Analysis of Selected Geophysical Logs at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania

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Abstract

The U.S. Geological Survey (USGS), as part of technical assistance to the U.S. Environmental Protection Agency (USEPA), collected borehole geophysical log data in 34 industrial, commercial, and public supply wells and 28 monitor wells at the North Penn Area 6 Superfund Site, in Lansdale, Pa., from August 22, 1995, through August 29, 1997. The wells range in depth from 50 to 1,027 feet below land surface and are drilled in Triassic-age shales and siltstones of the Brunswick Group and Lockatong Formation. The geophysical log data were collected to help describe the hydrogeologic framework in the area and to provide guidance in the reconstruction of the 28 monitor wells drilled during summer 1997. At the time of logging, all wells had open-hole construction.

The geophysical logs, caliper, fluid-resistivity, and fluid-temperature, and borehole video logs were used to determine the vertical distribution of water-bearing fractures. Heatpulse-flowmeter measurements were used to determine vertical borehole flow under pumping and nonpumping conditions. The most productive fractures generally could be determined from heatpulse-flowmeter measurements under pumping conditions. Vertical borehole flow was measured under nonpumping conditions in most wells that had more than one water-bearing fracture. Upward flow was measured in 35 wells and probably is a result of natural head differences between fractures in the local ground-water-flow system. Downward flow was measured in 11 wells and commonly indicated differences in hydraulic heads of the fractures caused by nearby pumping. Both upward and downward flow was measured in three wells. No flow was detected in eight wells.

Natural-gamma-ray logs were used to estimate the attitude of bedding. Thin shale marker beds, shown as spikes of elevated radioactivity in the natural-gamma logs of some wells throughout the area, enable the determination of bedding-plane orientation from three-point correlations. Generally, the marker beds in and near Lansdale strike about N. 48°-60° E. and dip about 11° NW. Acoustic televiewer logs run in selected boreholes indicate that the attitude of many water-bearing fractures commonly is similar to that of bedding.

Introduction

Ground water at the North Penn Area 6 (NP6) Superfund Site is contaminated with organic solvents. The site covers about 3 mi^2 in and near Lansdale, Montgomery County, Pa., and includes at least six properties identified as potential sources of contamination (Black and Veatch, 1994). The location of the 62 production-type and monitor wells logged at the site are shown in figure 1. Some industries in the area have been operating since the 1940's, whereas others began operations as late as the 1980's (Black and Veatch, 1994). Various solvents, degreasers, and other types of organic compounds—such as trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), and tetrachloroethylene (PCE)—and metals were used by these industries (CH2MHill, 1991).

In 1979, TCE was measured in concentrations greater than 4.5 micrograms per liter (ug/L) in eight North Penn Water Authority (NPWA) public supply wells in the Lansdale area (Black and Veatch, 1994). This concentration nearly exceeds the U.S. Environmental Protection Agency's (USEPA) maximum contaminant level (MCL) in drinking water of 5 ug/L (U.S. Environmental Protection Agency, 1994). In 1986, the USEPA Region III requested water-use information from 17 industries in the area, and numerous residential wells were sampled. The NP6 was placed on the National Priority List (NPL) in March 1989. Results of environmental investigations by property owners, the Pennsylvania Department of Environmental Protection (PADEP), and by USEPA and its contractors confirmed that the ground water beneath the Borough of Lansdale is contaminated with volatile organic compounds (VOC's). Concentrations of TCE as great as 9,240 ug/L were measured in water samples from municipal public supply wells, and VOC's also were detected in samples from industrial and domestic wells and in samples from a tributary to West Branch Neshaminy Creek (CH2MHill, 1991). A

Remedial Investigation/Feasibility Study (RI/FS) was initiated by the USEPA and its contractors in 1991.

The USGS provided technical assistance to the USEPA in the RI/FS. That assistance included the collection and analysis of borehole-geophysical data at existing industrial, commercial, and public-supply wells, and at and near the NP6 Superfund Site from August 1995 to August 1997. Caliper, natural-gamma, single-point-resistance, fluid-resistivity, fluid-temperature, and borehole-flow (heatpulse-flowmeter) logs were collected in most boreholes. Borehole video logs were collected in 19 boreholes. The purpose of the analysis of geophysical logs and video logs was to help describe the hydrogeologic framework in the area by (1) investigating the vertical distribution of water-bearing fractures, (2) characterizing the ground-water flow system, and (3) determining the local geologic structure of the aquifer.

This report presents detailed borehole geophysical data at four selected wells and provides information regarding the stratigraphy at NP6. Detailed information regarding the USGS borehole geophysical investigation of NP6 is presented in Conger (1999).

Hydrogeologic Setting

The NP6 site is in the Gettysburg-Newark Lowlands Section of the Piedmont Physiographic Province. The site and surrounding area are underlain by sedimentary rocks of the lower Brunswick Group and Lockatong Formation of the Newark Supergroup (Lyttle and Epstein, 1987; Longwill and Wood, 1965; Berg and Dodge, 1981). Contacts between the Brunswick Group and the underlying Lockatong Formation are conformable and gradational, and the two formations interfinger (Longwill and Wood, 1965). The lower beds of the Brunswick Group consist predominantly of homogeneous, soft, red to reddish-brown mudstone and shale and some thin gray, brownish, and green shales (Rima, 1955; Longwill and Wood, 1965). Mudcracks, ripple marks, crossbeds, and burrows are common in all beds; some beds are micaceous (Lyttle and Epstein, 1987). Bedding planes are discontinuous and irregular (Rima, 1955). The lower Brunswick Group rocks contain detrital cycles of medium- to dark-gray and olive- to greenish-gray, thin-bedded and evenly bedded shale and siltstone that grade into the underlying Lockatong Formation (Lyttle and Epstein, 1987). Rocks of the Lockatong Formation contain detrital cycles of gray to black calcareous shale and siltstone, with some pyrite, and chemical 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; Rima and others, 1962). Beds generally strike northeast and dip to the northwest.

The NP6 site is on relatively flat upland terrain that is a surface-water divide between the Wissahickon Creek to the southwest, Towamencin Creek to the west, and tributaries to the West Branch Neshaminy Creek to the north and northeast.

Ground water at the NP6 site originates from infiltration of local precipitation and discharges to streams and to pumped wells, and leaks downward to deeper ground-water flow systems. Precipitation infiltrates the soil and weathered overburden, enters the ground water, and moves through vertical and horizontal fractures in the sandstone, shale, and siltstones. Primary porosity in the Brunswick Group is very low or nonexistent (Longwill and Wood, 1965). Therefore, primary permeability is also small. Ground water in the upper part of the Brunswick Group may be under unconfined (water-table) conditions. Ground water in the intermediate and deep part of the aquifer may be confined or semi-confined, resulting in borehole flow and local artesian conditions. Generally, wells constructed as open-hole boreholes deeper than approximately 50 ft penetrate multiple water-producing or water-receiving zones, and water levels measured in these wells represent composite heads. Where differences in potentiometric head are present, water in the borehole flows from zones of higher head to zones of lower head. Also, pumping from deeper zones may induce downward flow from shallower zones.

The depth to water in wells at the NP6 site range from about 6 to 69 ft below land surface (bls). Ground-water levels fluctuate with local pumping and seasonal variations in recharge. On a regional scale, ground water generally flows in a direction similar to the topographic gradient. In the Lansdale area, however, the configuration of water levels mapped in August 1996 (Senior and others, 1998) indicates the water table does not exactly reflect topography and cones of depression have formed as a result of pumping. The natural direction of flow probably is altered by pumping in many locations. In the rocks of the Brunswick Group, cones of depression caused by pumping tend to extend along strike or fracture orientation (Longwill and Wood, 1965).

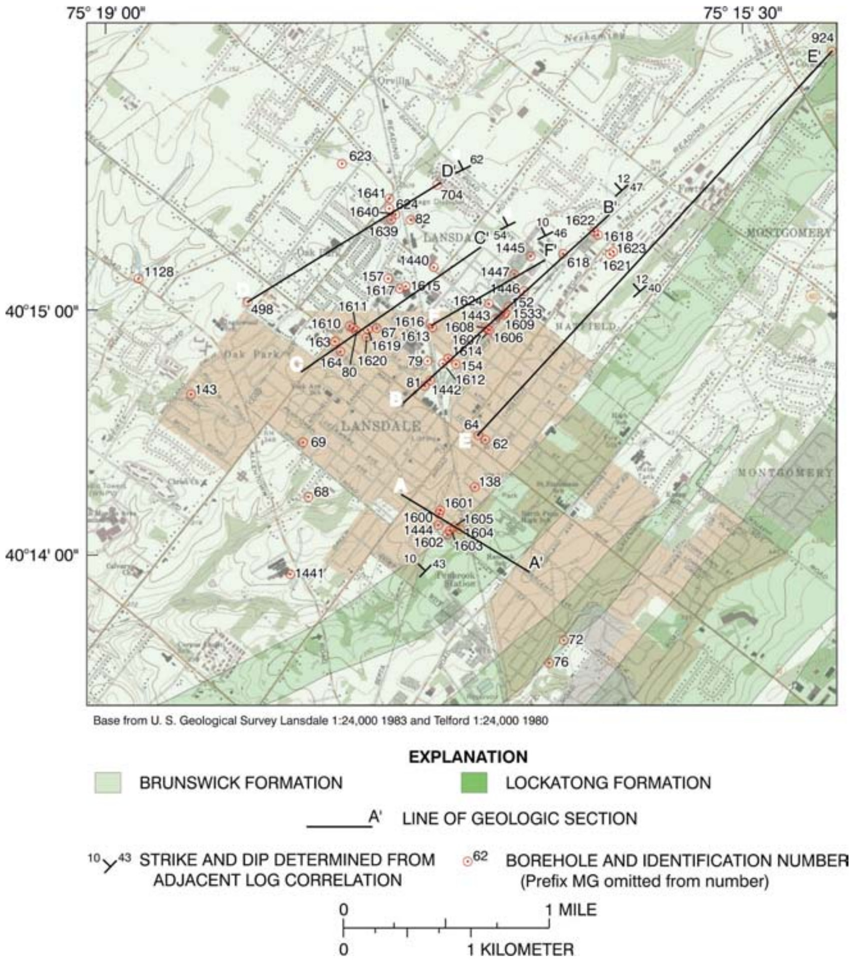

Figure 1. Location of boreholes logged at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania (Conger, 1999).

Analysis of Selected Borehole Geophysical Logs

Geophysical logs provide information on location and orientation of fractures (caliper and acoustic televiewer logs), water-producing and water-receiving zones, intervals of vertical borehole flow (fluid-resistivity and fluid-temperature logs), quantification of borehole flow (heatpulse-flowmeter data), lithologic correlation (natural gamma and single-point-resistance logs), and data on well construction (caliper and single-point-resistance). Borehole deviation logs record the deviation of a borehole from true vertical.

MG-68

The static water level at the time of logging on July 23, 1996 was 41.30 ft bls. The caliper log shows the total depth of the borehole is 460 ft and it is cased with 14-in.-diameter casing to 9 ft bls (fig. 2). The caliper log shows a decrease in borehole diameter from 14 in. to 10 in. at about 50 ft bls and from 10 in. to 8 in. beginning at 250 ft bls. The caliper log shows major fractures at 10, 18-20, 24-30, 44-50, 57-61, 106-109, 128-140, 169-

171, and 414-418 ft bls plus numerous smaller fractures throughout the open-hole interval. The caliper log shows minor constrictions at 131, 133, 139 ft bls, with larger constrictions at 409, 414, 417, 419, and 448-460 ft bls. These constrictions may be caused by blocks of fractured mudstone or siltstone shifting in the borehole over time. The natural-gamma log shows a possible shale bed, with elevated gamma readings, at 417-421 that might be used for stratigraphic correlation of geologic units with other wells. The single-point-resistance log shows minor fluctuations in lithology with a noticeable peak at about 285 ft bls that correlates to a minor fracture on the caliper log. The fluid temperature and fluid-resistivity logs show an abrupt change in slope at about 285 ft bls, which suggests that the minor fracture at 285 ft bls is a water-producing or water-receiving zone. The deviation log shows the borehole deviates from vertical approximately 3 ft to the south-southeast over the total length of the borehole (fig. 3).

The strike and dip of fracture planes were obtained from the acoustic televiewer. The results are shown on an equal-area stereonet with single points (poles) plotted in the lower hemisphere at right angles to the fracture planes. These poles indicate that most fracture planes trend northeast-southwest (fig. 4). The greatest concentration of poles is near the center of figure 4, probably indicating shallow bedding planes. Twenty possible bedding planes were identified, 16 planes dip to the northwest with an average strike of N. 84° E., and dip of 9° NW., that is nearly coincident with the regional strike and dip; 4 shallow planes dip to the southeast with an average strike and dip of N. 67° W., 7° SW. Thirteen high-angle fracture planes were identified in the borehole with a strike and dip of N. 73° E., 75° NE.

Under nonpumping conditions, the heatpulse-flowmeter measured upward borehole flow at 70, 120, 152, 310, 350, 370, 380, 406, and 426 ft bls. Downward flow was measured at 270 ft bls with no flow detected at 220 and 245 ft bls (table 1). Under nonpumping conditions, the suite of geophysical logs and heatpulse-flowmeter measurements indicate that the greatest quantity of water enters the borehole through the large fractures at 106-109 and 169-171 ft bls, through smaller fractures at about 240 and 321-323 ft bls, and below 426 ft bls. Additional water may enter the borehole through fractures at 249-255 ft bls. Most of the water exits the borehole through fractures above 70 ft bls and the small fractures at 284-288 ft bls. The nonpumping water level in the well was 41.84 ft bls.

A submersible pump was placed at 55 ft bls. The borehole was then pumped at approximately 3.75 gal/min. The water level in the borehole declined 0.83 ft after 77 min. of pumping. Under pumping conditions, the heatpulse-flowmeter measured upward borehole flow at 70, 100, 120, and 150 ft bls, downward flow at 270 ft bls, and no flow at 220 and 245 ft bls. Under pumping conditions, the suite of geophysical logs and heatpulse-flowmeter measurements indicate the greatest quantity of water enters the borehole through the fractures near 108-110 ft bls and above 70 ft bls.

Table 1. Summary of heatpulse-flowmeter measurements for borehole MG-68 at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania.

[gal/min, gallon per minute]

Depth (feet below land surface)	Flow rate (gal/min) nonpumping conditions	Flow direction nonpumping conditions	Flow rate (gal/min) pumping conditions	Flow direction pumping conditions
70	0.21	up	0.32	up
100	no data	no data	.47	up
120	.10	up	.15	up
150	no data	no data	.12	up
152	.08	up	no data	no data
220	no flow	not determined	no flow	not determined
245	no flow	not determined	no flow	not determined
270	.41	down	.16	down
310	.46	up	no data	no data
350	.16	up	no data	no data
370	.10	up	no data	no data
380	.16	up	no data	no data
406	.12	up	no data	no data
426	.11	up	no data	no data

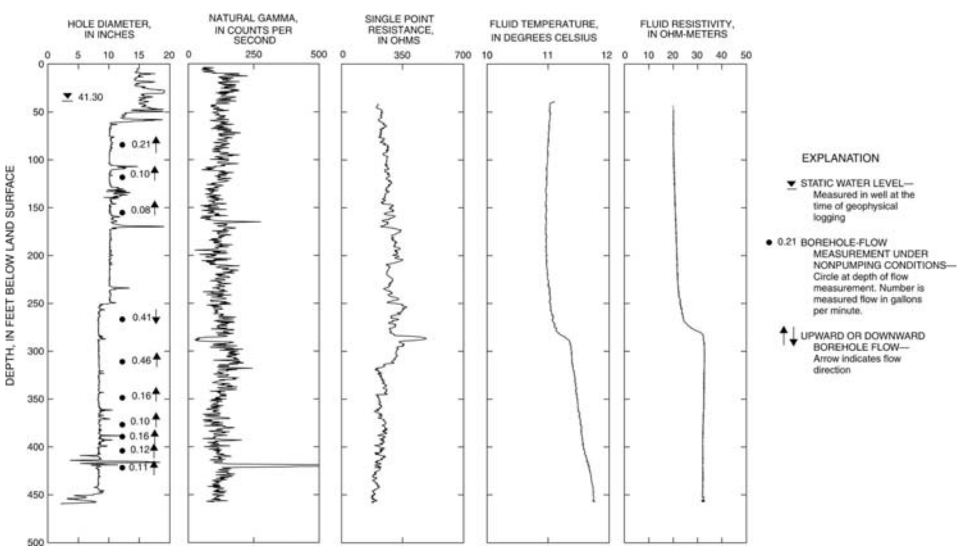

Figure 2. Borehole-geophysical logs and direction of nonpumping flow within borehole MG-68, North Penn Area 6 Superfund Site, Landsdale, Montgomery County, Pennsylvania.

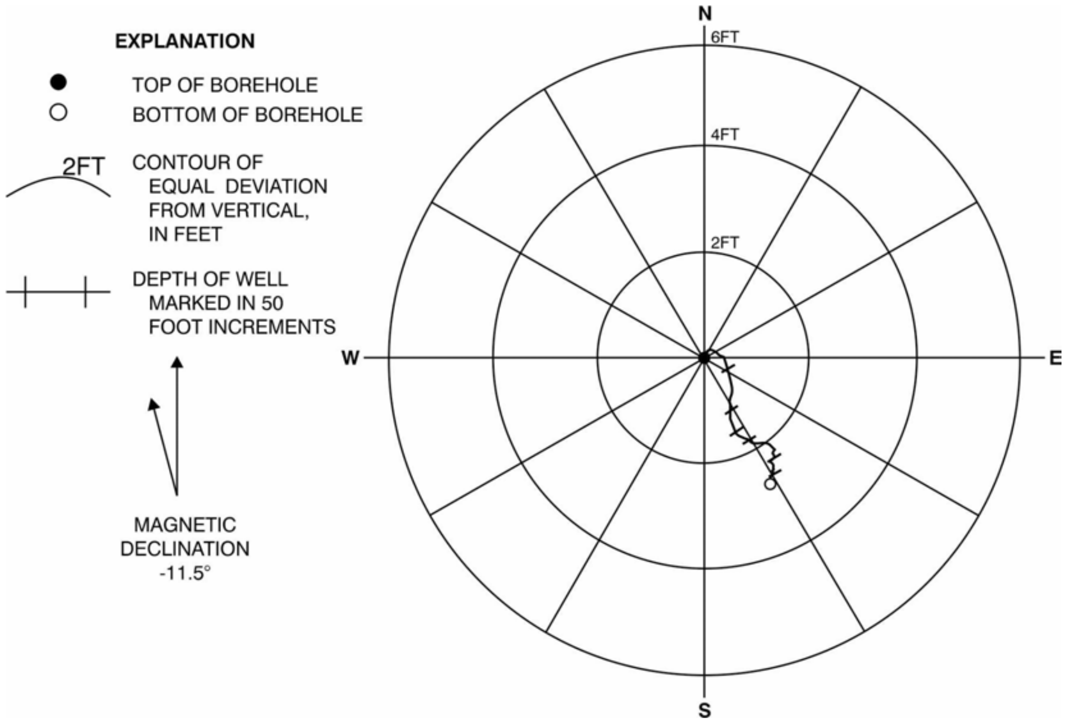

Figure 3. Magnitude and direction of deviation from vertical of borehole MG-68.

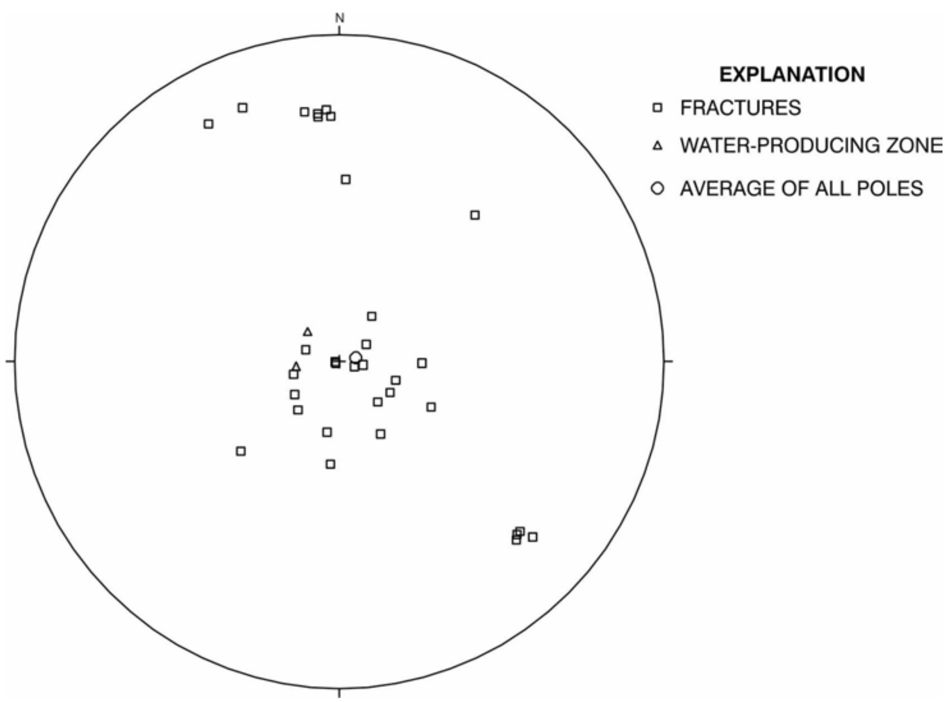

Figure 4. Equal-area lower hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole MG-68.

MG-138

The static water level at the time of logging on April 24, 1996 was 39.59 ft bls. The caliper log shows the total depth of the borehole is 424 ft and it is cased with 10-in.-diameter casing to 22 ft bls (fig. 5). The caliper log shows major fractures at 323-331 and 391-399 ft bls plus numerous smaller fractures throughout the open-hole interval. The natural-gamma log shows a possible shale bed, with elevated gamma readings, at 95-100 ft bls that might be used for stratigraphic correlation of geologic units with other wells. The single-point-resistance log shows an increase in resistance with greater depth. The large fractures at 323-331 and 391-399 correlate well to changes in the single-point-resistance log, indicating possible lithologic contacts. The large increase in resistance from 331 ft bls to the bottom of the well indicates a change in lithology. The fluid-resistivity and fluid-temperature logs show changes in slope at approximately 50 and 85 ft bls that correlate to fractures on the caliper log. The fluid-temperature log also shows changes in slope at 145 and 240 ft bls that correlate to small fractures on the caliper log.

Under nonpumping conditions, the heatpulse-flowmeter measured downward borehole flow at 53, 80, 102, 120, and 150 ft bls and upward flow at 44, 265, 315, and 401 ft bls. Possible but inconclusive upward flow was measured at 348 ft bls (table 2). Under nonpumping conditions, water enters the borehole through fractures at 50-52, 75-80, and 120 ft bls. This water moves downward and exits the borehole through fractures at 82-86, 130-142 ft bls, and between 157-240 ft bls. Additional water enters the borehole through fractures at 421-423 ft bls. This deeper water moves upward and exits the borehole through the fracture at approximately 240 and 391-399 ft bls.

A submersible pump was placed at 70 ft bls and the borehole was pumped at approximately 4.0 gal/min. The water level in the borehole declined 6.99 ft after 49 minutes of pumping before beginning to stabilize. Under pumping conditions, the heatpulse-flowmeter measured upward borehole flow at 80, 102, 120, 150, 183, 221, 265, 315, 345, 380, and 402 ft bls. Under pumping conditions, the heatpulse-flowmeter measurements indicate the greatest quantity of water enters the borehole through the fractures at 50-52 ft bls; minor amounts of water enter the borehole through fractures at 82-86 and 421-423 ft bls.

Table 2. Summary of heatpulse-flowmeter measurements for borehole MG-138 at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania

[gal/min, gallon per minute]

Depth (feet below land surface)	Flow rate (gal/min) nonpumping conditions	Flow direction nonpumping conditions	Flow rate (gal/min) pumping conditions	Flow direction pumping conditions
44	0.08	up	no data	no data
53	.89	down	no data	no data
80	1.20	down	0.34	up
102	.56	down	.19	up
120	.90	down	.19	up
150	.19	down	.19	up
183	no data	no data	.14	up
221	no data	no data	.18	up
265	.11	up	.21	up
315	.22	up	.16	up
345	no data	no data	.23	up
348	possible flow	possibly up	no data	no data
380	no data	no data	.18	up
401	.19	up	no data	no data
402	no data	no data	.23	up

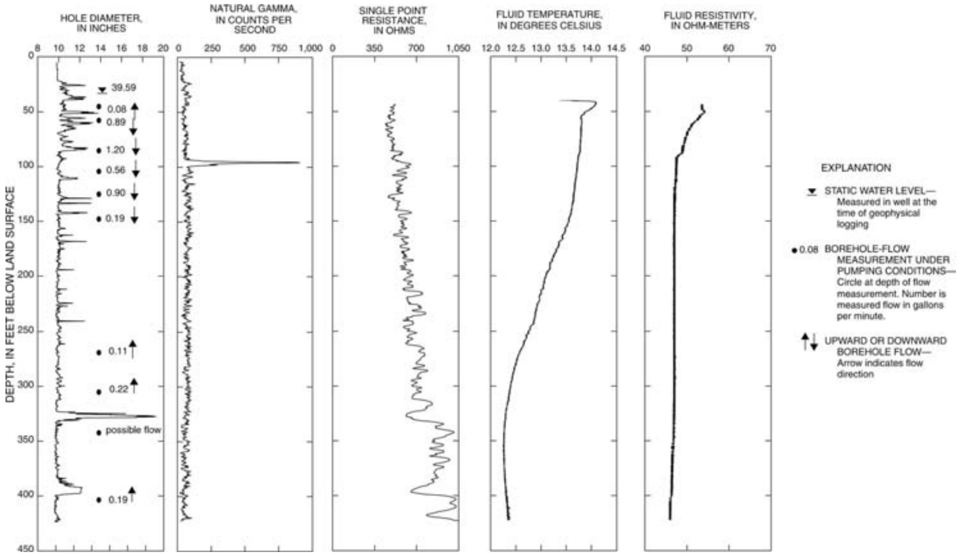

Figure 5. Borehole-geophysical logs and direction of nonpumping flow within borehole MG-138, North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania.

MG-498

The static water level in the well at the time of logging on August 7, 1996 was 46.16 ft bls. The caliper log shows the total depth of the borehole is 587 ft and it is cased with 12-in.-diameter casing to 97 ft bls (fig. 6). The caliper log shows major fractures and fracture zones at 116-122, 157-164, 167-169, 220-227, 244-246, 249-251, 254-257, 390-393, 403-405, and 435-442 ft bls plus numerous smaller fractures throughout the open-hole interval. The caliper log shows the borehole diameter is 12 in. from 97-413 ft bls and 10 in. from 413-587 ft bls. The natural-gamma log shows shale units, with elevated gamma readings, at 202-204, 294-296, and 321-326 ft bls that might be used for stratigraphic correlation of geologic units with other wells. The fluid-resistivity log shows changes in slope at 110 and 152 ft bls that correlate to fracture zones shown on the caliper log. The fluid-temperature log shows a change in slope at approximately 440 ft bls that correlates to fractures shown on the caliper log.

Under nonpumping conditions, the heatpulse-flowmeter measured upward flow at 450, 480, 526, and 554 ft bls. No flow was measured at 104, 136, 190, 240, 290, 340, 386, and 424 ft bls (table 3). Under nonpumping conditions, the suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 566-576 ft bls. This water moves upward and exits the borehole through fractures at 435-442 ft bls.

A submersible pump was placed at 60 ft bls and the well was pumped at approximately 4.0 gal/min. After 77 minutes of pumping, the water level declined 4.86 ft but never completely stabilized. This indicates that part of the discharge was derived from borehole storage and part from the aquifer, resulting in a flow measurement less than the actual rate. A check measurement of flow within the casing while pumping the well indicated that only 0.19 gal/min of the 4.0 gal/min discharge could be measured by the heatpulse flowmeter. This is mostly the result of flow bypassing the flowmeter. Because the large casing diameter exceeds the 8-in. maximum recommended by the heatpulse-flowmeter manufacturer, all flow measurements should be considered relative estimates. Under pumping conditions, the greatest quantity of water enters the borehole through fractures at 157-169 ft bls.

Table 3. Summary of heatpulse-flowmeter measurements for borehole MG-498 at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania

[gal/min, gallon per minute]

Depth (feet below land surface)	Flow rate (gal/min) nonpumping conditions	Flow direction nonpumping conditions	Flow rate (gal/min) pumping conditions	Flow direction pumping conditions
90	no data	no data	0.19	up
104	no flow	not determined	.17	up
136	no flow	not determined	.12	up
190	no flow	not determined	.06	up
240	no flow	not determined	no flow	no data
290	no flow	not determined	no data	no data
340	no flow	not determined	no data	no data
386	no flow	not determined	no data	no data
424	no flow	up	no data	no data
450	0.34	up	no data	no data
480	.09	up	no data	no data
526	.08	up	no data	no data
554	.09	up	no data	no data

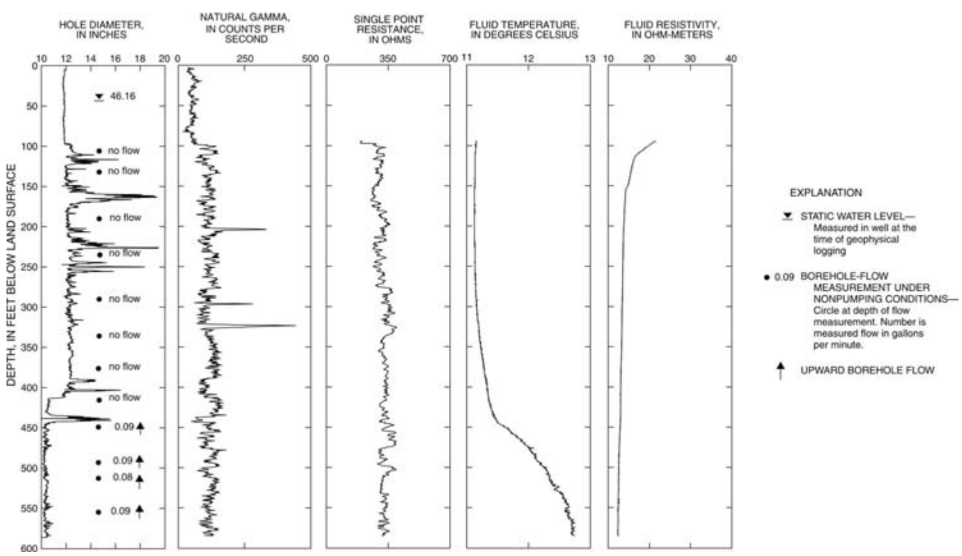

Figure 6. Borehole-geophysical logs and direction of nonpumping flow within borehole MG-498, North Penn Area 8 Superfund Site, Lansdale, Montgomery County, Pennsylvania.

The static water level in the well at the time of logging on May 21, 1996 was 18.34 ft bls. The caliper log shows the total depth of the borehole is 486 ft and it is cased with 8-in.-diameter casing to 9 ft bls (fig. 7). The caliper log shows major fractures and fracture zones at 10-16, 33, 70, 83, 118, 122, 203-206, 215-223, 227-231, 304-306, and 462-464 ft bls plus numerous smaller fractures throughout the open-hole interval and a borehole constriction at 203 ft bls. The natural-gamma log shows a shale unit, with a slightly elevated gamma reading, at 216-218 ft bls that might be used for stratigraphic correlation of geologic units with other wells. The single-point-resistance log shows little variation in lithology. The fluid-temperature and fluid resistivity logs show major changes in slope at 33 and 72 ft bls and minor slope changes at 203 and 300 ft bls that correlate to fractures shown on the caliper log. The deviation log shows the borehole deviates approximately 28 ft to the south-southwest over the total length of the borehole (fig. 8).

The strike and dip of fracture planes were obtained from the acoustic televiewer. The results are shown on an equal-area stereonet with single points (poles) plotted in the lower hemisphere at right angles to the fracture planes. These poles indicate that many fracture planes trend northwest-southeast (fig. 9). The greatest concentration of poles is near the center of figure 9, probably indicating shallow bedding planes. Forty-nine planar features were identified, 39 planes dip to the northeast with an average strike of N. 50° W., 8° NE., 10 shallow planes dip to the southwest with a strike and dip of N. 51° W., 4° SW. Forty-three higher-angle fracture planes were identified in the borehole with an average strike and dip of N. 79° W., 22° NE

Under nonpumping conditions, the heatpulse-flowmeter measured downward flow at 42, 60, 78, 108, 146, 180, 208, 236, and 264 ft bls (table 4). A submersible pump was placed at 50 ft bls, and the well was pumped at a rate of approximately 4.0 gal/min. The water level in the well declined 2.11 ft after 112 minutes of pumping and never completely stabilized, which indicates that part of the discharge was derived from borehole storage and part from the aquifer, resulting in a flow measurement less than the actual rate. The suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate water enters the borehole through fractures at 33 and 70 ft bls. This water exits the borehole through fractures at 118-137, 172, 203-206, 215-231, and below 265 ft bls; probably through the fracture at 304-306 ft bls. Under pumping conditions, the greatest quantity of water enters the borehole through fractures above 42 ft bls and 83-137 ft bls.

Table 4. Summary of heatpulse-flowmeter measurements for borehole MG-1128 at North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania

[gal/min, gallon per minute]

Depth (feet below land surface)	Flow rate (gal/min) nonpumping conditions	Flow direction nonpumping conditions	Flow rate (gal/min) pumping conditions	Flow direction pumping conditions
42	0.89	down	no data	no data
60	.88	down	1.0	up
78	1.3	down	.84	up
108	1.3	down	.52	up
146	.81	down	.12	up
180	.54	down	.08	up
208	.41	down	no data	no data
236	.13	down	no data	no data
264	.10	down	no data	no data

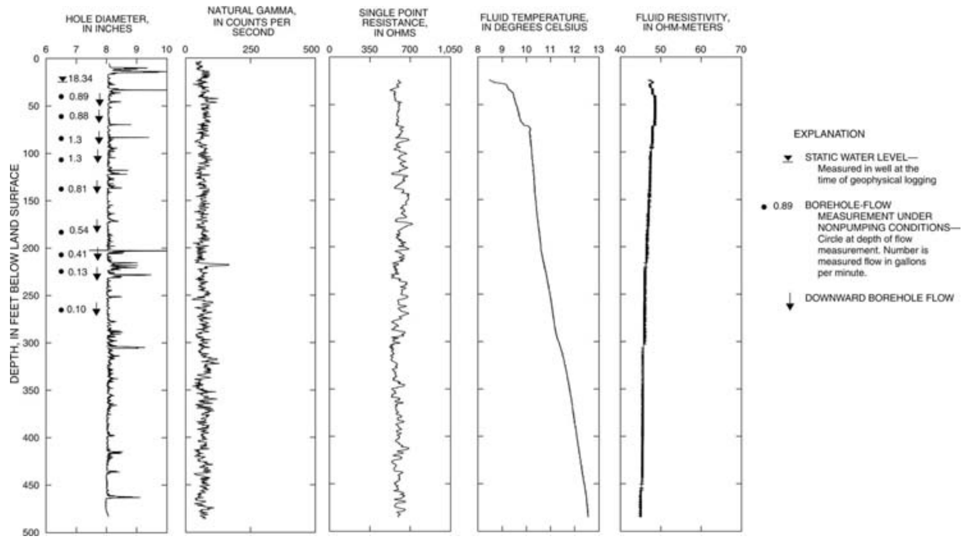

Figure 7. Borehole-geophysical logs and direction of nonpumping flow within borehole MG-1128, North Penn Area 6 Superfund Site, Lansdale, Montgomery County, Pennsylvania.

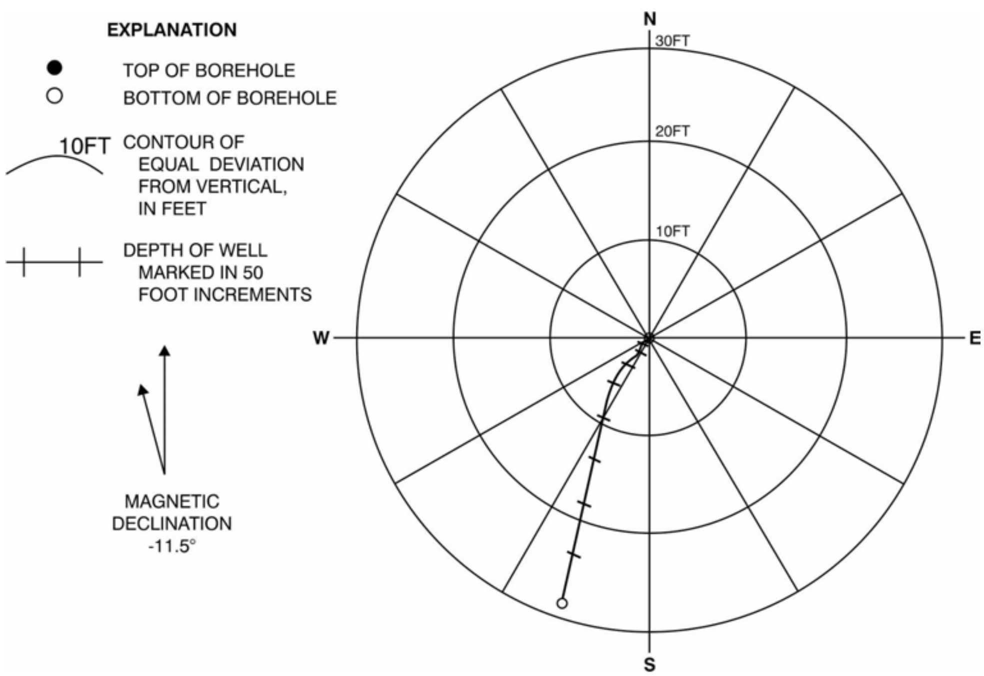

Figure 8. Magnitude and direction of deviation from vertical of borehole MG-1128.

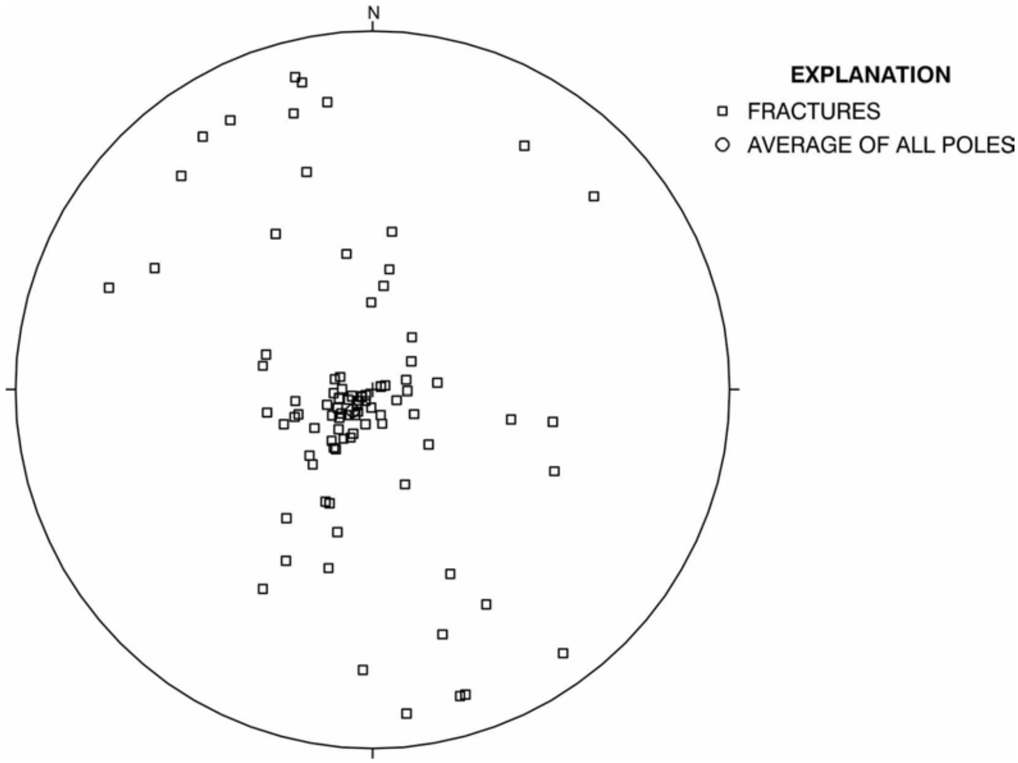

Figure 9. Equal-area lower hemisphere, stereographic projection of poles perpendicular to fracture planes in borehole MG-1128.

CORRELATION OF NATURAL-GAMMA LOGS

Stratigraphic correlation between wells at the NP6 Superfund Site was done using elevated natural-gamma readings associated with thin shale beds. The elevated gamma readings are generally from 2 to more than 10 times greater than readings for other parts of the borehole. The orientation of these shale marker beds at several locations in Lansdale was determined by calculating the strike and dip of elevated natural-gamma readings (spikes) from logs for sets of three wells. The locations of wells used in correlations are shown with cross-sections in figure 1. Natural-gamma spikes associated with the radioactive shale marker beds can be correlated at distances of 5,000 ft or greater along strike. Regional correlation in the dip direction, however, is limited to less than 3,000 ft because at that distance, well depths typically are not great enough to penetrate the marker beds estimated to dip at an angle of about 11^{o}.

Near the center of Lansdale (fig. 1), natural-gamma logs for wells MG-81, MG-1612, MG-1614, MG-1608, and MG-618 were correlated as shown in the cross-section B-B’ (fig. 10). The strike in this area is about N. 47^{o} E., with a dip of about 12° NW.

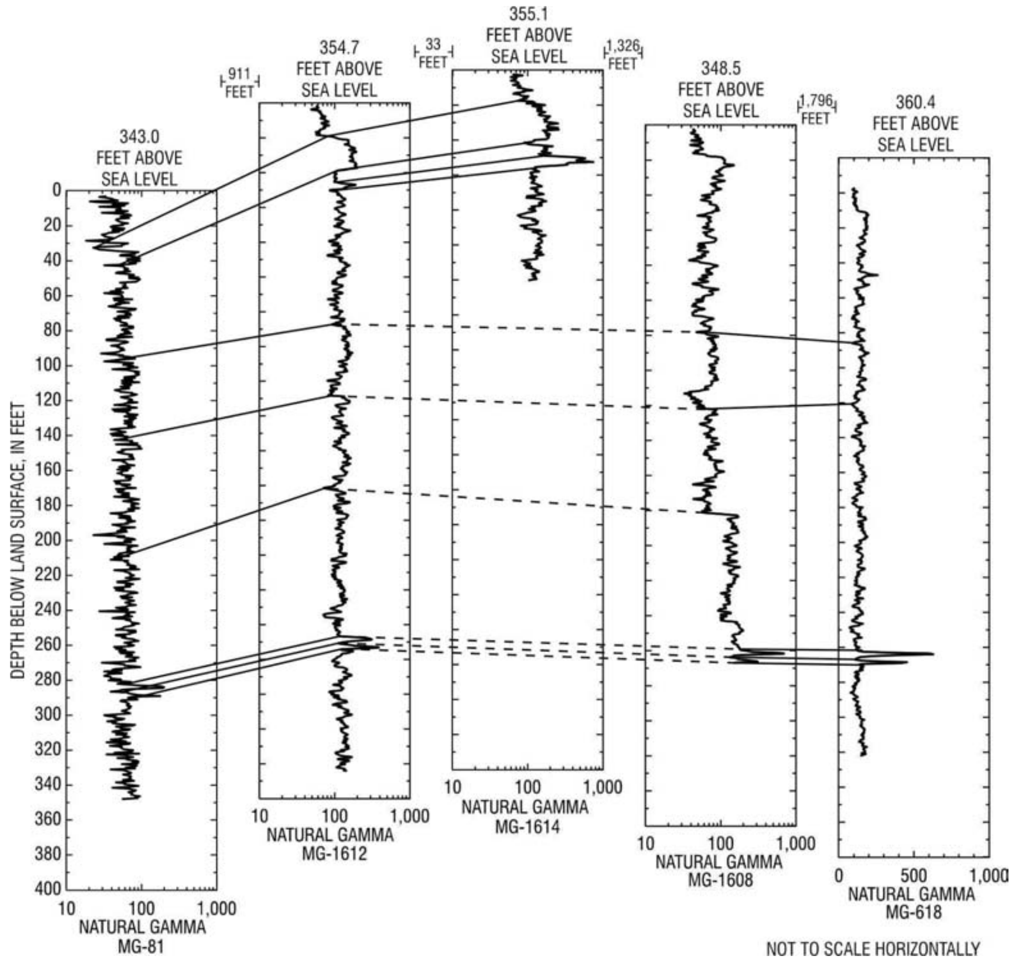

Figure 10. Correlation of natural-gamma logs MG-81, MG-1612, MG-1614, MG-1608, and MG-618, cross section B-B'. (Dashes represent an inferred correlation.)

CONCLUSIONS

Generally, in the Lansdale area, boreholes constructed as open holes deeper than approximately 50 ft penetrate multiple water-bearing zones in the Triassic-age shales and siltstones, and water levels measured in these boreholes represent composite heads. Water in the intermediate (approximately 50-200 ft) and deep (approximately 200 ft or greater) part of the aquifer is under confined or semi-confined conditions. Differences in hydraulic head with depth result in vertical borehole flow in open boreholes. Borehole flow, when present, was upward in 35 boreholes throughout the Lansdale area regardless of depth or location. Borehole flow was downward in 11 wells that may be affected by nearby pumping. Both upward and downward flow was measured in three boreholes. No flow was detected in eight wells. Any open-construction borehole with multiple water-producing zones can potentially cross-contaminate other zones in the Lansdale area.

Correlation of USGS natural-gamma logs in the Lansdale area show that thin shale marker beds of the Brunswick Group and Lockatong Formation, generally strike 40-62° NE. and dip about 8-12° NW. in the central and northern section of Lansdale. Acoustic televiewer logs indicate that many water-bearing fractures are oriented similarly to bedding planes. Boreholes located along the regional strike of N. 48° to 60° E. typically can be correlated with natural-gamma logs. Boreholes that are located perpendicular to regional strike (dip direction) can usually be correlated, providing the boreholes are less than 3,000 ft apart, have similar elevation, and are at least 500 ft deep. The frequency of shale units with higher natural-gamma readings increase toward the northwest.

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