HYDROGEOLOGIC SETTING

The study area in and near Lansdale is in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province. The North Penn Area 6 site and surrounding area are underlain by sedimentary rocks of the Lockatong Formation and lower beds of the Brunswick Group of the Newark Supergroup (Lyttle and Epstein, 1987) (fig. 2). Sediments of the Newark Supergroup were deposited in a rift basin during the Triassic age (260 million years ago). Following deposition, sediments in the Newark Basin were buried, compacted, and faulted. Commonly, the Lockatong Formation is relatively resistant to erosion and tends to form ridges that rise above flat or rolling topography underlain by rocks of the Brunswick Group. Lansdale and the North Penn Area 6 site are underlain mostly by rocks of the Brunswick Group and are on relatively flat upland terrain that is a surface-water divide between Wissahickon Creek to the south, Towamencin Creek to the west, and tributaries to the West Branch Neshaminy Creek to the north and northeast (figs. 1 and 2).

Geology

The Lockatong Formation consists of detrital sequences (cycles) of gray to black calcareous shale and siltstone, with some pyrite, and chemical sequences (cycles) of gray to black dolomitic siltstone and marlstone with lenses of pyritic limestone, overlain by massive gray to red siltstone with analcime (Lyttle and Epstein, 1987). Interbeds of reddish-brown, sandy siltstone have been mapped in the Lockatong Formation south of Lansdale (Lyttle and Epstein, 1987). The Lockatong Formation overlies the Stockton Formation, which consists of gray to reddish-brown sandstones, shales, and siltstones. Contacts between the Lockatong Formation and the overlying Brunswick Group are conformable and gradational, and the two formations may interfinger (Lyttle and Epstein, 1987). The lower beds of the Brunswick Group consist predominantly of homogeneous, soft, red to reddish-brown and gray to greenish-gray mudstones and clay- and mud-shales, with some fine-grained sandstones and siltstones. Some beds are micaceous. Bedding is irregular and wavy. Interbedded silt-shales and siltstones are moderately well sorted. The Brunswick Group rocks contain detrital cycles of medium- to dark-gray and olive- to greenish-gray, thin-bedded and evenly bedded shale and siltstone, similar to the underlying Lockatong Formation. Red-brown shale, red-brown sandstone, and gray shale are the most frequently reported rock types in drillers' logs for monitor wells drilled in 1997 in Lansdale (Black & Veatch Waste Science, Inc., written commun., 1997).

Bedding in the Newark Basin generally strikes northeast and dips to the northwest. The regional homoclinal dip has been cut by normal and strike-slip faults and warped by transverse folds (Schlische, 1992). Many faults with small displacements have not been mapped. The beds of the Brunswick Group and Lockatong Formation generally strike northeast and dip shallowly to the northwest in the vicinity of the North Penn Area 6 site; strike gradually shifts from northeast in central Lansdale to east-northeast in the area south of Lansdale near Upper Gwynedd Township (fig. 2) (Longwill and Wood, 1965). Thin shale marker beds in the Brunswick Group identified by elevated natural-gamma activity on geophysical logs can be correlated over distances of 1,000 ft [300 m (meters)] or more. High natural-gamma activity typically is associated with thin gray shale beds. Correlation of natural-gamma activity in logs collected by USGS in and near Lansdale shows that these shale beds strike 48° to 60° northeast and dip 6° to 30° northwest; the average dip is about 11° (Conger, 1999).

Ground-Water System

Ground water in the rocks underlying Lansdale and the North Penn Area 6 site originates from infiltration of precipitation. After infiltrating through soil and saprolite (extensively weathered rock), ground water moves through fractures and openings 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. The degree of hydraulic connection between the layers varies. 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.

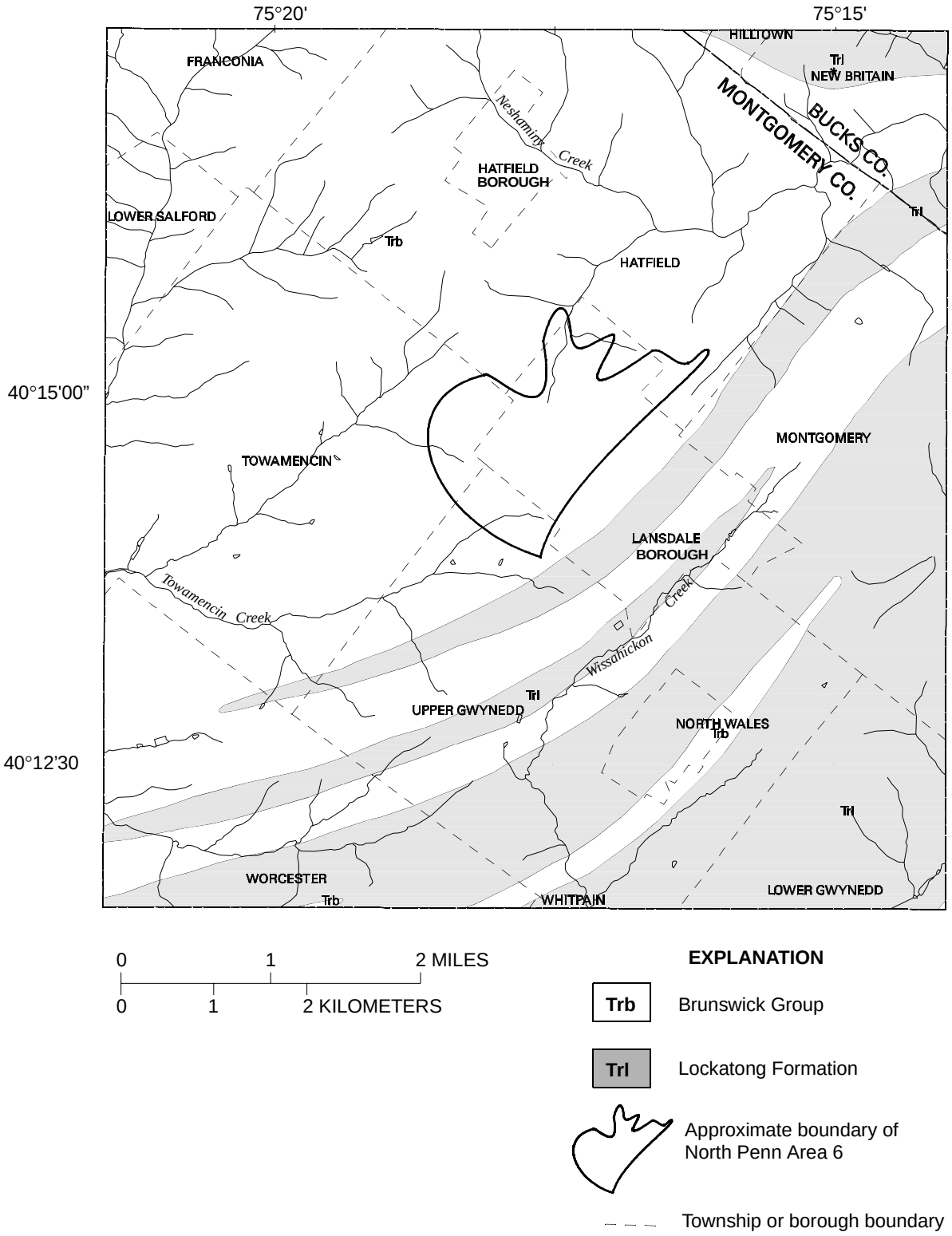

Figure 2.-- Bedrock geology in area of Lansdale, Pa.

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. Reported estimates of recharge 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). Senior and Goode (1999) estimated a recharge rate of 8.3 in / yr (212 mm / yr) in the Lansdale area by calibration of a regional ground-water-flow model using measured hydraulic heads and streamflow. 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.

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 ground-water-flow system. Shallow and deep 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. Pumping from deep zones may induce downward flow from shallow zones. 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 probably is thin and is difficult to delineate. In some areas, perched water is present at shallow depths [less than 50 ft (15 m)]. Water in the deeper part of the aquifer generally is confined or partially confined, resulting in artesian conditions.

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. 3).

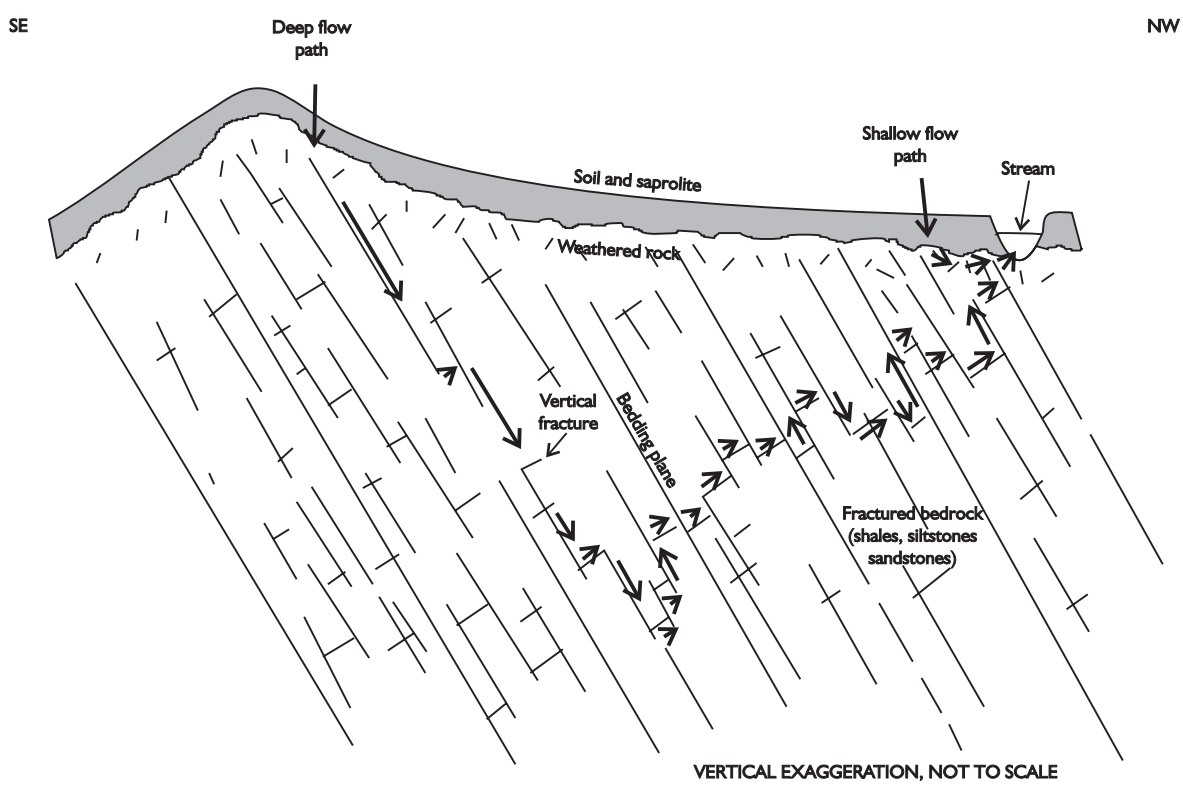

Figure 3.-- Schematic of conceptual model of ground-water-flow system for fractured sedimentary rock aquifer with dipping beds.

Regional ground-water flow in the area of Lansdale, Pa., was simulated using the porous-media model MODFLOW and calibrated using MODFLOWP for steady-state conditions (Senior and Goode, 1999). All recharge entering the top surface of the model area was assumed to discharge to wells or streams. Streams and topographic divides were assumed to form no-flow boundary conditions for the model (fig. 4). The model was configured with three vertical layers and two horizontal zones and a horizontal grid with uniform cell size of 328 ft x 328 ft (100 m x 100 m). The top layer of the 3-layer model represented weathered rock and soil, was 40-ft (13-m) thick, and was assumed to be isotropic and homogeneous. The bottom two layers of the model represented unweathered fractured rock, were each 328-ft (100-m) thick, and were assumed to be anisotropic with highest hydraulic conductivity (K) in the strike direction. Two zones of different hydraulic conductivity (K) were used for parts of the aquifer dominated by rocks of the Brunswick Group, in one zone, and the Lockatong Formation in the other. Senior and Goode (1999) assumed the regional-scale ground-water flow in the fractures could be modeled approximately using the porous-media model. In this model, the K values used represent the regional-scale effective properties of the bulk aquifer. Local-scale flow dominated by high-K zones within the aquifer could not be simulated in detail with this model.

Calibration of the regional model to 1996 conditions yielded estimates of the regional-scale K of the formations (table 1; Senior and Goode, 1999). The transmissivity of the weathered zone (layer 1) was estimated as 0.16 ft / d (hydraulic conductivity) x 40 ft (layer thickness) = 6.4 ft^2 / d (0.59 m^2 / d). The transmissivity of the underlying Brunswick Group (layers 2 and 3) in the strike direction was estimated as 5.35 ft / d x 656 ft = 3,510 ft^2 / d (326 m^2 / d). The transmissivity of the Brunswick Group in the dip direction was estimated as 3,510 ft^2 / d x 0.090 = 316 ft^2 / d (29 m^2 / d). The geometric mean (square root of the product) of the directional transmissivities corresponds to the “effective” isotropic transmissivity controlling drawdown due to pumping (Kruseman and de Ridder, 1990, p. 134). For the Brunswick Group, the geometric mean transmissivity was about 1,050 ft^2 / d (97 m^2 / d). The transmissivity of the unweathered part of the Lockatong Formation (in layers 2 and 3) was similarly estimated as 732 ft^2 / d (68 m^2 / d) in the strike direction and 64 ft^2 / d (6 m^2 / d) in the dip direction; the geometric mean was 215 ft^2 / d (20 m^2 / d). Most of the water moving horizontally through the model did so in layers 2 and 3, which represent unweathered fractured rock. The transmissivity of the zone representing the Brunswick Group was higher than that of the Lockatong Formation zone.

Table 1.-- Optimum and approximate, individual, 95-percent confidence-interval values for hydraulic conductivity, anisotropy ratio, and recharge for calibrated simulation of ground-water flow in and near Lansdale, Pa.

[K, hydraulic conductivity; ft / d, feet per day; -, dimensionless; in. / yr, inches per year]

Parameter	(units)	Optimum value	Approximate, individual, 95-percent confidence interval	
			lower value	upper value
K - Brunswick Group[1]	(ft/d)	[2]5.35	4.04	7.05
K - Lockatong Formation[1]	(ft/d)	[2]1.12	0.89	1.40
K - weathered zone[3]	(ft/d)	0.16	0.01	2.00
Anisotropy ratio of bedrock[4]	-	0.090	0.060	0.119
Recharge	(in./yr)	8.3	7.9	8.8

[1] Model layers 2 and 3 representing unweathered bedrock.
[2] In strike direction of model layers 2 and 3.
[3] Model layer 1 representing soil and saprolite.
[4] K(across strike)/K(along strike) for model layers 2 and 3.

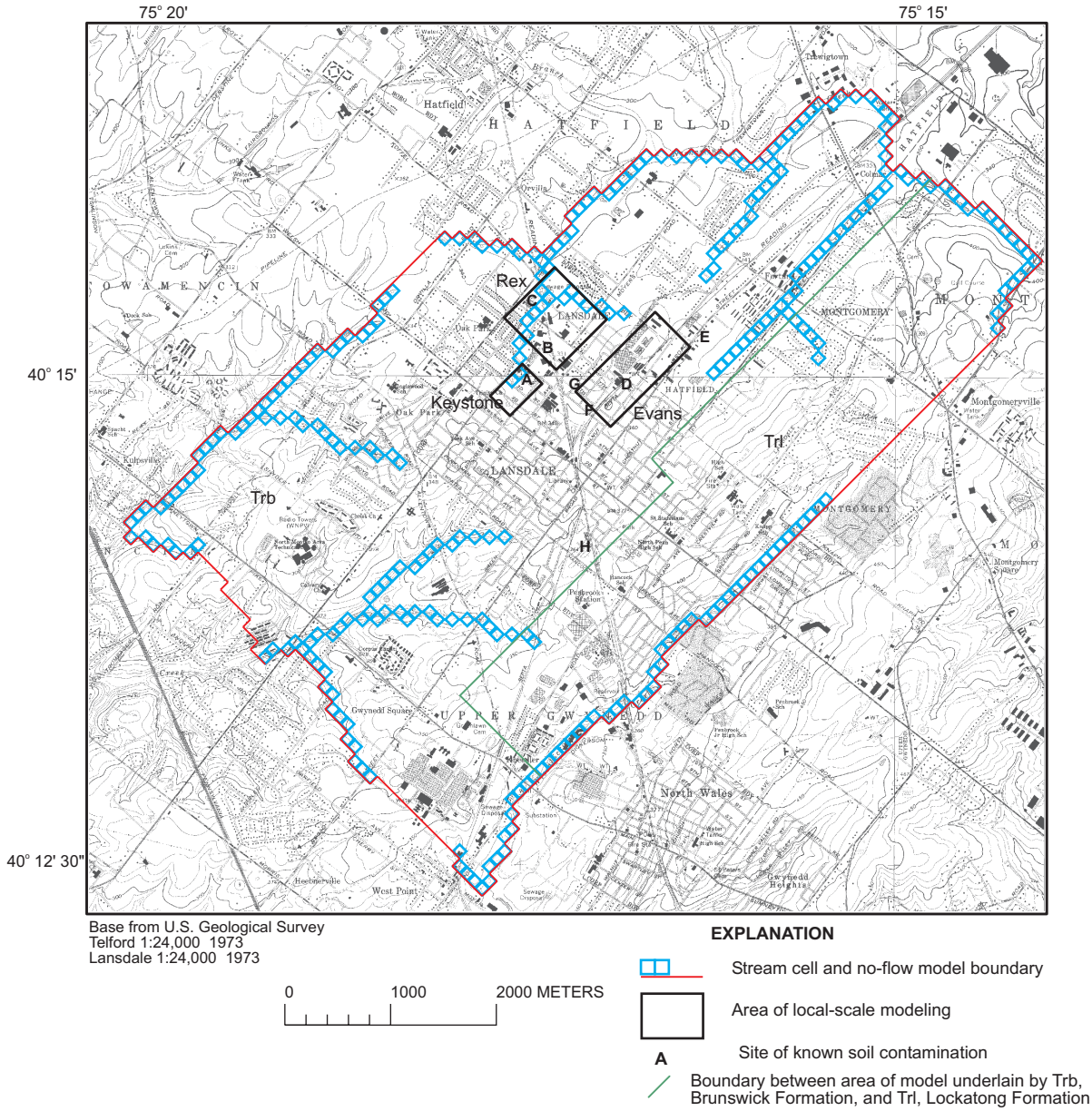

Figure 4.-- Boundaries and stream cells of regional-scale ground-water-flow model grid and areas of local-scale models at the John Evans and Sons property (Evans) in north-central Lansdale and at the Keystone Hydraulics property (Keystone) and the J.W. Rex Co. property (Rex) in northwestern Lansdale, Pa. Also shown are selected areas of soil contamination and the parts of the model area underlain by the Lockatong Formation (Trl) and Brunswick Group (Trb) (modified from Senior and Goode, 1999).

The calibrated flow model was used to simulate ground-water flow and hydraulic heads under three scenarios with different pumping conditions. It was assumed that the flow in a semi-confined aquifer system responds relatively quickly to changes in pumping rates; hence, a steady-state model was used. The first scenario, with no pumping, represents unstressed ground-water conditions with all recharge to the saturated zone discharging to streams as base flow. The second scenario, year 1994, represents periods with high pumping rates in the Lansdale area. The third scenario, year 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 North Penn Water Authority (NPWA), and several industrial wells were shut down due to plant closure. Overall pumping was a smaller fraction of average recharge (average ground-water discharge) in 1997 than in 1994 (Senior and Goode, 1999). Average recharge estimated for the 1996 calibration period was 8.3 in./yr (inches per year).

Particle tracking using MODPATH (Pollock, 1994) illustrates the paths of ground-water flow simulated by the regional flow model (fig. 5, Senior and Goode, 1999). On the basis of calibrated anisotropic transmissivities and vertical hydraulic conductivity and the computed three-dimensional hydraulic gradients, water particles were tracked through the flow system from recharge to discharge locations in streams or wells from eight areas of known soil contamination in and near Lansdale (table 2). The particle paths are skewed toward the direction of highest transmissivity (strike of the sedimentary beds), reflecting a regional anisotropy ratio of about 11 to 1.Hydraulic head in model layer 2 and recharge contributing areas for the 1997 simulation are shown in figure 5 (Senior and Goode, 1999).

Table 2.-- Selected sites and primary 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.

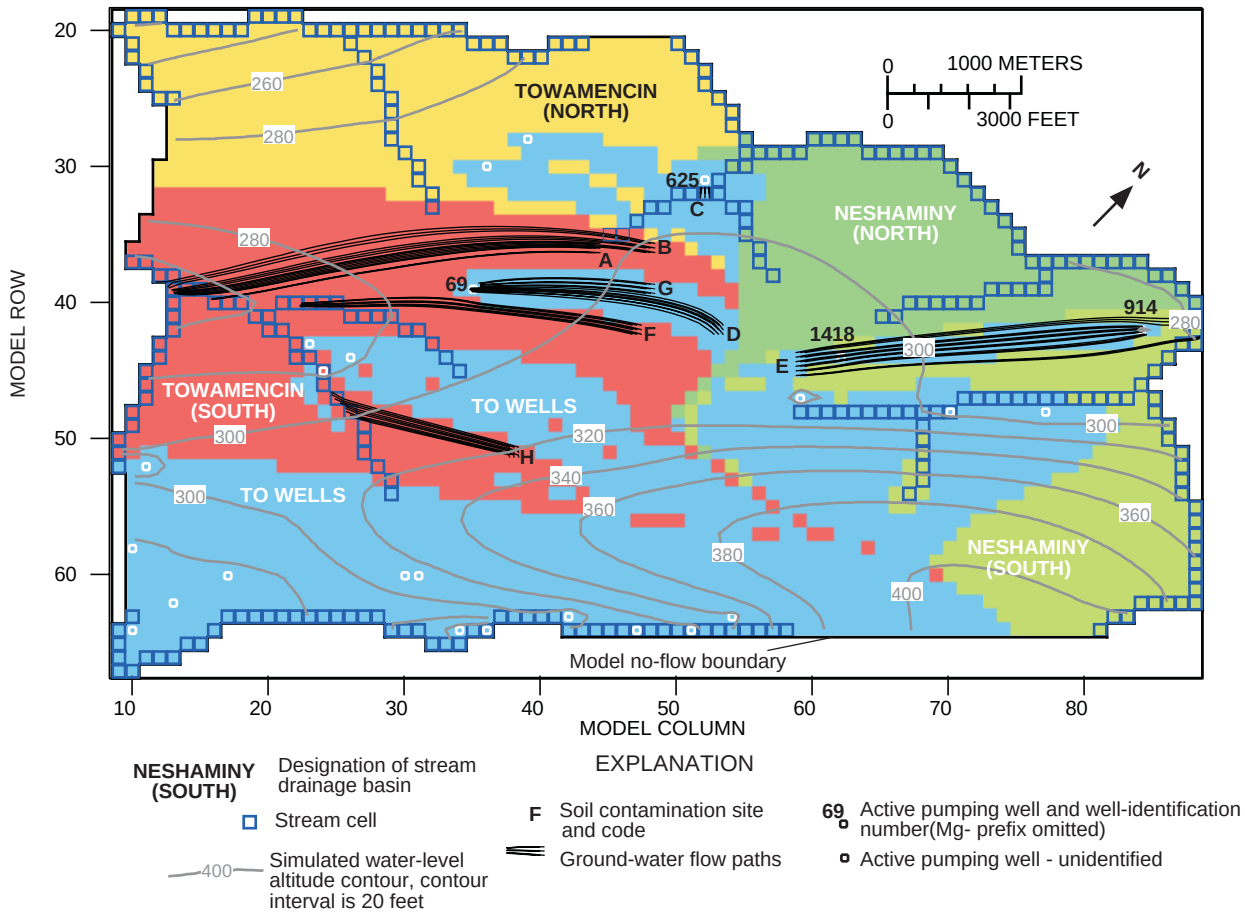

Figure 5.-- Simulated hydraulic head in model layer 2, which represents the upper 328 feet of unweathered, fractured bedrock, and stream and well contributing areas in Lansdale and vicinity for 1997 conditions (modified from Senior and Goode, 1999). Simulated recharge within a colored contributing area discharges to the indicated stream or pumping wells.