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Ground-Water System, Estimation of Aquifer Hydraulic Properties, and Effects of Pumping on Ground-Water Flow in Triassic Sedimentary Rocks in and near Lansdale, Pennsylvania

by Lisa A. Senior and Daniel J. Goode

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
	Temperature	
degree Fahrenheit (°F)	$°C = 5/9 \times (°F - 32)$	degree Celsius

Other Abbreviations

µg/L micrograms per liter

mg/L milligrams per liter

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.

GROUND-WATER SYSTEM, ESTIMATION OF AQUIFER HYDRAULIC PROPERTIES, AND EFFECTS OF PUMPING ON GROUND-WATER FLOW IN TRIASSIC SEDIMENTARY ROCKS IN AND NEAR LANSDALE, PENNSYLVANIA

by Lisa A. Senior and Daniel J. Goode

ABSTRACT

Ground water in Triassic-age sedimentary fractured-rock aquifers in the area of Lansdale, Pa., is used as drinking water and for industrial supply. In 1979, ground water in the Lansdale area was found to be contaminated with trichloroethylene, tetrachloroethylene, and other man-made organic compounds, and in 1989, the area was placed on the U.S. Environmental Protection Agency's (USEPA) National Priority List as the North Penn Area 6 site. To assist the USEPA in the hydrogeological assessment of the site, the U.S. Geological Survey began a study in 1995 to describe the ground-water system and to determine the effects of changes in the well pumping patterns on the direction of ground-water flow in the Lansdale area. This determination is based on hydrologic and geophysical data collected from 1995-98 and on results of the simulation of the regional ground-water-flow system by use of a numerical model.

Correlation of natural-gamma logs indicate that the sedimentary rock beds strike generally northeast and dip at angles less than 30 degrees to the northwest. The ground-water system is confined or semi-confined, even at shallow depths; depth to bedrock commonly is less than 20 feet (6 meters); and depth to water commonly is about 15 to 60 feet (5 to 18 meters) below land surface. Single-well, aquifer-interval-isolation (packer) tests indicate that vertical permeability of the sedimentary rocks is low. Multiple-well aquifer tests indicate that the system is heterogeneous and that flow appears primarily in discrete zones parallel to bedding. Preferred horizontal flow along strike was not observed in the aquifer tests for wells open to the pumped interval. Water levels in wells that are open to the pumped interval, as projected along the dipping stratigraphy, are drawn down more than water levels in wells that do not intersect the pumped interval. A regional potentiometric map based on measured water levels indicates that ground water flows from Lansdale towards discharge areas in three drainages, the Wissahickon, Towamencin, and Neshaminy Creeks.

Ground-water flow was simulated for different pumping patterns representing past and current conditions. The three-dimensional numerical flow model (MODFLOW) was automatically calibrated by use of a parameter estimation program (MODFLOWP). Steady-state conditions were assumed for the calibration period of 1996. Model calibration indicates that estimated recharge is 8.2 inches (208 millimeters) and the regional anisotropy ratio for the sedimentary-rock aquifer is about 11 to 1, with permeability greatest along strike. The regional anisotropy is caused by up- and down-dip termination of high-permeability bed-oriented features, which were not explicitly simulated in the regional-scale model. The calibrated flow model was used to compare flow directions and capture zones in Lansdale for conditions corresponding to relatively high pumping rates in 1994 and to lower pumping rates in 1997. Comparison of the 1994 and 1997 simulations indicates that wells pumped at the lower 1997 rates captured less ground water from known sites of contamination than wells pumped at the 1994 rates. Ground-water flow rates away from Lansdale increased as pumpage decreased in 1997.

A preliminary evaluation of the relation between ground-water chemistry and conditions favorable for the degradation of chlorinated solvents was based on measurements of dissolved-oxygen concentration and other chemical constituents in water samples from 92 wells. About 18 percent of the samples contained less than or equal to 5 milligrams per liter dissolved oxygen, a concentration that indicates reducing conditions favorable for degradation of chlorinated solvents.

SUMMARY AND CONCLUSIONS

Ground water in the area of Lansdale, Pa., is used for drinking water and for industrial and commercial supply, and is known to be contaminated with volatile organic compounds that were used at several industrial facilities. An area in Lansdale and vicinity was placed on the National Priority List by the USEPA and is designated the North Penn Area 6 site. The USGS provided technical assistance to USEPA through this study to describe the ground-water flow system and evaluate the effects of changes in the well pumpage on ground-water flow directions as wells shut down in Lansdale during the 1990’s. The USGS collected hydrologic data from 1995 to 1998 to characterize the ground-water flow system. These data included water-level and streamflow measurements, geophysical logs, selected chemical measurements of ground-water samples, and water-level response to pumping during aquifer tests. Using these data, a conceptual model of the ground-water system was developed and ground-water flow under various pumping scenarios was simulated.

The Lansdale area is underlain by Triassic-age fractured shales, siltstones, and sandstones of the Brunswick Group and Lockatong Formation. These rocks generally strike northeast and dip at angles less than 30 degrees to the northwest, as indicated by correlation of natural-gamma logs and in agreement with reported attitudes in literature. The Borough of Lansdale is on an upland area that forms a divide between three streams—Towamencin Creek to the southwest, Wissahickon Creek to the southeast, and Neshaminy Creek to the north. The bedrock aquifer is recharged by precipitation. Except perhaps at very shallow depths [less than 50 ft (15 m)], most of the aquifer is under confined or semi-confined conditions.

Water levels were measured near-continuously at seven wells from fall 1995 to spring 1998. Water levels were observed to respond to earth tides and changes in barometric pressure. Water levels generally declined in 1995 and 1997, years with less-than-normal precipitation, and rose in 1996, a year with greater-than-normal precipitation. Water levels in 100- to 500-ft (30.5- to 152-m) deep wells distributed throughout the area were measured in August 22-23, 1996, and January 12-13, 1998, to estimate the potentiometric surface of the bedrock aquifer in the region. The potentiometric surface estimated from these levels reflects land-surface topography, although the ground-water divide lies north of the topographic divide in the Borough of Lansdale.

Streamflow was measured periodically at five sites during 1995-96 to provide an estimate of annual base flow. The amount of annual recharge that discharged to streams averaged about 3.2 in. (81 mm) over a 10-mi^2 (25.9-km^2) area of Lansdale in 1996. Streamflow measurements at about 20 sites in May 1995 indicated the upper reaches of Wissahickon Creek and a tributary to West Branch Neshaminy Creek were dry, discharge from the Lansdale sewage treatment plant contributed most of the flow in another tributary to West Branch Neshaminy Creek, and Towamencin Creek has a higher base flow relative to the surface-drainage area than the other streams.

Geophysical logs were run in 31 observation, industrial, water supply, and commercial wells and 27 monitor wells newly drilled in 1997 to determine distribution of water-bearing zones, directions of borehole flow, attitude of beds from stratigraphic correlation of natural-gamma logs, and attitude of water-bearing fractures. Wells ranged in depth from 49 to 1,027 ft (14.9 to 313 m). Water-bearing zones were most frequently detected in the interval from 50 to 300 ft (15 to 91.4 m) below land surface. Upward flow under nonpumping conditions was measured in 35 of 58 wells. Downward flow was measured in 11 wells and inferred in 1 well, and many of these were near pumping wells. Upward and downward flow was measured in three wells. No flow was detected in eight wells. Many water-bearing fractures were oriented in attitudes similar to that of bedding, which generally strikes to the northeast and dips to the northwest in the area.

Single-well, aquifer-interval-isolation tests (packer tests) were done by USGS at three wells in spring 1997 in Lansdale. The aquifer-interval-isolation tests indicate discrete water-bearing openings generally are not well connected in the vertical direction. Evidence for limited vertical hydraulic connection between water-bearing openings includes differences in static potentiometric head up to 15 ft (46 m) over 300 vertical ft (91 m) and typically small drawdown in zones adjacent to the isolated pumped zone. Estimated values for transmissivity (T) ranged from 0.54 to 240 ft^2/d (0.05 to 22 m^2/d) for tests of isolated intervals and ranged up to two orders of magnitude within a single well. No relation between depth and specific capacity or estimated transmissivity was noted in the results of tests of isolated zones in the three wells. The chemical composition of water from isolated intervals generally differed at least slightly. In tests of two of three wells, concentrations of manmade VOC’s were highest in the shallowest zones tested.

Multiple-well aquifer tests were done at three sites in fall 1997. Effects of heterogeneity and limited vertical permeability were observed in all tests. The variability of the extent of response to pumping at all three sites underscores the heterogeneity of three-dimensional hydraulic conductivity in the fractured-rock formations. Estimated values of transmissivity determined from analyses of multiple-well tests, assuming isotropic radial flow, ranged from 210 to 2,300 ft^2/d (20 to 210 m^2/d). For analyses considering anisotropic response, a 20-fold difference was determined in directional transmissivity. The maximum transmissivity was 10,700 ft^2/d (990 m^2/d) in the dip direction and the minimum transmissivity was 520 ft^2/d (48 m^2/d) in the strike direction. Preferred horizontal flow in the strike direction was not observed for these tests because analyses were limited to wells open to pumped intervals, as projected along bedding. These results are consistent with a multiple-aquifer conceptual model of the ground-water system in which flow is primarily in zones oriented parallel to the dipping bedding.

Ground-water flow under steady-state conditions was simulated by use of a numerical model (MODFLOW). The model was oriented parallel to regional strike and consisted of three layers to represent saprolite and weathered rock near the surface and intermediate and deep zones of unweathered rock. The hydraulic properties of the model were subdivided laterally on the basis of geologic mapping of the Lockatong Formation and Brunswick Group. The model was calibrated against measured water levels (1996) and base flow estimated from seasonal measurements (1995-96) by use of a parameter-estimation program (MODFLOWP). Calibration yielded a regional anisotropy ratio of 11 to 1; preferred permeability was in the strike direction. Calibrated values were 8.3 in. (212 mm) for recharge, 5.35, 1.12, and 0.16 ft/d (1.63, 0.34, and 0.049 m/d) for the maximum hydraulic conductivity of the Brunswick Group, Lockatong Formation, and weathered layer, respectively. Discharge was much greater to the Towamencin Creek than to the West Branch Neshaminy and Wissahickon Creeks.

The calibrated ground-water flow model was used to simulate ground-water flow during periods of relatively high pumpage (1994) and relatively low pumpage (1997). Ground-water flowpaths originating from recharge near known areas of soil contamination were simulated. Pumping public-supply well Mg-67 (NPWA well L-8) and industrial wells Mg-153, Mg-620, Mg-621, and Mg-1045 captured ground water from several of these sources in the 1994 scenario. Because pumping at these wells ceased by 1997, ground water from those sources were no longer captured at those wells. Greater amounts of contaminated ground water moved away from Lansdale to surrounding areas under pumping conditions in 1997 than in 1994. Relatively small changes in the uncertain hydraulic properties of the model will result in changes in the simulated discharge paths of ground water from source areas.

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