mm) (Sloto and Schreffler, 1994). The permeability of soils, saprolite, and underlying bedrock of the Triassic sedimentary rocks of the Newark Basin probably is lower than in areas underlain by other rocks in the Piedmont.

Measurements of base flow (ground-water discharge to streams) commonly are used to estimate recharge. White and Sloto (1990) report that base flow in two areas underlain by Triassic sedimentary rocks in the Piedmont in southeastern Pennsylvania averaged 5.9 to 7.9 in. (150 to 200 mm) over a 13-year period from 1959 to 1972. In the Lansdale area, ground-water discharge to streams is reduced by ground-water pumping, therefore, recharge can be estimated by summing base flow and ground-water pumpage, as discussed in the section on "Numerical Simulation of Regional Ground-Water Flow."

Water-Bearing Zones

Water-bearing zones in the shales, silstones, and sandstones underlying Lansdale are discrete fractures. These fractures have been identified in boreholes using drillers' logs and (or) a combination of geophysical logs (caliper, fluid resistivity, and fluid temperature), heatpulse-flowmeter measurements, and borehole television surveys. The depth of water-bearing fractures determined by a series of flowmeter measurements in a borehole may differ from that reported from drillers' logs, in part because of differences in pumping rates. Pumping rates during drilling, which typically are much higher than rates maintained during heatpulse-flowmeter measurements, can enhance development of water-bearing fractures at and above the depth of drilling and make the actual depth of water-bearing zones difficult to determine.

Fractures are identified from caliper logs, acoustic televiewer images, or borehole television surveys, and water-producing zones are identified using a combination of caliper logs, fluid-resistivity logs, and heatpulse-flowmeter measurements. Water-bearing fractures can produce or receive (thieve) water. Changes in slope with depth of the fluid-temperature or fluid-resistivity logs can indicate the presence of water-bearing fractures. From the heatpulse-flowmeter measurements, changes in vertical borehole flow can indicate the presence of water-bearing fractures. Where increases in flow rates are measured, fractures are contributing water to the well; where decreases in flow rates are measured, fractures are receiving water. Wells with intra-borehole flow must have both producing and receiving zones. Examples of geophysical logs that can be used identify water-bearing zones (fractures) in three wells with different flow patterns in Lansdale are shown in figures 8-10. Under nonpumping conditions, downward flow only was measured in well Mg-164 (fig. 8), upward flow only was measured in well Mg-69 (fig. 10), and upward and downward flow were measured in well Mg-68 (fig. 9). Both inflow at producing zones and outflow at receiving zones could be estimated from heatpulse-flowmeter measurements and geophysical logs for wells Mg-68 and Mg-69 (figs. 9 and 10); inflow only was determined for well Mg-164 (fig. 8). A complete description of borehole geophysical logs done by USGS in 62 wells in and near the North Penn Area 6 site, Lansdale, Pa., is given by Conger (1999).

Some fractures transmit more water than others. The relative productivity of fractures can be determined by use of the heatpulse flowmeter under pumping conditions. The transmissivity of water-bearing zones can be determined quantitatively using controlled tests, such as the aquifer-interval-isolation tests (packer tests) done by USGS on three wells in Lansdale and described in detail in the section on "Single-Well, Interval-Isolation Tests." The flowmeter measurements probably show the location of only the most productive zones and may not detect all water-bearing zones. The drillers' logs of monitor wells drilled in 1997 indicate many of the most productive zones in wells are associated with sandstone rather than shale beds (Black & Veatch Waste Science, Inc., 1998). In well Mg-1604 (fig. 3), the primary water-bearing fractures appear to be in the sandstone contact with the overlying shale near the bottom of the hole.

Thirty-one existing industrial, commercial, public-supply, and observation wells in and near Lansdale were included in analysis of heatpulse-flowmeter measurements. Twenty-eight monitor wells drilled in 1997 were excluded from this analysis because most were shallow [less than 150 ft (46 m)] in depth and many lacked heatpulse-flowmeter measurements under pumping conditions. The 31 wells ranged in depth from 144 to 1,027 ft (43.9 to 313 m); the median depth was 339 ft (103 m) and the average depth was 356 ft (108.5 m). Casing lengths ranged from 3.5 to 138 ft (1.1 to 42 m); the median length was 22 ft (6.7 m) and the average length was 34 ft (10.4 m)]. Heatpulse-flowmeter measurements for all wells are described by Conger (1999).

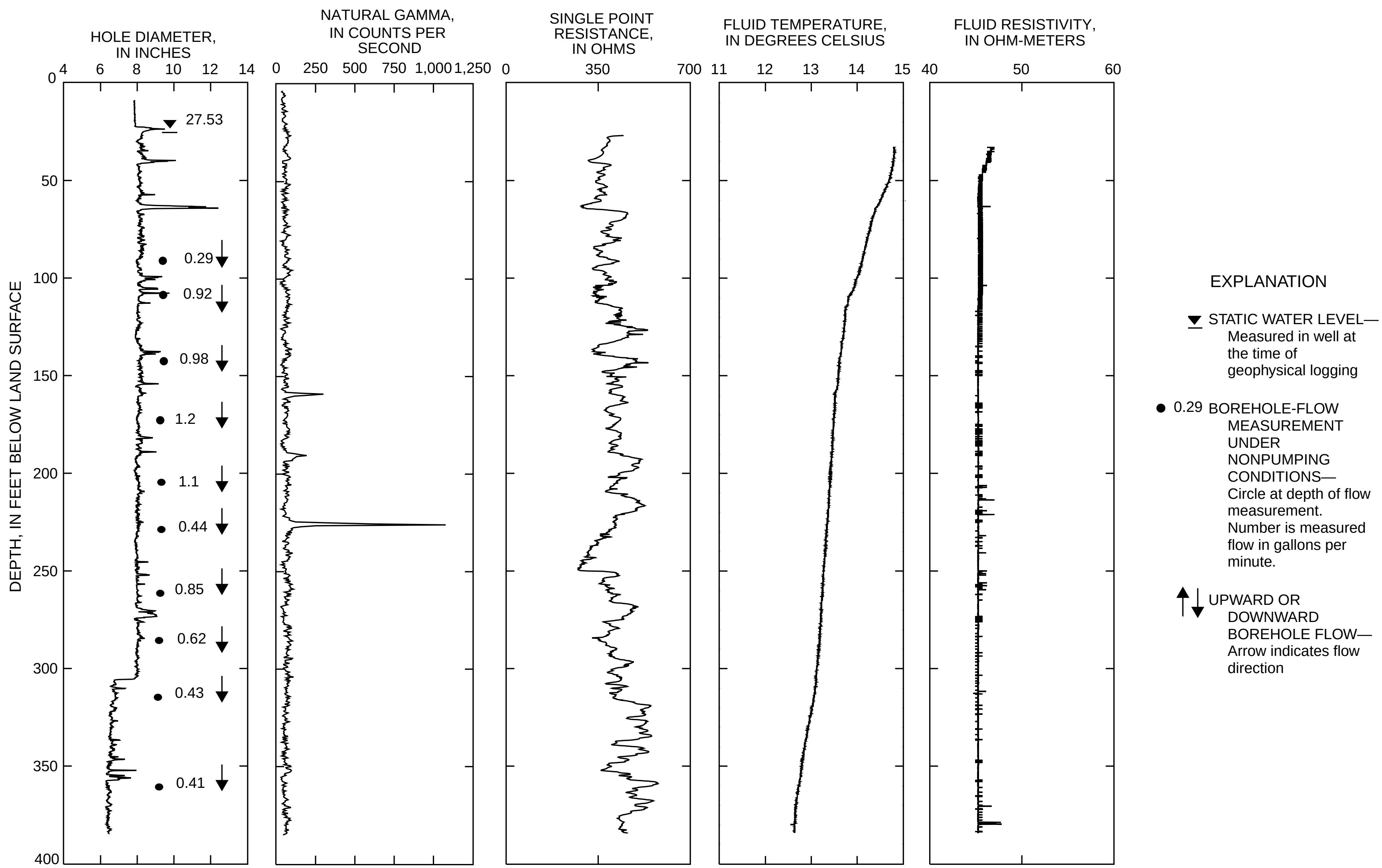


Figure 8. Geophysical logs of well Mg-164 in Lansdale, Pa.

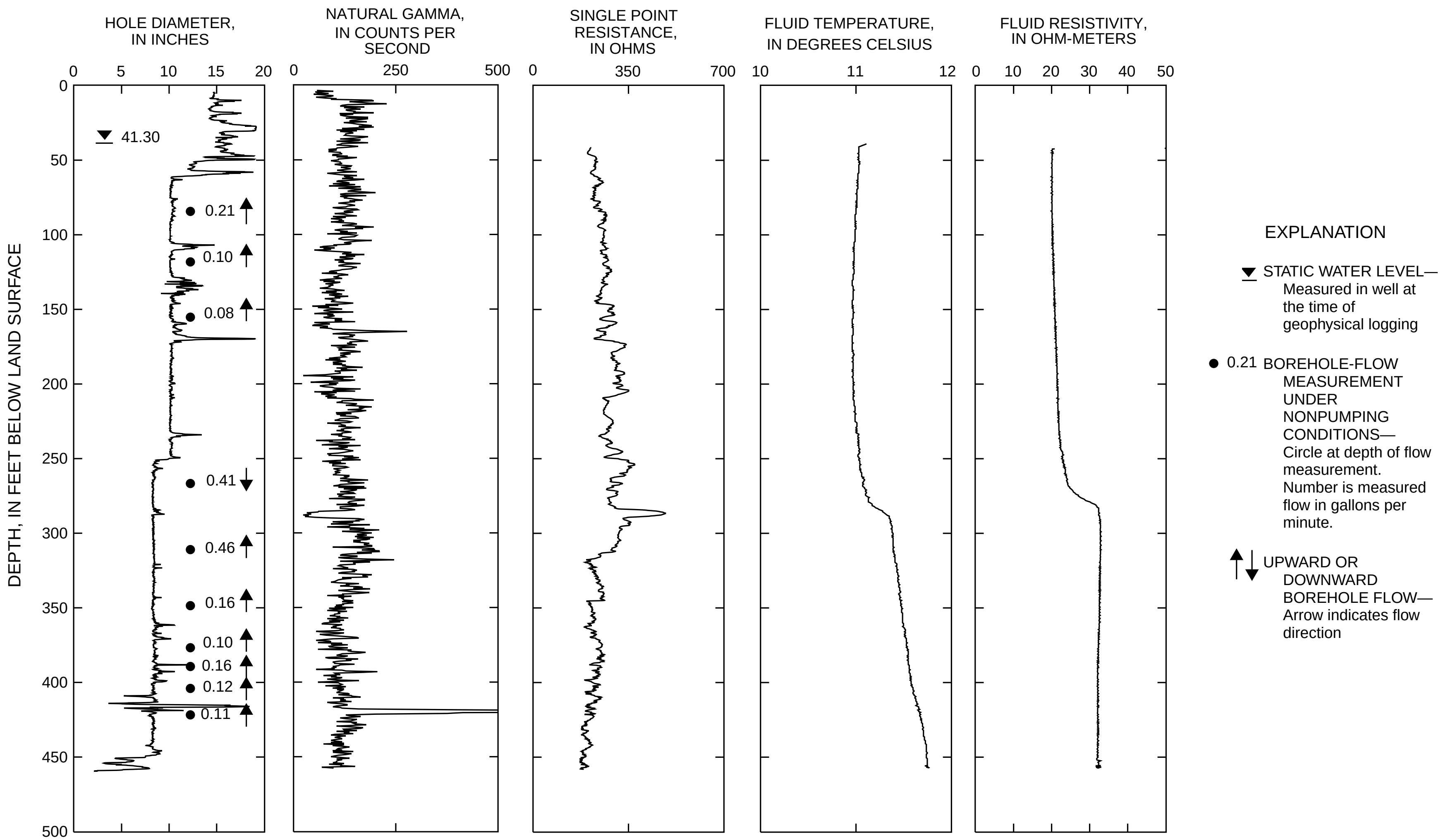


Figure 9. Geophysical logs of well Mg-68 in Lansdale, Pa.

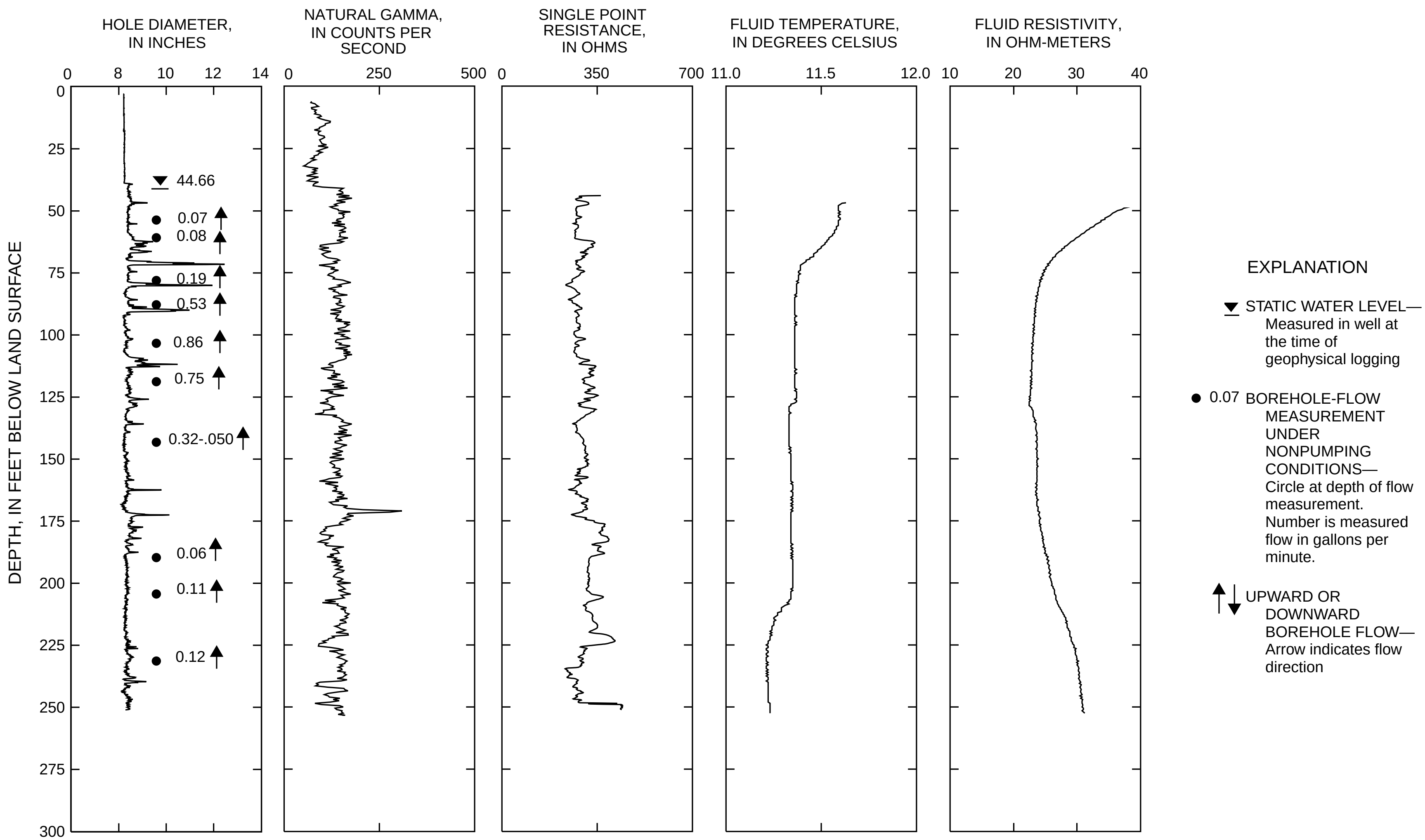


Figure 10. Geophysical logs of well Mg-69 in Lansdale, Pa.

Water-bearing zones (fractures) detected during heatpulse-flowmeter measurements in 31 wells logged in and near Lansdale are summarized in table 1. The greatest number of water-bearing zones detected per foot drilled were in the interval of 50-100 ft (15.2 - 30.5 m) below land surface, followed by the interval of 100-200 ft (30.5-61 m) below land surface. These two intervals contained about 67 percent of all water-bearing zones detected. The majority of the most productive zones detected in each well also were in the intervals of 50-100 ft (15.2-30.5 m) and 100-200 ft (30.5-61 m) below land surface; about 76 percent of the most productive zones were in these intervals.

Water-bearing zones at depths shallower than 50 ft (15.2 m) below land surface were detected less frequently than in the interval between 50-100 ft (15.2-30.5 m) below land surface (table 1). This result may reflect lower productivity in the 0- to 50-ft (15.2-30.5 m) interval, which is weathered and where potentially productive fractures may be partially closed with clay, but also may reflect the interval's smaller sample of open-hole footage because the upper part of the interval is unsaturated or cased off. The frequency of water-bearing zones detected appear to decrease with depth below 100 ft (30.5 m) and just one zone was detected below 500 ft (152.4 m) below land surface. However, because the amount of footage drilled below land surface also decreased with depth, these results could partly reflect the smaller sample of aquifer with depth.

Borehole television surveys and acoustic televiewer logs indicate most identified water-bearing fractures dip at shallow angles, similar to bedding. Examples of water-bearing near-horizontal (bedding-plane opening) and near-vertical fractures are shown in borehole television images of figures 8-10 well Mg-1444 (fig. 11). A plot of poles to fracture planes including water-bearing fractures for well Mg-67 is shown in figure 12. Points near the center of the plot represent low-angle features, such as bedding, and points near the perimeter of the plot represent high-angle features, such as near-vertical fractures that are approximately orthogonal to bedding. The orientation of water-bearing zones for well Mg-67, as interpreted from the acoustic televiewer log, is similar to bedding. Some features, such as the near-vertical water-bearing fracture at 72 ft in well Mg-67, are not detected from acoustic televiewer logs.

Table 1. *Depth distribution of water-bearing zones determined from geophysical logging of 31 wells[1] in and near Lansdale, Pa.*

[>, greater than]

	Depth interval, in feet below land surface							Total
	0-50	50-100	100-200	200-300	300-400	400-500	>500	
Number of wells drilled no deeper than this interval	0	0	5	9	9	4	4	31
Percentage of all wells drilled no deeper than this interval	0	0	16.1	29.0	29.0	12.9	12.9	99.9
Footage drilled in interval[2]	857	1,419	2,946	2,271	1,351	612	752	10,208
Percentage of total footage drilled	8.4	13.9	28.9	22.2	13.2	6.0	7.4	100
Number of water-bearing zones in interval	7	32	42	19	6	3	1	110
Percentage in interval of total water-bearing zones	6.4	29.1	38.2	17.3	5.5	2.7	.9	100
Number of water-bearing zones per 100 feet drilled in interval	.8	2.3	1.4	.8	.4	.5	.1	6.3
Number of water-bearing zones determined to be most productive[3] for well in interval	2	9	13	4	0	0	0	28
Percentage in interval of total most productive[3] water-bearing zones for all wells	7.1	32.1	46.4	14.3	0	0	0	99.9
Number of water-bearing zones determined to be most productive[3] for well per 100 feet drilled in interval	.2	.6	.4	.2	0	0	0	.27

[1] Wells Mg-62, 64, 67, 68, 69, 72, 76, 79, 80, 81, 138, 143, 142, 154, 157, 163, 164, 498, 618, 623, 624, 704, 1128, 1284, 1440, 1441, 1443, 1444, 1445, 1446, and 1447 were included in analysis.

[2] Uncased or open-hole footage when logged.

[3] Relative productivity of water-bearing zone determined by pumping well while measuring borehole flow with heatpulse flowmeter.

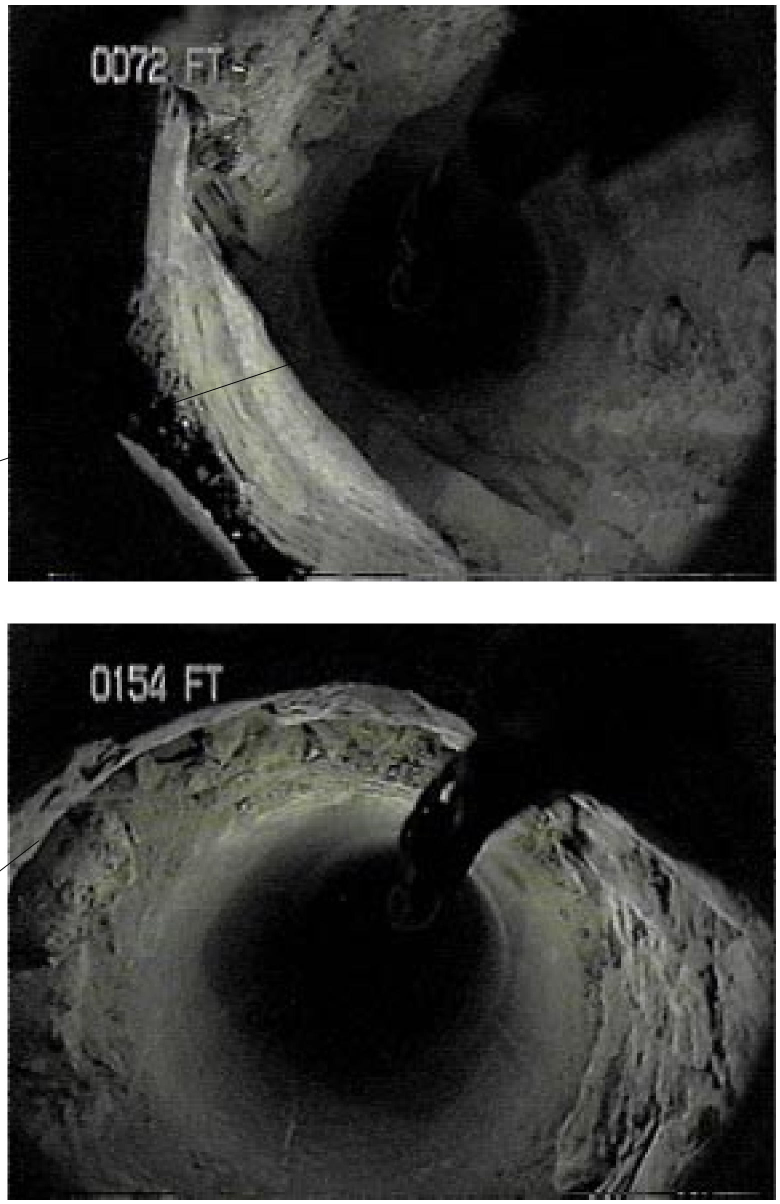


Figure 11. Borehole television image of (A) vertical fracture, and (B) horizontal fracture in well Mg-1444 in Lansdale, Pa.

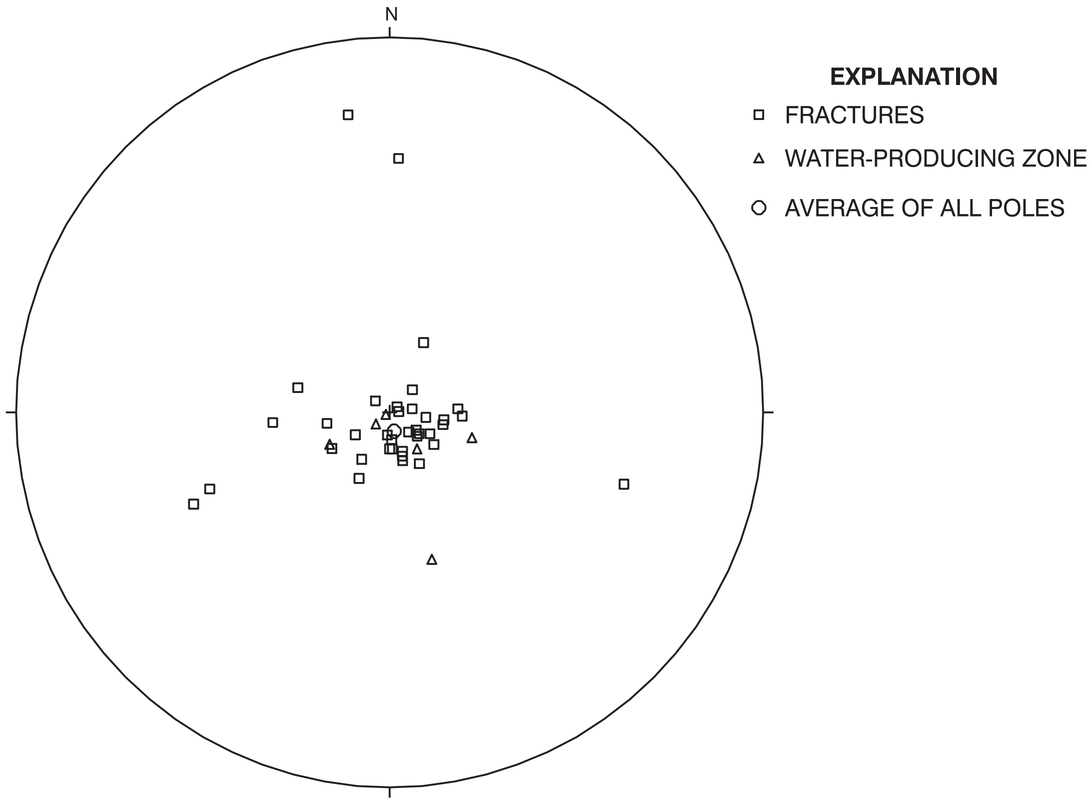


Figure 12. Equal-area, lower-hemisphere plot of poles to fracture planes measured by acoustic televiewer in well Mg-67 in Lansdale, Pa.

Water Levels

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

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

Water levels were measured continuously during fall 1995 through spring 1998 in seven Lansdale area wells. During this same period, water levels in three other wells were measured for short (less than 1 year) periods. The wells were constructed as open holes, ranged in depth from 179 to 507 ft (54.6 to 154.5 m), were cased from 9 to 97 ft (2.7 to 29.6 m) below land surface, and had multiple water-bearing zones (table 2). Depth to water generally was smaller in wells near streams (discharge areas) than in wells in upland areas near divides or at distances away from streams (pl. 1, table 2). Under natural conditions, depth to water in a water-table aquifer is related to topography. Water levels generally are closest to land surface in valleys near streams (discharge areas) and deepest below land surface on hilltops (recharge areas).

Table 2. *Well depth, casing length, depth to water, and change in water levels from January 1996 to January 1997 and from January 1997 to January 1998 for selected wells in and near Lansdale, Pa.*

[ft bls, feet below land surface; ft, feet; --, no data]

U.S. Geological Survey local well number Mg-	Well depth (ft bls)	Casing length (ft)	Within 200 ft of stream	Depth to water on 1-23-96 to-1-24-96 (ft bls)	Depth to water on 1-7-97 (ft bls)	Depth to water on 1-13-98 (ft bls)	Change in water level 1996-97 (ft)	Change in water level 1997-98 (ft)
67	292	19	yes	14.71	10.81	15.44	3.90	-4.63
68	500	9	yes	--	40.90	44.68	--	-3.78
81	320	33	no	[1] 50.27	38.52	45.50	11.75	-6.98
82	350	18	yes	10.86	11.49	11.86	-.63	-.37
143	400	30	yes	3.85	--	--	--	--
152	203	22	no	--	47.97	56.19	--	-8.22
618	343	47	no	66.20	54.71	62.01	11.49	-7.3
623	507	97	no	[2] 21.24	19.91	23.53	1.33	-3.62
704	400	83	no	16.30	16.84	18.55	-.54	-1.71
Average							4.55	-4.10

[1] Measured on 1/18/96.
[2] Measured on 1/3/96.

In wells not affected by nearby pumping, rising water levels indicate recharge periods. The long-term (1995-98) response of water levels to recharge by precipitation is shown on figures 13 and 14. In southeastern Pennsylvania, the autumns of 1995 and 1997 were drought periods and water levels declined accordingly. The autumn of 1996 ended a year of higher-than-average precipitation. Ground-water levels were some of the highest on record in southeastern Pennsylvania in December 1996. Annual precipitation as measured at Allentown, Pa., a weather station about 20 mi (32 km), north of Lansdale, was 38.46 in. (977 mm) in 1995, 56.87 in. (1,444 mm) in 1996, and 38.49 in. (978 mm) in 1997. Normal annual precipitation (computed for a 30-year period, 1960-90) at Allentown, Pa., is 43.52 in. (1,105 mm) (National Oceanic and Atmospheric Administration 1995; 1996; 1997).

The range of seasonal fluctuation varied among the wells, reflecting the different hydrologic settings of the observation wells and possibly also spatial variability in recharge rates or storage characteristics of the aquifer. The range of fluctuations generally increased with depth to water (table 2). For example, the rise from October 1995 to May 1996 was about 20 ft (6.1 m) in well Mg-618 (fig. 14) but only about 6 ft (1.8 m) in well Mg-67 (fig. 13). The average change in water levels in six wells was 4.55 ft from January 1996 to January 1997 and was -4.10 ft from January 1997 to January 1998 (table 2), reflecting an increase in annual precipitation of 18.41 in. in 1996 and a decrease of 18.38 in. in 1997 compared to precipitation in the previous year of 1995 and 1996, respectively.

Water levels in most wells, except for Mg-1441 and Mg-618, appeared unaffected by local pumping. The weekly schedule of nearby industrial pumping is reflected in the rapid, periodic decline and recovery in measured water levels during the week and the rise in water levels (recovery) over weekends in well Mg-1441, such as March 31-April 1, April 7-8, April 14-15, April 21-22, and April 28-29, 1996 (fig. 15). Water levels in well Mg-618 also declined and recovered periodically (7-day cycle) in apparent response to industrial pumping, although to a lesser extent than in Mg-1441.

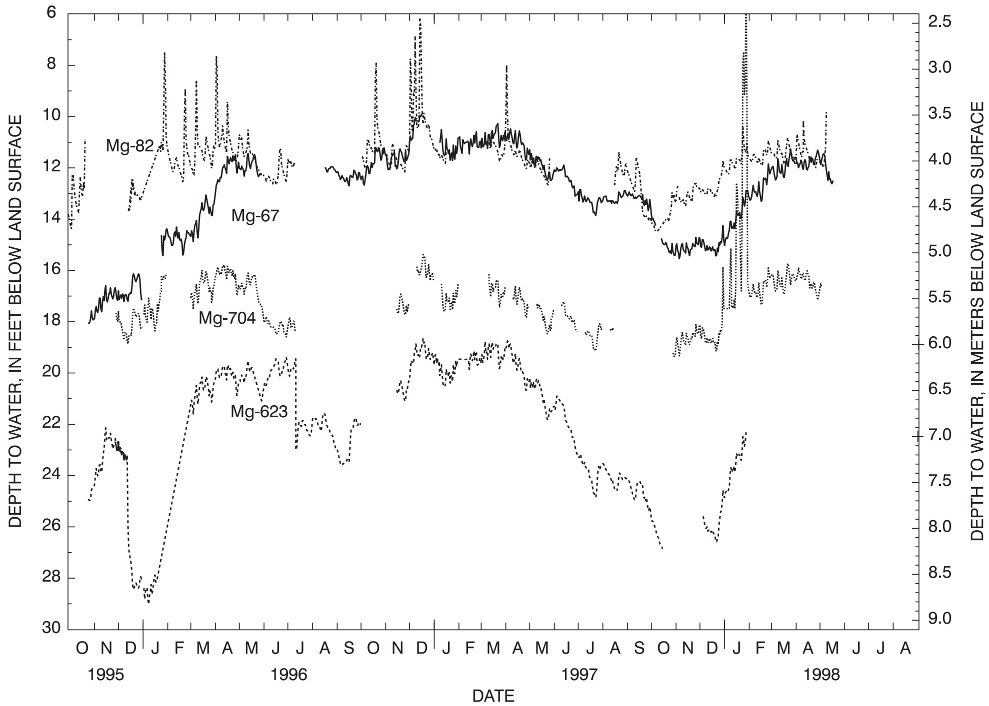


Figure 13. Long-term (annual or greater) water levels showing seasonal recharge in wells Mg-82, Mg-67, Mg-704, and Mg-623 in Lansdale, Pa.

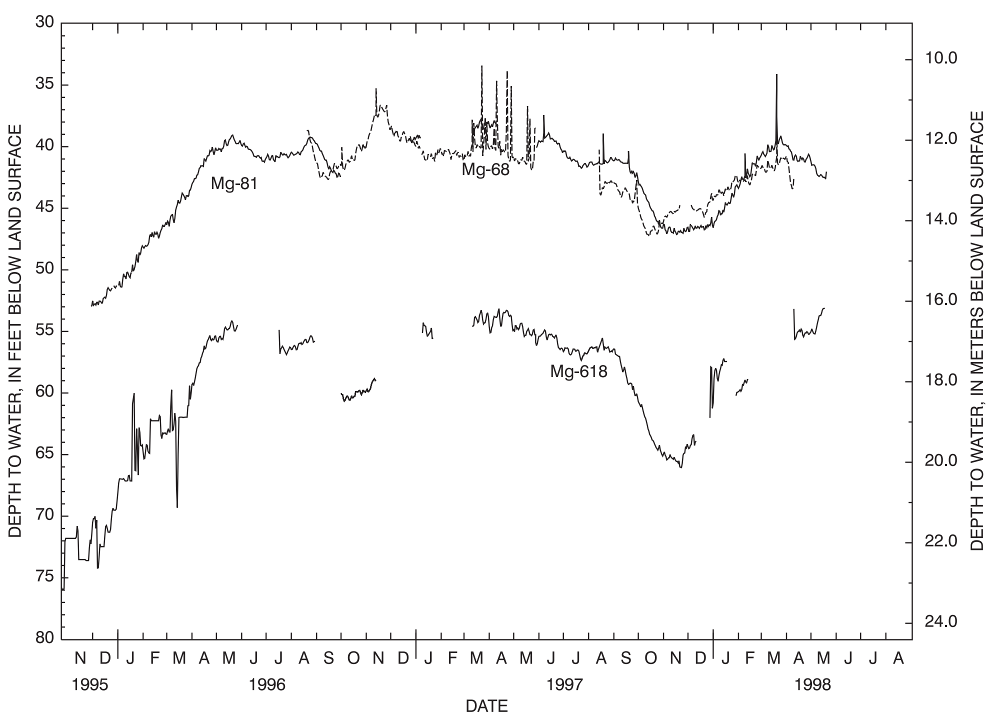


Figure 14. Long-term (annual or greater) water levels showing seasonal recharge in wells Mg-81, Mg-68, and Mg-618 in Lansdale, Pa.

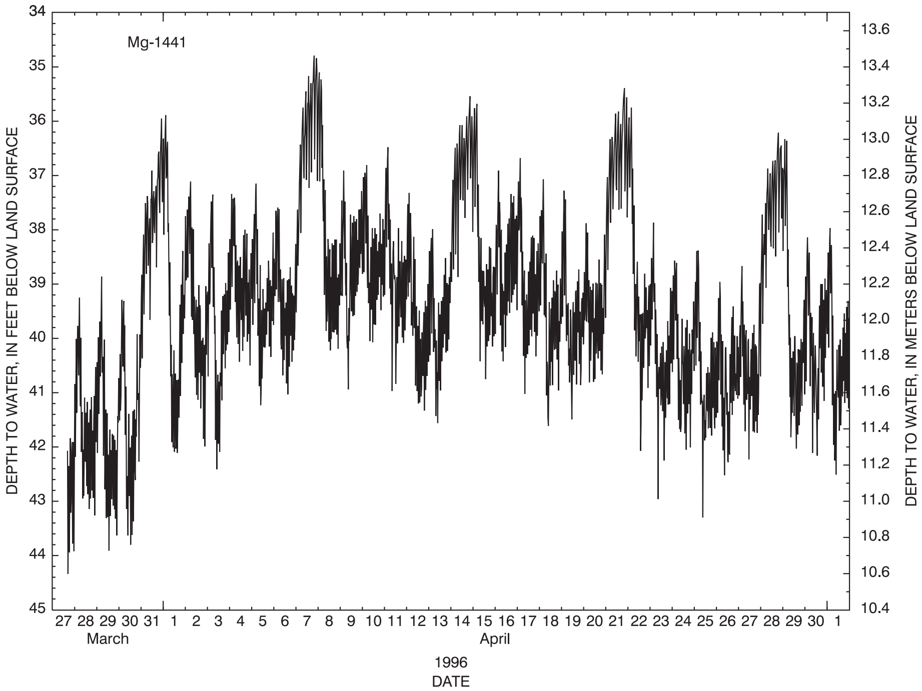


Figure 15. Water levels in well Mg-1441 showing response to nearby pumping in Lansdale, Pa., February-March 1996.

The short-term (few days or less) response to precipitation is shown in figure 16. In most wells monitored in the Lansdale area, the response is rapid (within a few hours of rainfall), indicating the rise in water levels probably is caused by an increase in hydrostatic pressure rather than physical infiltration of water. The rapid response of water levels to precipitation indicates these wells penetrate confined parts of the aquifer.

In confined ground-water systems, ground-water levels also can fluctuate with changes in earth tides and barometric pressure. The apparent effect of earth tides on water levels in well Mg-704 in Lansdale (fig. 17) indicates that the water-bearing zones of this well are confined or semiconfined. Earth tides are characterized by semi-diurnal fluctuations and are caused by the force of gravity exerted by the sun and moon on the earth and by centrifugal forces produced by the revolution of the earth and moon around their common center of gravity (Hsieh and others, 1987). Twice-daily peaks occur at low tide when the earth is compressed. The increased pressure results in a rise in water levels in wells completed in confined aquifers. Daily patterns as a result of earth tides similar to those in water levels of Mg-704 (fig. 17) were observed in water levels in most wells that were monitored in Lansdale. The effect of changes in barometric pressure on water levels in a well in Lansdale during November 1997 is shown in figure 18. Water levels rise in response to declines in barometric pressure and fall in response to increases in barometric pressure. This inverse response of water level to barometric pressure indicates that the water-bearing zones of the well in Lansdale (fig. 18) are under confined conditions. Similar responses to changes in barometric pressure were observed where measured in most wells in the Lansdale area.

Water levels in and near Lansdale were measured in more than 130 wells during 2 days in August 1996 and again in 80 wells during 2 days in January 1998 to prepare maps of the regional potentiometric surface. Because most water levels were measured in wells that were constructed as open holes and ranged in depth from 70 to 600 ft (21 to 183 m) in depth, water levels represent the composite head of multiple water-bearing zones. Vertical head differences between discrete water-bearing zones were less than 20 ft (6.1 m) in three wells tested using inflatable packers to

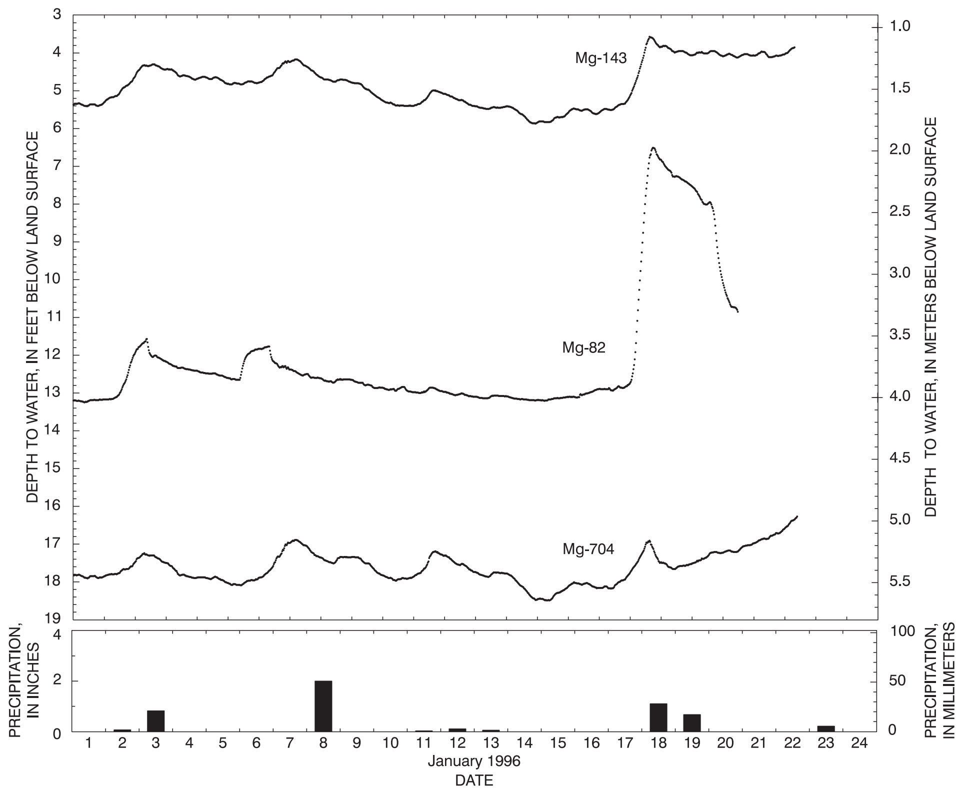


Figure 16. Short-term water-level response to precipitation in wells Mg-143, Mg-82, and Mg-67 in Lansdale, Pa., January 1996.

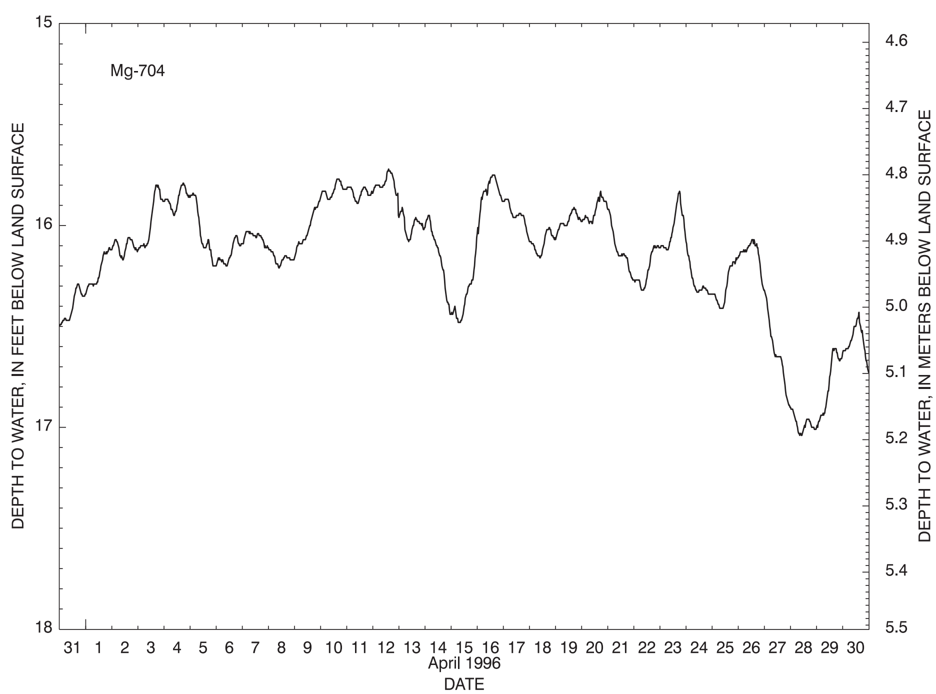


Figure 17. Water levels in well Mg-704 showing water-level response to earth tides in Lansdale, Pa., April 1996.

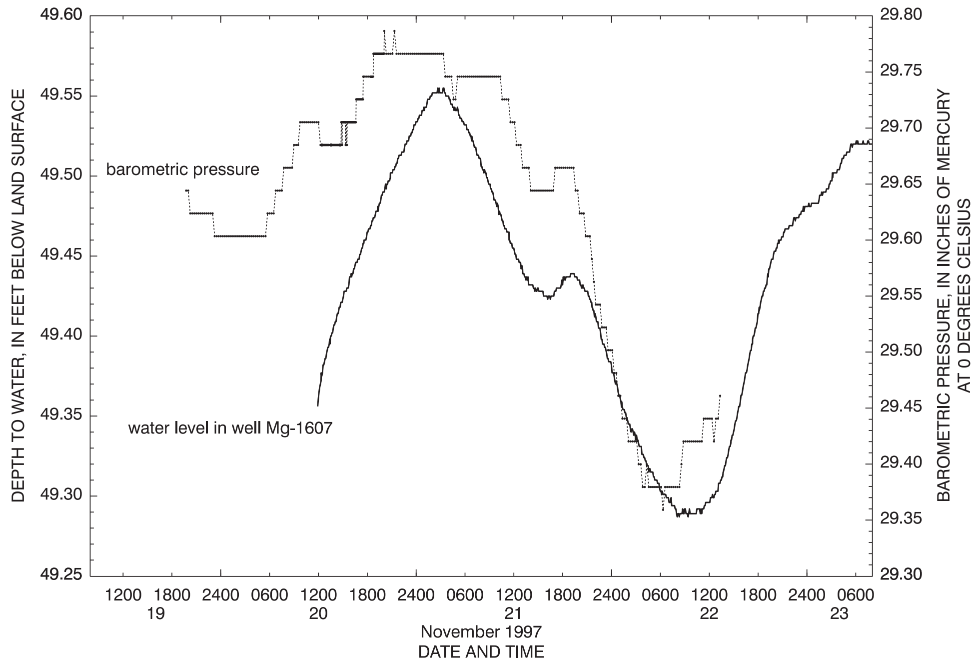
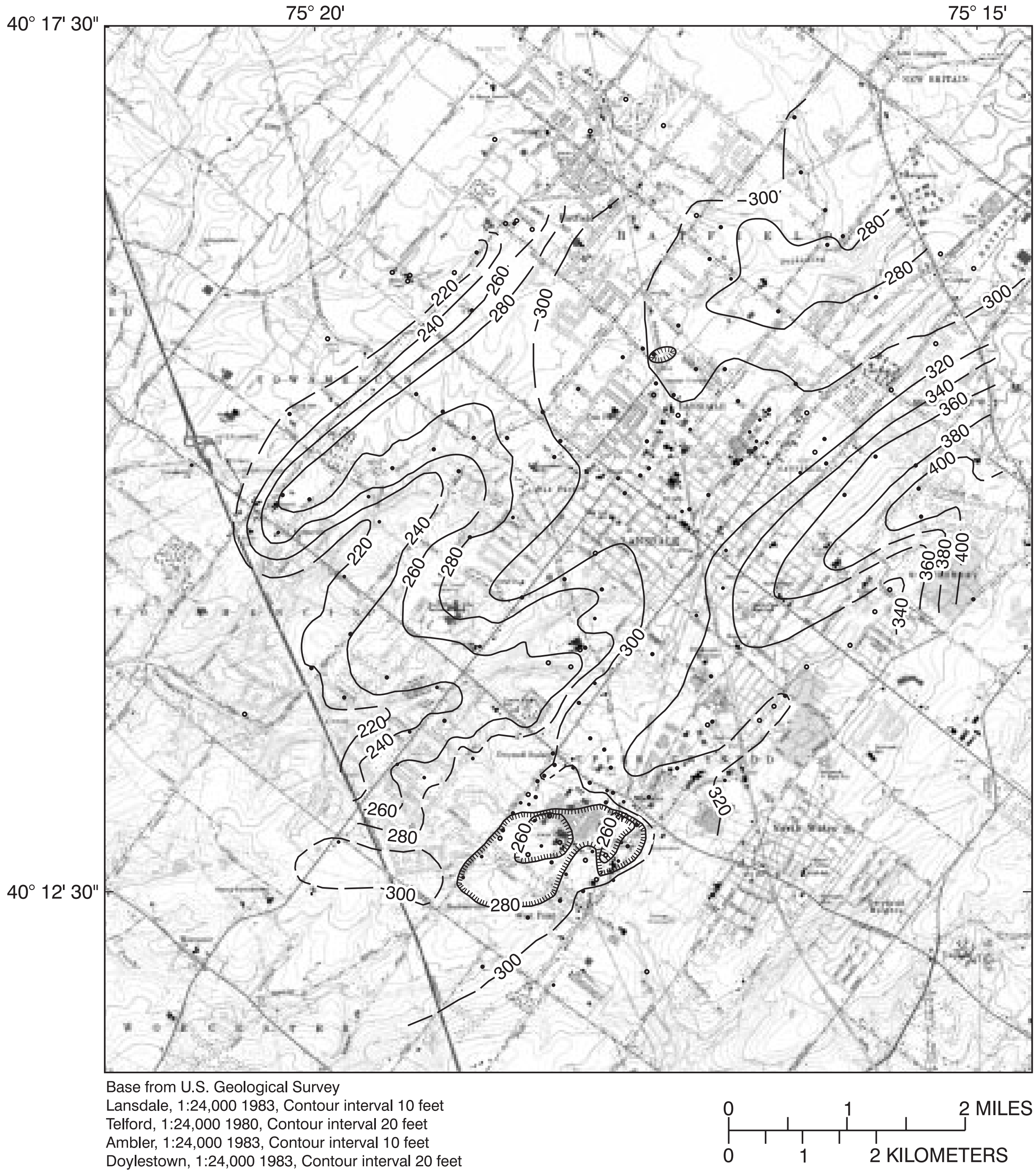


Figure 18. Water levels in well Mg-1607 showing response to barometric pressure, Lansdale, Pa., November 1997.

isolate zones, as discussed in the section on “Single-Well, Interval-Isolation Tests.” Assuming these wells are representative of other wells in the Lansdale area, the relative error in contouring composite heads on a 20-ft (6.1-m) interval should be small.

A map of water levels measured on August 22-23, 1996 (fig. 19; Senior and others, 1998), shows that water-level altitudes are highest under the small ridge east of Lansdale, underlain by the Lockatong Formation, and lowest along Towamencin Creek southwest of Lansdale. The contoured water-level altitudes, as mapped, represent only changes in a potentiometric surface in the horizontal direction. Although the contoured water levels in the semi-confined aquifer beneath Lansdale do not represent the water table, the surface is nevertheless similar to topography. Commonly, the water table closely replicates topography, especially in aquifers with low permeability and (or) storage. The shape of the contoured water-level surface differs from topography in the central part of the study area under Lansdale. In central Lansdale, the ground-water divide between the West Branch Neshaminy Creek Basin to the north and the Towamencin Creek Basin to the south is about 0.75 mi (0.47 km) north of the surface-water (topographic) divide. Also, the contoured water-level surface, which is nearly flat in the area of the ground-water divide, has a slope inverse to that of topography along an axis from the southeast to the northwest; changes in the permeability of the bedrock aquifer possibly influence the configuration of the water-level surface in this area. The shape of the contoured water-level surface also differs from topography in an area south of Lansdale, where industrial pumping has caused a cone of depression. A map of water levels measured January 13-14, 1998 (fig. 20), shows a general configuration similar to the map of water levels measured on August 1996, although water levels in January 1998 generally were several feet lower than in August 1996. A dry period of about 6 months preceded January 1998.



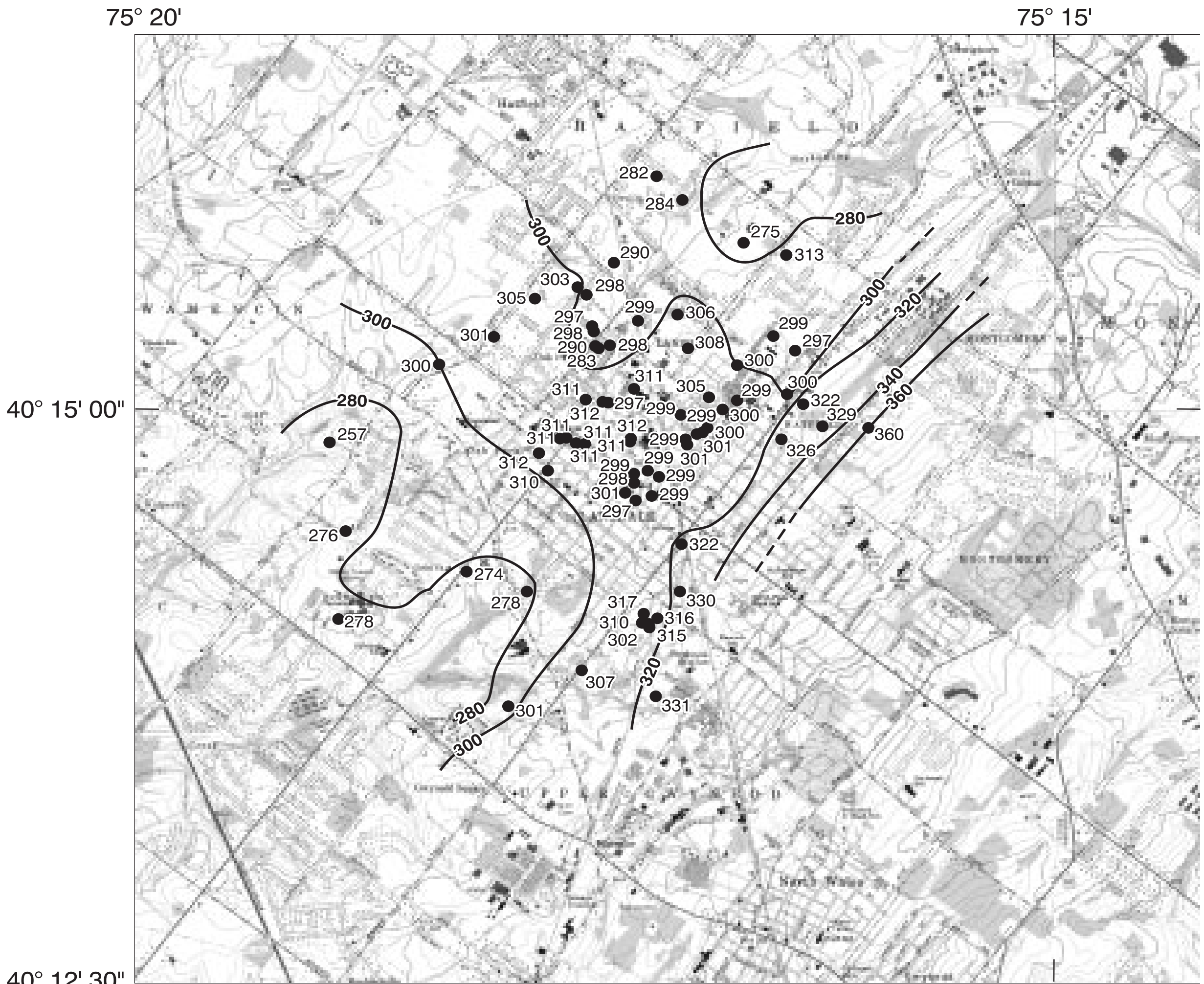
EXPLANATION

—300— — POTENTIOMETRIC CONTOUR -- Shows altitude of potentiometric surface as defined by measured water levels. Dashed where approximately located. Hachured contour indicates depression in potentiometric surface. Contour interval 20 feet. Datum is sea level.

• WATER-LEVEL MEASUREMENT SITES

•P WELL KNOWN TO BE PUMPING FOR PUBLIC SUPPLY OR INDUSTRIAL USES DURING PERIOD OF WATER-LEVEL MEASUREMENTS

Figure 19. Measured water levels and contoured water-level surface in and near Lansdale, Pa., August 22-23, 1996 (From Senior and others, 1998).



Base from U. S. Geological Survey
Lansdale 1:24,000 1983, Contour interval 10 feet
Telford 1:24,000 1980, Contour interval 20 feet
Ambler 1:24,000 1983, Contour interval 10 feet
Doylestown 1:24,000 1983 Contour interval 20 feet

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

–300– POTENTIOMETRIC CONTOUR - Shows altitude of potentiometric surface as defined by measured water levels. Dashed where approximately located. Contour interval 20 feet. Datum is sea level.

●331 LOCATION AND ALTITUDE OF STATIC WATER LEVEL MEASURED IN A DRILLED WELL COMPLETED IN BEDROCK - Altitude in feet above sea level.

Figure 20. Measured water levels and contoured water-level surface in and near Lansdale, Pa., January 13-14, 1998.

The water levels from January 1998 include measurements in vertically nested monitor wells and, therefore, includes data on differences in vertical heads. In most monitor-wells nests, the water-level altitude in the deepest well of the nest is higher than the water-level altitude in the shallowest well, indicating an upward vertical gradient. In a few well nests, the water-level altitude in the shallowest well of the nest is higher than water-level altitude in the deeper well, indicating a downward vertical gradient. In aquifer-interval-isolation tests done in three wells in Lansdale, water levels for different water-bearing zones were measured after inflation of straddle (set of two) packers. Water levels in the deepest zones were higher than levels in the shallower zones, but water levels in the shallowest zone were slightly lower than levels in the next deepest zone isolated. These observations, described in detail in the section “Single-Well, Interval-Isolation Tests,” indicate an upward vertical gradient from zones at depth and a smaller downward vertical gradient from the shallowest zone. Vertical hydraulic gradients are discussed in detail in the section on “Ground-Water Flow.”

Ground-Water Flow

Ground water flows from higher to lower head (water-level altitude), and therefore the general direction of horizontal ground-water flow can be estimated from a map of the water table or potentiometric surface. If there are no vertical head differences, then flow is strictly planar (two-dimensional). In isotropic aquifers, where hydraulic conductivity is independent of direction, the flow is parallel to hydraulic gradient. In anisotropic aquifers, where hydraulic conductivity depends on direction, the flow is at an angle (toward the direction of highest permeability) to the hydraulic gradient. The maps of water levels in August 1996 (fig. 19) and January 1998 (fig. 20) indicate that ground water generally flows from the small ridge east of Lansdale toward Lansdale, in the central part of the study area. From central Lansdale, a triple divide, ground water flows north, southwest, and south in directions similar to the topographic gradient toward three separate drainages.

On a local or borehole scale, ground-water flow directions may appear to deviate from regional flow directions. These local-scale deviations may be the result of vertical gradients, nearby pumping, or natural flow through a complex network of fractures in the dipping-bed hydrogeologic system. Where differences in potentiometric head between zones of water-bearing fractures in a well are present, water in the well flows vertically from zones of high head to zones of low head. The well allows rapid flow between these different water-bearing zones, which under natural conditions are separated by layers of unfractured or low-permeability bedrock. Examples of downward and upward vertical borehole flow between producing and receiving fractures in wells in Lansdale are shown in figures 8 and 10, respectively.

Vertical flow in open-hole wells under nonpumping conditions was measured by use of a heatpulse flowmeter or brine-tracing techniques in 58 wells in the area of Lansdale. The wells included 31 available observation, industrial, commercial and public-supply wells that ranged in depth from 144 to 1,027 ft (43.9 to 313 m) and 27 monitor wells drilled in the summer of 1997 that ranged in depth from 49 to 385 ft (14.9 to 117.3 m). Of the 58 wells tested, upward borehole flow was measured in 35 wells, downward flow only was measured in 11 wells and inferred in 1 well (Mg-76), upward and downward flow were measured in 3 wells, and no detectable flow was measured in 8 wells (table 3; Conger, 1999). Measured upward flow rates ranged from 0.01 to 1.2 gal/min (0.038 to 4.54 L/min), and downward flow rates ranged from 0.02 to 12 gal/min (0.076 to 45.4 L/min). In wells with upward flow, water commonly exited the well in fractures at depths typically ranging from 30 to 70 ft (9.1 to 21.3 m) below land surface. In wells with downward flow, water commonly exited the well in fractures at depths greater than 100 ft (30 m) below land surface. The location of wells where flow was measured and direction of vertical flow in the well are shown in figure 21.

Table 3. *Depth and direction of vertical flow and inferred depths of fractures with inflow and outflow in wells logged under nonpumping conditions in and near Lansdale, Pa. (Conger, 1999)*

[ft bls; feet below land surface; gal/min, gallons per minute; --, not detected or measured; <, less than; >, greater than; -, not applicable]

U.S. Geological Survey local well number Mg-	Depth of well (ft bls)	Depth to water (ft bls)	Upward flow		Downward flow		No flow	Inflow	Outflow
			Range of depths with upward flow (ft bls)	Flow rate or range of flow rates (gal/min)	Range of depths with downward flow (ft bls)	Flow rate or range of flow rates (gal/min)	Depths with no flow detected (ft bls)	Depths of fractures with inflow[1] (ft bls)	Depths of fractures with outflow[1] (ft bls)
62	382	--	120-345	0.02	--	--	--	>345	<120
64	1,027	--	106-376	.06	--	--	--	>376, 111-115	<86
67	[2]294	--	--	--	65-114	0.07	--	24, 54-58, 72-75, 114	>114
68	460	41.8	85-148	.11-.46	--	--	--	108-110, 169-171, 321-323, 361-371, >426	<70, 284-288
69	251	44.7	52-234	.06-.86	--	--	--	125-129, 158-162, 238-242	47, 67-72, 80, 90, 109-113, 208
72	298	--	--	--	165	12	--	71,79-86	250
76	367	--	--	--	--	--	--	51-100	232
79	284	--	--	--	68-150	.02	--	124	166
80	270	13.3	170-248	.16-.25	--	--	--	253-258	144-154
81	350	--	--	--	--	--	[3] 230, 310	-	-
82	[4] 375	--	56-70	.04	--	--	35	>70	--
138	424	39.6	265-401	.11-.19	53-150	.08-1.2	--	50-52, 421-423	82-86, 130-142, 157-175, 240, 391-399
143	392	--	--	--	--	--	[2] 130-350	-	-
152	196	49.4	55-186	.07-.25	--	--	--	63-68, >186	<63
154	183	51.2	85-140	.10-.18	--	--	60, 145-170	140-142	63-88
157	268	6.6	52-240	.12-.30	--	--	--	124-127, 187, >240	<52, 64-68, 92-97
163	318	25.4	37-300	.11-.30	--	--	--	>300	<37, 104-111, 234
164	385	27.5	--	--	92-332	.29-1.2	--	62-65, 99-113, 154, 245-257	222, 270-274, 300-348, >362
498	587	46.2	450-554	.08-.09	--	--	104-424	566-576	435-442
618	342	--	130-200	.01	--	--	315	--	--
624	633	--	66-322	.01	--	--	--	>322	<66
704	380	--	--	--	--	--	[2] 105-315	--	--
1128	486	18.3	--	--	42-264	0.10-1.3	--	33, 70	118-137, 172, 204, 215-231, >265
1284	442	9.4	88-426	.06-.40	--	--	--	292, 438	82, 90-92, 256
1440	208	--	--	--	64-118	.02	--	108	128
1441	178	--	--	--	100-130	.23-.44	--	85, 118	161
1443	339	42.1	68-332	.07-.24	--	--	--	332	<68, 175, 225
1444	294	--	69-270	.07-1.2	--	--	--	260-265, 270	70-73

Table 3. *Depth and direction of vertical flow and inferred depths of fractures with inflow and outflow in wells logged under nonpumping conditions in and near Lansdale, Pa. (Conger, 1999)—Continued*

U.S. Geological Survey local well number Mg-	Depth of well (ft bls)	Depth to water (ft bls)	Upward flow		Downward flow		No flow	Inflow	Outflow
			Range of depths with upward flow (ft bls)	Flow rate or range of flow rates (gal/min)	Range of depths with downward flow (ft bls)	Flow rate or range of flow rates (gal/min)	Depths with no flow detected (ft bls)	Depths of fractures with inflow[1] (ft bls)	Depths of fractures with outflow[1] (ft bls)
1445	204	44.1	--	--	98-130	0.02-.07	--	84	110-120, 130-150
1446	144	53.9	68-90	0.06-.10	104	.10	--	73, 76, 97-101	54-59, 122
1447	145	47.2	--	--	54-114	.19-.36	--	48-50, 68-71, 82	104-108, 127-130
1600	150	48.8	56-142	.11-1.2	--	--	--	147-149	50, 70
1601	100	55.4	80-92	.15-.36	--	--	65	84-90, 94-95	66-77
1602	131	55.1	81-123	.12-.96	--	--	66	115-116, 129	69-72
1603	98	64.7	--	--	70	.013	76, 86	65	73
1604	221	55.5	66-170	.14-.21	--	--	--	214-221	55-65
1605	95	60.8	--	--	--	--	73, 81, 88	-	-
1606	101	43.1	52-94	.07-.14	--	--	--	94-100	44-48
1607	161	42.2	64	.15	104-140	.10	--	73	52, 157-159
1608	307	39.7	--	--	--	--	240-288	-	-
1609	101	46.5	52-76	.10-.19	--	--	86	79-81	48
1610	122	13.6	46	.09	--	--	28, 74-110	49	30-40
1611	88	13.5	--	--	--	--	24-74	-	-
1612	384	49.8	66-360	.12-.73	--	--	--	310-312, 330-340, 370-382	50-54, 94-115
[5]1613	179	25.6	60-78	.11-.32	--	--	--	72-74, 94	40-55
1613	320	37.1	--	--	--	--	190-288	-	-
1614	121	50.5	58-100	.10-.22	--	--	--	102-120	50-56
1615	148	15.7	34-126	.07-.52	--	--	--	72-74,119, 140-148	19-28, 40-55
1616	101	26.6	40-74	.06-.12	--	--	90	81	30-34, 51-53
1617	49	13.5	--	--	--	--	25, 36	-	-
1618	181	52.0	85	0.10	--	--	70, 110-170	92	75-78
1619	150	11.9	50-70	.08-.11	--	--	90-134	92	20-42
1620	101	12.2	90	.13	--	--	46-70	>92	76
1621	161	50.5	80-150	.08-.46	--	--	--	96, 114, 134, >150	50-68
1622	101	50.4	86	.08	--	--	63	>89	50-74
1623	101	49.0	64-92	.09-.13	--	--	--	>92	50-62
1624	101	38.7	--	--	--	--	48-90	-	-
1639	149	24.7	--	--	42-100	1.1-1.3	--	30-38	102-113
1640	66	23.3	27-40	.06-.09	--	--	50	42	23, 30

[1] Fracture depths were inferred from geophysical logs (Conger, 1999).
[2] Well was logged only to 120 ft bls because of obstruction at that depth.
[3] Brine tracing.
[4] Only upper 92 feet of well Mg-82 was logged.
[5] Well Mg-1613 deepened to 320 feet and reconstructed with 182 feet of casing.

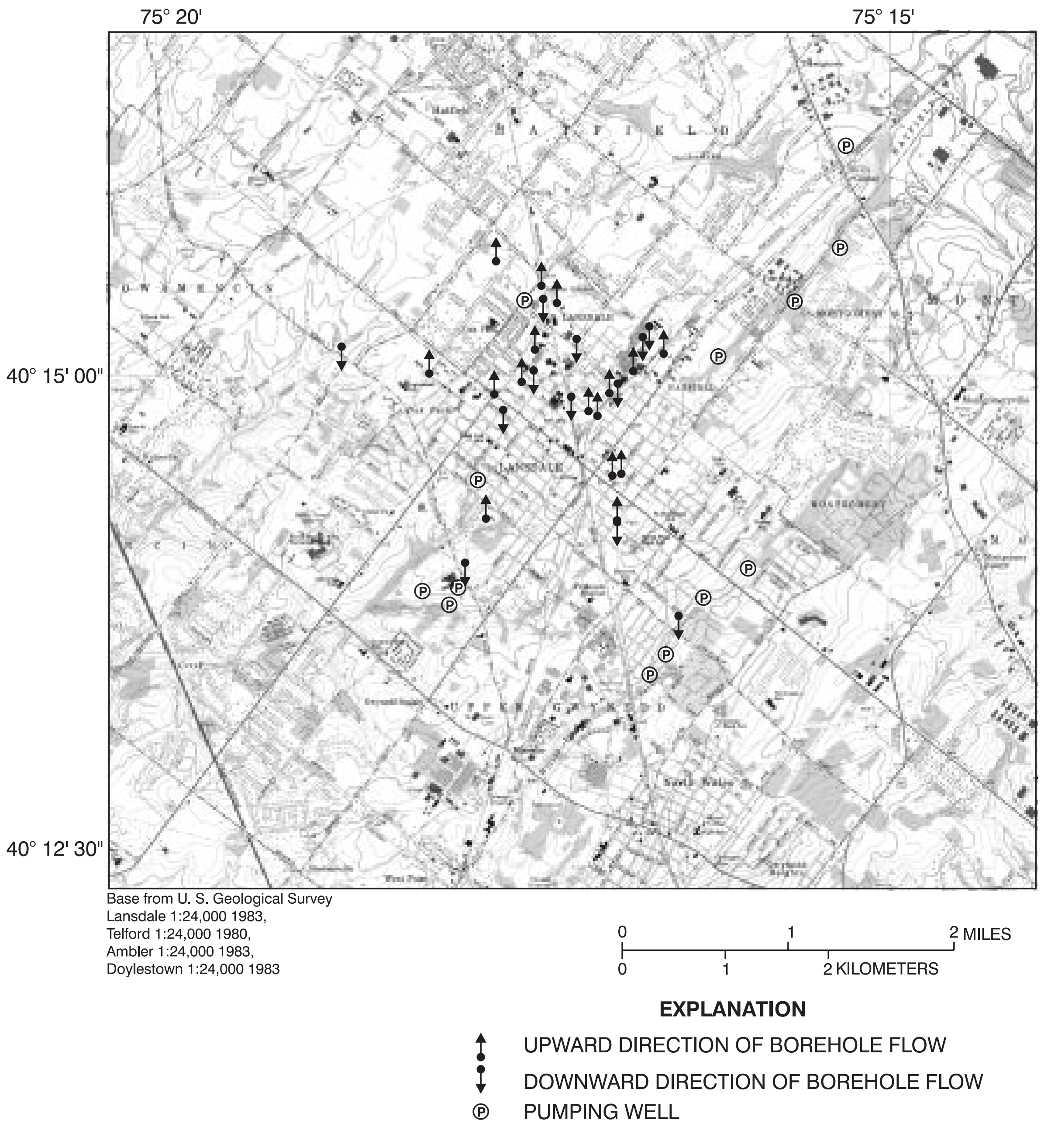


Figure 21. Directions of vertical flow measured in wells logged in and near Lansdale, Pa.

Upward flow open-hole wells in the central part of the study area in Lansdale appear to conflict with downward vertical gradients typically associated with a recharge area. The area of Lansdale borough is considered a recharge area because of its relatively high topographic position and because water levels there are higher than water levels down slope from the borough. However, because beds dip in the area, upward flow at the borehole scale is possible if the deep water-bearing zones within underlying beds have a higher head than the shallow zones within overlying beds, as a result of recharge at an up-dip and up-slope (topographic) location (fig. 22). Thus, in this conceptual model of the flow system, topography (difference in elevation) is an important factor in determining ground-water flow gradients. Ground-water flow in bedrock is primarily along bedding planes, and water-bearing zones within beds are separated by layers of less permeable aquifer material. Because depth to bedrock commonly is shallow, recharge through soil and saprolite enters fractured bedrock near the land surface. The resulting potentiometric head is related to land-surface altitude near the recharge area. Remnant bedding structures in the saprolite also may preferentially direct recharge down dip. Although the flow path may be complex, the net regional flow direction generally is down the regional topographic gradient. A schematic showing relation of topography, bedding, and potentiometric head indicates that the head at deeper water-producing bedding-plane fractures is higher than shallow water-producing bedding-plane fractures except at the shallowest fractures near the water table (fig. 22). In aquifer tests where discrete water-producing zones were isolated by packers, the shallowest water-producing zone in a well had a higher head than the second deepest zone, indicating a downward gradient that is consistent with the direction of recharge in shallow depths of the aquifer. The tests are discussed in detail in the section “Single-Well, Interval-Isolation Tests.”

Downward flow in many wells in and near Lansdale is associated with proximity to a deep pumping well that results in a decrease in potentiometric head in the area of influence of the pumping well. The greatest downward flow rate of 12 gal/min (45.4 L/min) was measured in well Mg-72 (pl. 1). This well is influenced by nearby pumping of public-supply wells along Wissahickon Creek. Although no flow tests were done, downward flow in another well, Mg-76 (pl. 1), was inferred from its location near pumping wells along Wissahickon Creek and the discrete inflections in the fluid-temperature log at probable water-bearing zones (Conger, 1999).

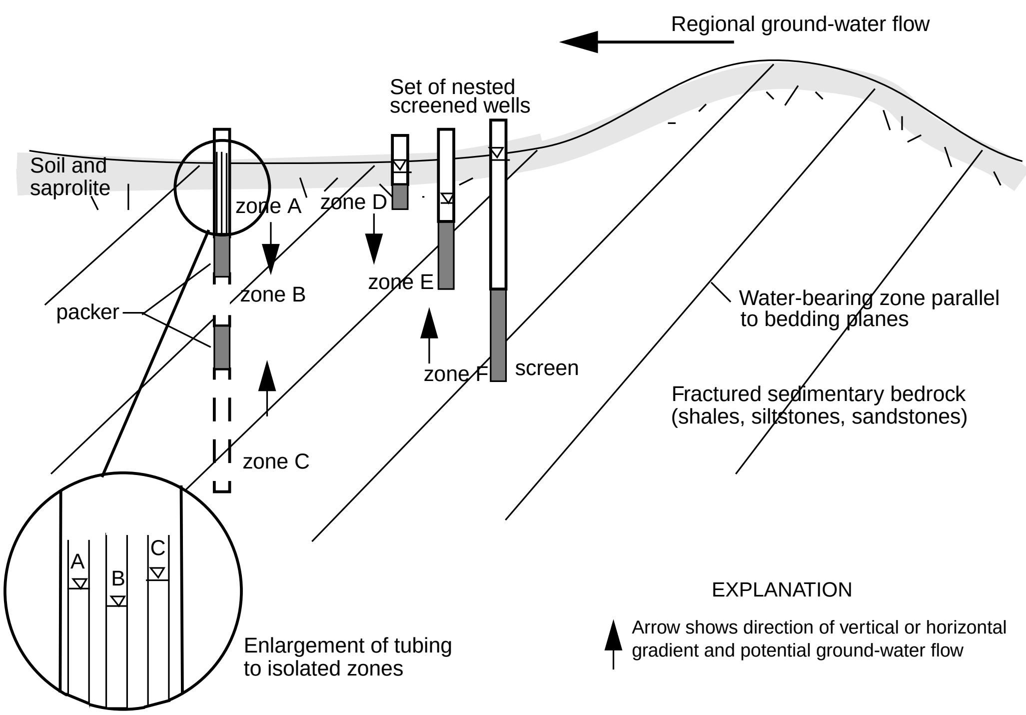


Figure 22. Conceptual ground-water flow system with wells open to different intervals in a fractured, sedimentary-rock aquifer with dipping beds.

Ground-Water/Surface-Water Relations

Streamflow is naturally composed of base flow and direct runoff. Anthropogenic withdrawals from and discharges to streams increase or decrease streamflow, respectively. Base flow is ground water discharged to streams. After rainfall or snowmelt, water of atmospheric origin that does not infiltrate or evaporate enters streams as direct runoff. Water that infiltrates is recharge. The proportion of streamflow that is base flow and direct runoff, as well as the relations between rainfall and runoff, depends on the hydrologic characteristics of a basin. Areas underlain by rocks with high permeability, such as carbonates, generally have more base flow and less direct runoff than areas underlain by rocks with low permeability, such as the Brunswick Group and Lockatong Formation (White and Sloto, 1990). Commonly, direct runoff of relatively high intensity is observed in small basins with steep slopes and low permeability soils and rocks compared to large basins with shallow slopes and high permeability rocks and soils. In urbanized areas, pavement or other impermeable land cover reduces natural infiltration and can increase the intensity and volume of direct runoff relative to undeveloped areas.

Base flow was measured seasonally at selected stream sites near Lansdale from spring 1995 through fall 1996 to provide an estimate of the quantity of ground water that discharges to streams (table 4, fig. 23). During this period,

Table 4. *Streamflow measured at five sites in and near Lansdale, Pa., May 1995 to November 1996 (See figure 24 for locations of sites.)*

[mi^2, square miles; ft^3/s, cubic feet per second; in., inches; --, no data]

Site number	Site location	Drainage area[1] (mi^2)	Streamflow, under base-flow conditions (ft^3/s) — Dates: 5-9-95	1-31-96 to 2-8-96	5-23-96	8-30-96	11-13-96	Estimated mean[3] in 1996	Estimated annual[2] base flow in 1996 (in.)
SW-3	Tributary to W. Branch Neshaminy Creek at Cowpath Rd. near Kulp School	2.38	1.39	6.58	2.93	2.13	3.38	3.8	21.4
	Tributary to W. Branch Neshaminy Creek at Cowpath Rd. near Kulp School, corrected for Lansdale sewage discharge[4]	2.38	[5]-.31	.55	[5]-.27	[5]-.34	.45	.28	1.6
SW-10	Tributary to W. Branch Neshaminy Creek at Cowpath and Line Rds.	1.10	dry	.106	.0085	dry[6]	.015	.03	.37
SW-13	Wissahickon Creek at Hancock St.		dry	.814	--	--	--	---	--
SW-13A	Wissahickon Creek at Wissahickon Ave.	2.45	--	--	.36	.07	.80	.51	3.2
SW-13A	Wissahickon Creek at Wissahickon Ave., corrected for industrial discharge[7]	2.45	--	--	--	--	--	[7].48	[7]3.0
SW-17	Towamencin Creek at Sumneytown Rd.	2.06	.27	.875	.78	.40	1.37	.86	6.6
SW-17	Towamencin Creek at Sumneytown Rd., corrected for industrial discharge[8]	2.06	--	--	--	--	--	[8].74	[8]5.7
SW-21	Tributary to Towamencin Creek at Troxell Rd.		.035	.306	--	--	--	--	--
SW-21A	Tributary to Towamencin Creek at Keeler Rd.	2.01		[9] .70	.53	.10	1.40	.68	4.6

[1] Drainage area, as determined from surface topography may differ from actual stream capture zone.

[2] Estimated annual base was flow calculated from the estimated mean base flow for the surface drainage area.

[3] Mean base flow was estimated from four seasonal measurements, assuming linear interpolation between measurements.

[4] Daily values of sewage-plant discharge for date of streamflow measurement were provided by Lansdale Borough Sewage Treatment plant.

[5] Negative values indicate that sewage plant discharge exceeds downstream streamflow; reach above site probably loses flow to ground water.

[6] Flow was very low to dry; too small to measure.

[7] Mean flow corrected by subtracting discharge of 20,500 gallons/day (260 days/year) from Precision Tube as reported to Pennsylvania Department of Environmental Protection (PADEP).

[8] Mean flow corrected by subtracting discharge of 77,600 gallons/day from Lehigh Valley Dairy as reported to PADEP.

[9] Estimated from sum of measurements at SW-21 and SW-20 (0.294 ft^3/s) and SW-22 (0.10 ft^3/s).

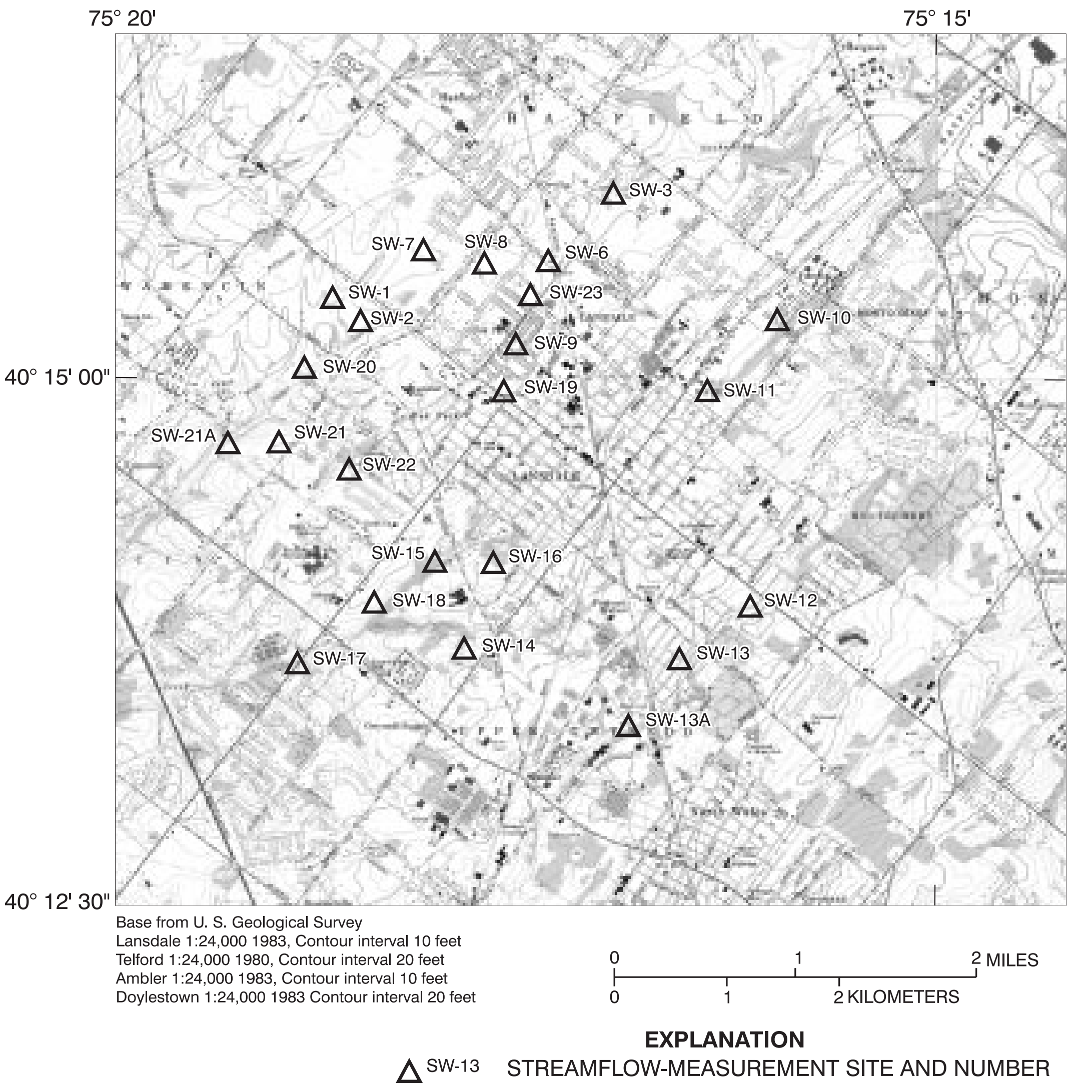


Figure 23. Location of streamflow-measurement sites in and near Lansdale, Pa.

some streams were dry, as a result of limited precipitation and lack of ground-water discharge. Estimated base-flow discharge to streams averaged about 3.2 in. (81 mm) over a 10-mi^2 (25.9-km^2) area of Lansdale in 1996. This amount of base flow represents only part of recharge to the area. Base flow is an estimate of recharge minus possible losses to ground-water pumping, ground-water evapotranspiration, ground-water underflow to adjacent basins, and change in storage.

During May 1995, base flow at 23 stream sites and discharge from 1 pipe outfall was measured to provide data on gains and losses to streams (table 5). Where stream losses are noted between measurement sites (table 5, fig. 23), streamwater has infiltrated along the intervening reach to the ground-water system. In these areas, the potentiometric head of the ground-water system is lower than the water surface in the stream. The accuracy of the streamflow measurements should be considered in evaluating apparent gains or losses. The measurement error is estimated to be up to 10 percent.

Table 5. *Streamflow at selected sites in and near Lansdale, Pa., under base-flow conditions, May 8-9, 1995, and during stormflow recession, May 10, 1995 (Site locations are shown on figure 23.)*

[ft^3/s, cubic feet per second; +, gain; -, loss; <, less than; µS/cm, microsiemens per centimeter; NA, not applicable]

Stream site	Method of measurement if other than standard[1]	Date	Discharge (ft^3/s)	Gain/Loss (ft^3/s)	Specific conductance (µS/cm)	Type of stream bottom
Tributary to Towamencin Creek						
SW-1		5-9-95	very low[2]	NA	NA	
SW-2		5-9-95	dry	NA	NA	
SW-20	Flume	5-9-95	0.30	+0.30	320	
SW-22	Flume	5-9-95	.015	NA	390	bedrock
SW-21	Flume	5-9-95	.035	+.02	460	bedrock
Towamencin Creek						
SW-16		5-10-95	.28	NA	258	rocky/bedrock
SW-15		5-10-95	.74	+.046	235	rocky/bedrock
SW-18	Flume	5-9-95[3]	.057	NA	500	rocky/bedrock
SW-14		5-10-95	.85	NA	175	bedrock
SW-17		5-9-95	.27	NA	825	silt/rocky/bedrock
SW-17 (repeat)		5-10-95	.85	+.74	270	silt/rocky/bedrock
Wissahickon Creek						
SW-12		5-9-95	very low	NA	NA	rocky
SW-13		5-9-95	dry	<-.001	NA	rocky
Tributary to W. Branch Neshaminy Creek near Line Rd.						
SW-11		5-9-95	very low	<-.001	NA	clay
SW-10		5-10-95	dry	NA	NA	rocky
Tributary to W. Branch Neshaminy Creek north of Moyers Rd.						
SW-19	Flume	5-8-95	.063	NA	410	rocky
SW-9	Flume	5-8-95	.09	+.027	455	gravel
pipe from JW Rex		5-8-95	.067	NA	800	NA
SW-23		5-8-95	.112	NA	700	rocky
SW-7		5-9-95	seep	NA	NA	clay
SW-8		5-9-95	dry	<-.001	NA	rocky
SW-6		5-8-95	2.34	[4]+2.10	850	silt/rocky
SW-3		5-8-95	1.39	-.95	770	silt/rocky
Other tributaries to W. Branch Neshaminy Creek south of Moyers Rd.						
SW-4		5-10-95	.025	NA	378	clay
SW-5		5-10-95	.051	NA	200	clay

[1] Standard method is based on measured flow velocities multiplied by cross-sectional area of stream channel.
[2] Very low flow was too small to measure.
[3] Discharges in Towamencin Creek from 5-9-95 and 5-10-95 cannot be directly compared because precipitation during the night of 5-9-95 resulted in a change in conditions from base flow to recessions after a storm.
[4] Discharge from the Lansdale Borough Sewage Treatment plant was estimated to range from 1.7 to 2.0 ft^3/d at the time flow measured at SW-6 below plant discharge point.

The ground-water and surface-water systems are not well connected throughout the area of Lansdale. In some parts of the study area, water levels in wells near streams are similar to stream levels, indicating good hydraulic connection. However, in several locations where deep observation wells were drilled adjacent to streams, the observed water level in the wells was either higher (well Mg-930) or lower (wells Mg-68, Mg-1124, and Mg-1126) than the observed stream level (pl. 1). Where ground-water levels are higher than the stream, there is potential for upward flow or discharge to the stream. Where ground-water levels are lower than the stream, there is potential for infiltration of water from the stream to the ground-water system. Ground-water levels near streams may be lowered by nearby pumping. The connection between the stream and the ground-water system is affected by the permeability of materials of the streambed. Low permeability clays and weathered bedrock can reduce ground-water discharge to streams and infiltration from the stream to the ground-water system. In the Lansdale area, streambed materials consist of fractured bedrock in parts of the Towamencin and Wissahickon Creeks and clay and silt in most tributaries to West Branch Neshaminy Creek and other parts of the Towamencin and Wissahickon Creeks. Where streams are underlain solely by unweathered fractured bedrock, the upper part of the bedrock aquifer and the surface-water system probably are in direct hydraulic connection. Water in the deep parts of the aquifer may not discharge to the shallow, small, headwater streams that originate in the area of Lansdale but rather travel down-gradient to discharge to larger streams or pass into other basins as underflow.

Ground-Water Quality

The chemical composition of ground water is derived from the weathering of minerals and biologically mediated reactions in soils and aquifer materials. The quality of ground water can be affected by the introduction of synthetic organic compounds and pollutants, such as in the area of Lansdale where VOC’s are ground-water contaminants (CH2MHill, 1991; Black & Veatch Waste Science, Inc., 1998). Chlorinated solvents PCE and TCE may degrade to VC by dehalogenation under reducing conditions (Bouwer and McCarty, 1983); VC may degrade to carbon dioxide under oxidizing conditions (McCarty and Semprini, 1994).

To assess general ground-water chemistry and determine the extent of reducing conditions favorable for degradation of chlorinated solvents, the USGS measured the water temperature, pH, specific conductance, alkalinity, and dissolved-oxygen concentration of water samples in the field during fall 1997. Measurements were made on water samples collected at a sampling port from pumping wells that were being sampled by USEPA’s contractor, B&V, for VOC’s and other constituents. The water temperature, pH, specific conductance, and alkalinity were measured by USGS by use of methods outlined in Wood (1976) and Wilde and Radtke (1998). Dissolved oxygen was measured by use of the azide modification of the Winkler titration method (American Public Health Association and others, 1976). The field analyses (tables 6 and 22) indicate that ground water in and near Lansdale generally has a near neutral pH and moderate alkalinity that probably represents dissolution of carbonate minerals in the Brunswick Group and Lockatong Formation. Many water samples were near saturation with respect to calcite, as calculated from calcium concentration, alkalinity, and pH. The median pH was 7.3, and the median alkalinity was 188 mg/L as $CaCO_3$ for wells sampled (table 6). Only two samples had alkalinity of less than 130 mg/L. Both samples were from shallow wells, suggesting that the water in the wells may have relatively short contact time with aquifer materials compared to water from deeper wells.

Table 6. *Summary of chemical properties or constituents measured in the field for water samples from selected wells in and near Lansdale, Pa., fall 1997*

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; <, less than; $CaCO_3$, calcium carbonate]

Chemical property or constituent	Units	Number of wells	Minimum	10th percentile	Median	90th percentile	Maximum
Water temperature	°C	[1] 92	12.0	13	14.5	16.3	21.8
pH	units	[1] 92	5.6	7.0	7.3	7.7	8.2
Specific conductance	µS/cm	93	330	420	610	750	1,240
Dissolved oxygen	mg/L	[2] 91	<.1	.4	2.0	5.5	9.2
Alkalinity	mg/L as $CaCO_3$	[3] 82	54	150	190	230	320

[1] Missing value for sample from one well.
[2] Missing values for samples from two wells.
[3] Missing values for samples from 10 wells.

A pH in the range of 5 to 9 is optimal for biodegradation of the chlorinated solvents (Wiedemeier and others, 1996, p. 2-22). All 39 wells sampled in the area of Lansdale in 1997 had water with a pH in the range of 5 to 9 (table 6). Alkalinity greater than twice the background alkalinity may indicate degradation of chlorinated solvents (Wiedemeier and others, 1996, p. 2-22). Background alkalinity is estimated to range from 150 to 200 mg/L as $CaCO_3$ in ground water in the Lansdale area.

The specific conductance, a measure of total dissolved ions, ranged between 333 and 1,286 µS/cm and was moderately correlated with alkalinity (r=0.6), suggesting that dissolved anions other than bicarbonate are present in ground water at concentrations large enough to affect conductance. These other anions include chloride, sulfate, and nitrate. In samples collected in fall 1997 (Black & Veatch Waste Science, Inc., 1998) from 39 (of 93) wells, concentrations of chloride ranged from about 5 to 196 mg/L, with a median of 49 mg/L; sulfate ranged from 17 to 193 mg/L, with a median of 38 mg/L; and nitrate concentrations ranged from less than 0.05 mg/L as N (reporting level) to 0.92 mg/L as N, with a median of 0.34 mg/L as N.

Chloride concentrations greater than twice the background concentration may indicate dechlorination of chlorinated solvents (Wiedemeier and others, 1996, p. 2-22). Chloride concentrations greater than 10 mg/L are greater than natural background, indicating an anthropogenic source of chloride. In the urbanized Lansdale area, almost all water samples contained more than 10 mg/L chloride, but determination of background chloride concentrations is difficult because of the several possible sources. Chloride can be introduced into the ground water by road salting, leaking sewage lines, septic systems, or by degradation (dehalogenation) of chlorinated organic solvents such as PCE and TCE. Sulfate concentrations less than 20 mg/L and nitrate concentrations less than 0.5 mg/L as N are thought to be consistent with reducing conditions favorable for degradation of chlorinated solvents (Wiedemeier and others, 1996, p. 2-22). Although most water from 39 wells sampled in 1997 in the Lansdale area contained less than 0.5 mg/L as N nitrate, most water samples also contained more than 20 mg/L sulfate.

Concentrations of dissolved oxygen ranged from less than 0.1 mg/L (reporting level) to 9.2 mg/L; the median concentration was 2 mg/L. The generally low but detectable concentrations of dissolved oxygen measured in well samples indicate some persistence of oxygen in ground water through the recharge process. Where dissolved oxygen is present near saturation concentrations of about 11 mg/L at 12°C (American Public Health Association and others, 1976, p. 446), there is rapid recharge and (or) lack of oxidation reactions along the recharge path. Generally, where dissolved oxygen is absent or is present at low concentrations, recharge is slow and (or) oxidation reactions along the recharge path or in the ground-water system are active. Reactions that consume oxygen include oxidation of natural and synthetic organic compounds; these reactions may be biologically mediated. Wiedemeier and others (1996, p. 2-22) have proposed that oxygen concentrations less than 0.5 mg/L indicate reducing conditions favorable for degradation of chlorinated solvents. About 18 percent (16 of 91) of the wells sampled in 1997 by B&V yielded water that contained concentrations less than or equal to 0.5 mg/L dissolved oxygen, and most of these wells (11) were in an area from 3rd to 9th Sts., west of Cannon St. in the northwestern part of Lansdale Borough (table 22, pl. 1). VC and cis-1,2-DCE, products of TCE and PCE degradation, also were measured in ground water in this area. The low concentrations of dissolved oxygen and detection of cis-1,2-DCE and VC in this area suggest past or ongoing degradation of chlorinated solvents.