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Geology, Hydrology, and Ground-Water Quality of the Galena-Platteville Aquifer in the Vicinity of the Parson's Casket Hardware Superfund Site, Belvidere, Illinois

Water-Resources Investigations Report 00–4152

U.S. DEPARTMENT OF THE INTERIOR
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By Robert T. Kay

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De Kalb, Illinois
2000

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Flow rate	
gallon per minute (gal/min)	3.7685	liters per minute
	Hydraulic conductivity*	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity**	
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

*<u>**Hydraulic conductivity:**</u> Foot per day is the mathematically reduced term of cubic foot per day times foot per square foot of aquifer cross-sectional area.

<u>Transmissivity**</u>**:** The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Abbreviated water-quality units used in this report: Chemical concentration is given in metric units. Chemical concentration is given in micrograms per liter (µg/L). Micrograms per liter is a unit expressing the concentration of chemical constituents in solution as weight (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter (mg/L).

Abbreviations

µS/cm	microSiemens per centimeter
mg/L	milligrams per liter
µg/L	micrograms per liter

Geology, Hydrology, and Ground-Water Quality of the Galena-Platteville Aquifer in the Vicinity of the Parson's Casket Hardware Superfund Site, Belvidere, Illinois

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Abstract

The geology, hydrology, and distribution of contaminants in the Galena-Platteville aquifer in the vicinity of the Parson's Casket Hardware Superfund site in northeastern Belvidere, Ill., were characterized on the basis of data collected from boreholes using geophysical logging and packer assemblies. Horizontal flow in the Galena-Platteville aquifer is affected by a network of subhorizontal fractures that are concentrated in the weathered part of the bedrock, vugs and fractures present from the bottom of the weathered bedrock to the top of a shaley layer at about 662 ft (feet) above sea level, and through a widespread subhorizontal fracture at about 524 ft. Inclined fractures provide pathways for vertical flow within the Galena-Platteville aquifer. Some fractures and flow pathways appear to be affected by the stratigraphy of the Galena-Platteville deposits.

Water-level data indicate the potential for downward flow within the Galena-Platteville aquifer. During periods when pumping in nearby municipal-supply wells is minimal or absent, the direction of flow through the fracture at about 524 ft above sea level is south toward two industrial-supply wells. Flow through the fracture is toward the municipal-supply wells when they are being pumped. Flow in the upper part of the Galena-Platteville aquifer does not appear to be affected by pumping in nearby water-supply wells.

Chlorinated ethenes were the volatile organic compounds detected most often and at the highest concentration in the Galena-Platteville aquifer beneath northeastern Belvidere. Volatile organic compounds are migrating primarily to the southeast toward the Kishwaukee River, with components of movement to the north, east, and west. Volatile organic compound and monitored natural attenuation parameter data indicate reductive dechlorination of some chlorinated ethene compounds is occurring under either nitrate or iron-reducing conditions in the unconsolidated deposits and possibly the upper part of the Galena-Platteville aquifer near the center of the plume. Oxidizing conditions appear to be present at least in the upper part of the aquifer beneath most of the study area, and the occurrence of reductive dechlorination in the Galena-Platteville aquifer beneath most of the area of investigation is not clearly indicated.

INTRODUCTION

Volatile organic compounds (VOC's) have been detected in water from the Galena-Platteville aquifer beneath the Parson's Casket Hardware Superfund site (hereafter referred to as the PCHSS) in the northeastern part of the city of Belvidere, in Boone County, Ill. (fig. 1). The extent of contamination in this fractured-bedrock aquifer has not been defined nor has the potential for contaminants to migrate to ground-water receptors, especially nearby industrial- and municipal-supply wells and the Kishwaukee River. The U.S. Geological Survey (USGS), in cooperation with the Illinois Environmental Protection Agency (IEPA), investigated the geology, hydrology, and distribution of contaminants in the Galena-Platteville aquifer in the vicinity of the PCHSS. The area of concern for this investigation (hereafter referred to as the study area) extends to the Kishwaukee River

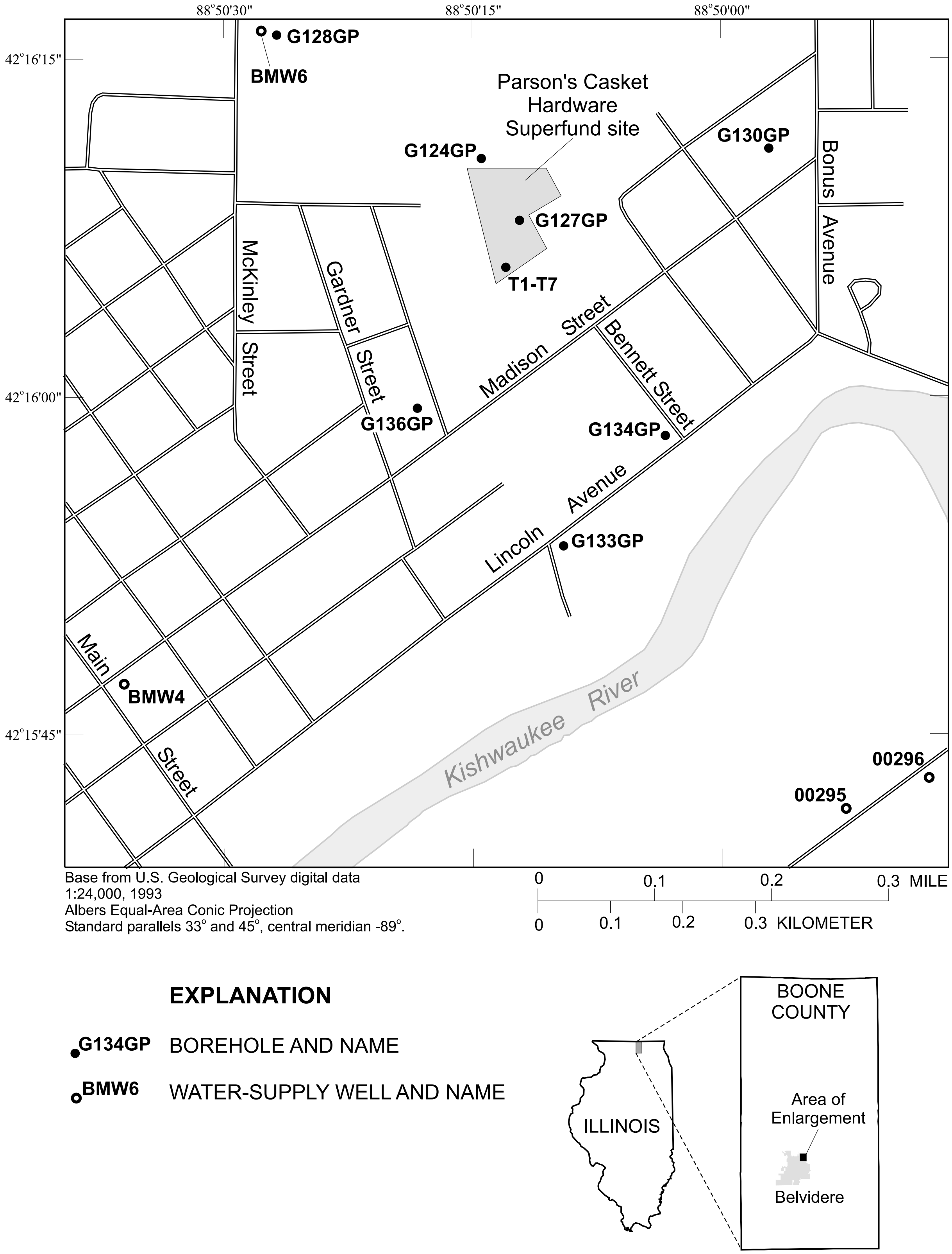

Figure 1. Location of study area, boreholes, and water-supply wells in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill.

to the south, approximately Gardner Street to the west, Bonus Avenue to the east, and approximately 100 ft north of the northern part of the PCHSS (fig. 1).

This investigation was designed to determine the nature and extent of contaminants in the Galena-Platteville aquifer in the vicinity of the PCHSS, to identify the pathways of contaminant migration through the aquifer and the potential receptors of the contaminated ground water, and to evaluate the potential for natural attenuation processes to eliminate contaminants from the aquifer or reduce their concentrations below regulatory levels. The information collected for this investigation will be used to assess remediation strategies at the PCHSS. In addition, the information obtained from this investigation can be used to determine the processes that affect the development of secondary-permeability features and the lateral continuity of these features in northeastern Belvidere.

The investigation comprised four principal efforts: 1) geophysical logging, 2) collecting water-level data, 3) aquifer testing, and 4) water-quality sampling. Natural-gamma, acoustic-televiewer, short-normal and fluid-column resistivity, temperature, caliper, and heat-pulse flowmeter logs were run in boreholes G124GP, G130GP, G133GP, G134GP, and G136GP, which were drilled for this investigation (fig. 1, table 1) to determine stratigraphy; location, orientation, and extent of hydraulically active vugs and fractures; and directions of ground-water flow in the Galena-Platteville aquifer beneath the study area. After completion of borehole testing, wells G124GPS and G124GPD were installed in borehole G124GP, well G130GP was installed in borehole G130GP, well G133GP was installed in borehole G133GP, wells G134GPS and G134GPD were installed in borehole G134GP, and wells G136GPS and G136GPD were installed in borehole G136GP (table 1). Static water-level measurements were collected in the boreholes from 19 intervals isolated with a packer assembly to identify the vertical direction of ground-water flow in the Galena-Platteville aquifer in the study area. In six completed monitoring wells, static water levels were measured at 15-minute intervals for a total period of about 1 month to help identify the presence of pumping effects from nearby water-supply wells on water levels and flow directions in the Galena-Platteville aquifer. Specific-capacity tests were done in each borehole and slug tests were done in 16 test intervals isolated with a packer assembly to quantify the hydraulic properties of the Galena-Platteville aquifer. Water samples were collected from 18 intervals isolated with a packer assembly to define ground-water quality and the spatial distribution of contaminants in the Galena-Platteville aquifer and to help evaluate the potential for natural attenuation of contamination in the aquifer beneath the study area.

Purpose and Scope

This report describes the results of an investigation that used packer assemblies and geophysical logging to characterize the geology, hydrology, and water quality of the Galena-Platteville aquifer beneath the study area in northeastern Belvidere, Ill. This work was done primarily in the summer and fall of 1999. The results of geophysical logging using conventional and heat-pulse flowmeter logs in six boreholes in the study area are presented in this report. In addition, the report presents the results of water-level monitoring in six completed monitoring wells, as well as water-level monitoring, aquifer testing, and water-quality sampling in as many as 19 test intervals isolated with a packer assembly in the six boreholes. This report identifies the pathways of ground-water flow and contaminant movement through the Galena-Platteville aquifer beneath the study area, the extent of the hydraulically active features transmitting the flow, and the potential for contaminant migration to ground-water receptors.

Acknowledgments

The author extends thanks to Jason Thorpe of the IEPA for his assistance with data collection. John Grabs and Ray Mastrolonardo of Tetra Tech EM Inc., Eric Runkel of the IEPA, James Grimes of the city of Belvidere, Gary Yunto of the Pillsbury Corporation, and Environmental Contractors of Illinois also are thanked for their assistance with the study. In addition, Mr. Allen Silver, Mr. and Ms. Wheeler, Camcar-Textron Corporation, Belvidere Construction Company, and the city of Belvidere are thanked for allowing access to their property.

Table 1. Borehole and well information, altitude of top of bedrock, and transmissivity data in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill.

[na, not available; -, altitude below sea level]

Borehole or well name	Latitude/longitude	Land-surface altitude (feet above sea level)	Depth of open interval (feet below land surface)	Altitude of open interval (feet above sea level)	Bedrock-surface altitude (feet above sea level)	Transmissivity (feet squared per day)
G124GP	42°16′11″/88°50′13″	782	35-267	515-747	752	na
G130GP	42°16′12″/88°49′57″	788	41-230	558-747	751	5,400
G133GP	42°15′54″/88°50′09″	778	45-268	510-733	738	430
G134GP	42°15′59″/88°50′03″	784	55-267	516-728	738	270
G136GP	42°16′01″/88°50′18″	782	28-283	499-754	759	1,100
BMW4	42°15′47″/88°50′36″	777	152-1,800	-1,023-625	732	na
BMW6	42°16′15″/88°50′28″	782	110-868	-86-672	757	na
00295	42°15′43″/88°49′44″	770	63-627	133-697	697	na
00296	42°15′42″/88°49′52″	778	55-550	230-725	725	27,000

Well name	Latitude/longitude	Altitude, top of inner casing (feet above sea level)	Depth of screened interval (feet below land surface)	Altitude of screened interval (feet above sea level)
G124GPS	42°16′11″/88°50′13″	784.56	42.5-47.5	734.5-739.5
G124GPD	42°16′11″/88°50′13″	784.58	258.5-263.5	518.5-523.5
G130GP	42°16′12″/88°49′57″	786.36	220-225	563-568
G133GP	42°15′54″/88°50′09″	777.53	249.5-254.5	523.5-528.5
G134GPS	42°15′59″/88°50′03″	784.08	57.5-62.5	721.5-726.5
G134GPD	42°15′59″/88°50′03″	783.93	255-260	524-529
G136GPS	42°16′01″/88°50′18″	781.73	32.5-37.5	744.5-749.5
G136GPD	42°16′01″/88°50′18″	781.61	255.5-260.5	521.5-526.5

GEOLOGY

The geologic units of primary concern to this investigation are the Ordovician-aged dolomite deposits of the Platteville and Galena Groups (figs. 2-7). Quaternary glacial and glaciofluvial deposits unconformably overlie these deposits. Argillaceous dolomite and sandstone deposits of the Glenwood Formation and the St. Peter Sandstone underlie the Platteville and Galena dolomites. The stratigraphy of the St. Peter Sandstone, Glenwood Formation, and Platteville and Galena Groups in the study area was determined by personnel from the Illinois State Geological Survey (ISGS) on the basis of cores collected at the PCHSS (Mills and others, 1998). The stratigraphic nomenclature used in this report is that of the ISGS (Willman and others, 1975, p. 61-81) and does not necessarily follow the usage of the USGS.

The St. Peter Sandstone is a coarse-to-medium grained quartz arenite, characterized by a high percentage of well-rounded quartz grains (Mills and others, 1998). The altitude of the top of the St. Peter Sandstone beneath the study area is about 420 ft above sea level.

The Glenwood Formation overlies the St. Peter Sandstone and is composed of interbedded sandstone and argillaceous dolomite beneath the study area (Mills and others, 1998). Sandstone layers predominate at the base of the formation, and argillaceous dolomite layers predominate at the top of the formation. The altitude of the top of the Glenwood Formation beneath the study area is about 450 ft above sea level.

The Platteville and Galena Groups are the uppermost bedrock deposits beneath the study area and consist of fractured, vesicular to vuggy, partly cherty, partly argillaceous dolomite with numerous shale partings. The groups are lithologically similar and are subdivided into formations primarily on the basis of subtle variations in clay and silt content (Willman and Kolata, 1978). Because natural-gamma logs measure variations in the amount of natural-gamma radiation emitted by the rock surrounding the borehole, which typically is a function of the clay content of the rock, comparing stratigraphic

SYSTEM	GROUP	FORMATION	LITHOLOGY	HYDROGEOLOGIC UNIT
QUATERNARY			Sand and gravel	Shallow unconsolidated aquifer
			Silt and clay	Unconsolidated semiconfining unit
			Sand and gravel	Deep unconsolidated aquifer
ORDOVICIAN	GALENA	Dubuque	Dolomite	Galena-Platteville aquifer
		Wise Lake		
		Dunleith		
	PLATTEVILLE	Guttenburg		
		Quimbys Mill		
		Nachusa		
		Grand Detour		
		Mifflin		
		Pecatonica		
	ANCELL	Glenwood	Argillaceous Dolomite	Semiconfining unit
			Sandstone	St. Peter Sandstone aquifer
		St. Peter Sandstone	Sandstone	

Figure 2. Generalized geologic column showing stratigraphy and hydrogeologic units in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Illinois.

descriptions and natural-gamma logs by previous investigators (Mills and others, 1998) has enabled the natural-gamma signal of the formations that compose the Platteville and Galena Groups to be identified. Natural-gamma signals from logs with stratigraphic descriptions obtained during previous investigations were compared with the natural-gamma logs obtained during the current investigation to correlate the stratigraphy of the Galena-Platteville deposits throughout the study area.

Although not penetrated by any of the boreholes drilled for this investigation, the Pecatonica Formation is the basal deposit of the Platteville Group and consists of a gray-to-brown, mottled, vuggy, fine-to-medium crystalline dolomite with some shale partings. The Pecatonica Formation overlies the Glenwood Formation and is present from about 451-478 ft above sea level beneath the study area (Mills and others, 1998).

The Mifflin Formation is composed of interbedded light gray and light brown, very fine to coarsely crystalline dolomite with interbedded gray, black, red, and brown shale. The altitude of the Mifflin Formation is about 478-501 ft beneath the study area. The upper part of the Mifflin Formation is penetrated by borehole G136GP.

The Grand Detour Formation overlies the Mifflin Formation and is composed of gray, very fine to medium crystalline dolomite with mottles and shale partings in some members. The Grand Detour Formation is present at an altitude of about 501-547 ft above sea level beneath the study area. Parts of the Grand Detour Formation can be identified by the peaks in the natural-gamma logs at about 524 and 534 ft (figs. 3, 5-7).

The Nachusa Formation overlies the Grand Detour Formation and is composed of mottled, brown and gray, fine to medium crystalline dolomite with some chert. The Nachusa Formation is present at an altitude of about 547-556 ft above sea level beneath the study area and corresponds to a low counts-per-second interval on the natural-gamma log between the upper part of the Grand Detour Formation and the lower part of the Quimbys Mill Formation (figs. 3, 5-7).

The Quimbys Mill Formation, the uppermost formation of the Platteville Group, is composed of gray, very fine to finely crystalline dolomite with thin shale partings and some chert. The Quimbys Mill Formation is present at an altitude of about 556-568 ft above sea level beneath the study area (figs. 3-7).

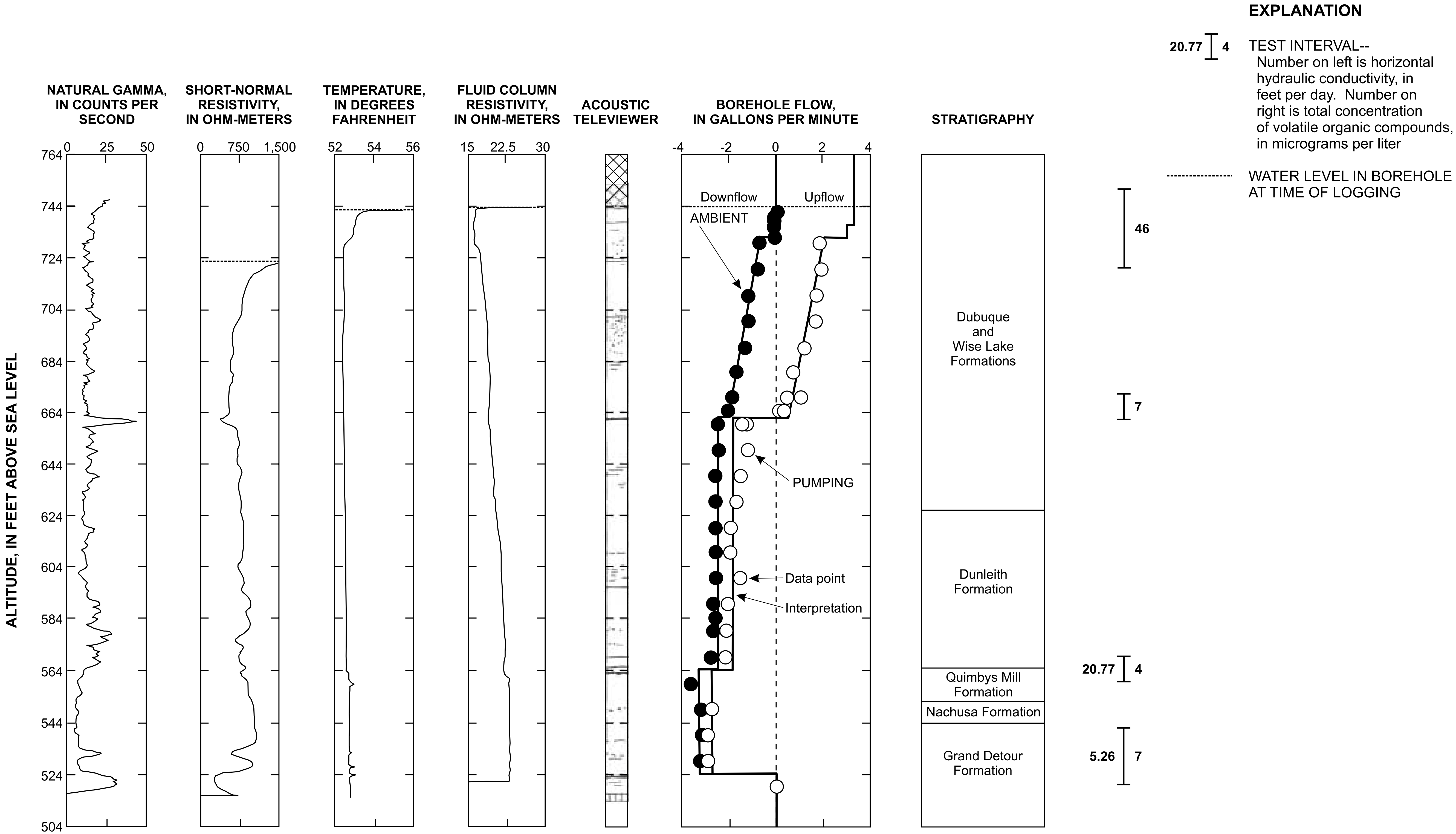

Figure 3. Natural-gamma, short-normal resistivity, fluid temperature, fluid-column resistivity, acoustic-televiewer, and flowmeter logs; stratigraphy; horizontal hydraulic conductivities; and total concentration of volatile organic compounds in the test intervals isolated with a packer assembly for borehole G124GP in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (See figure 1 for location of borehole.)

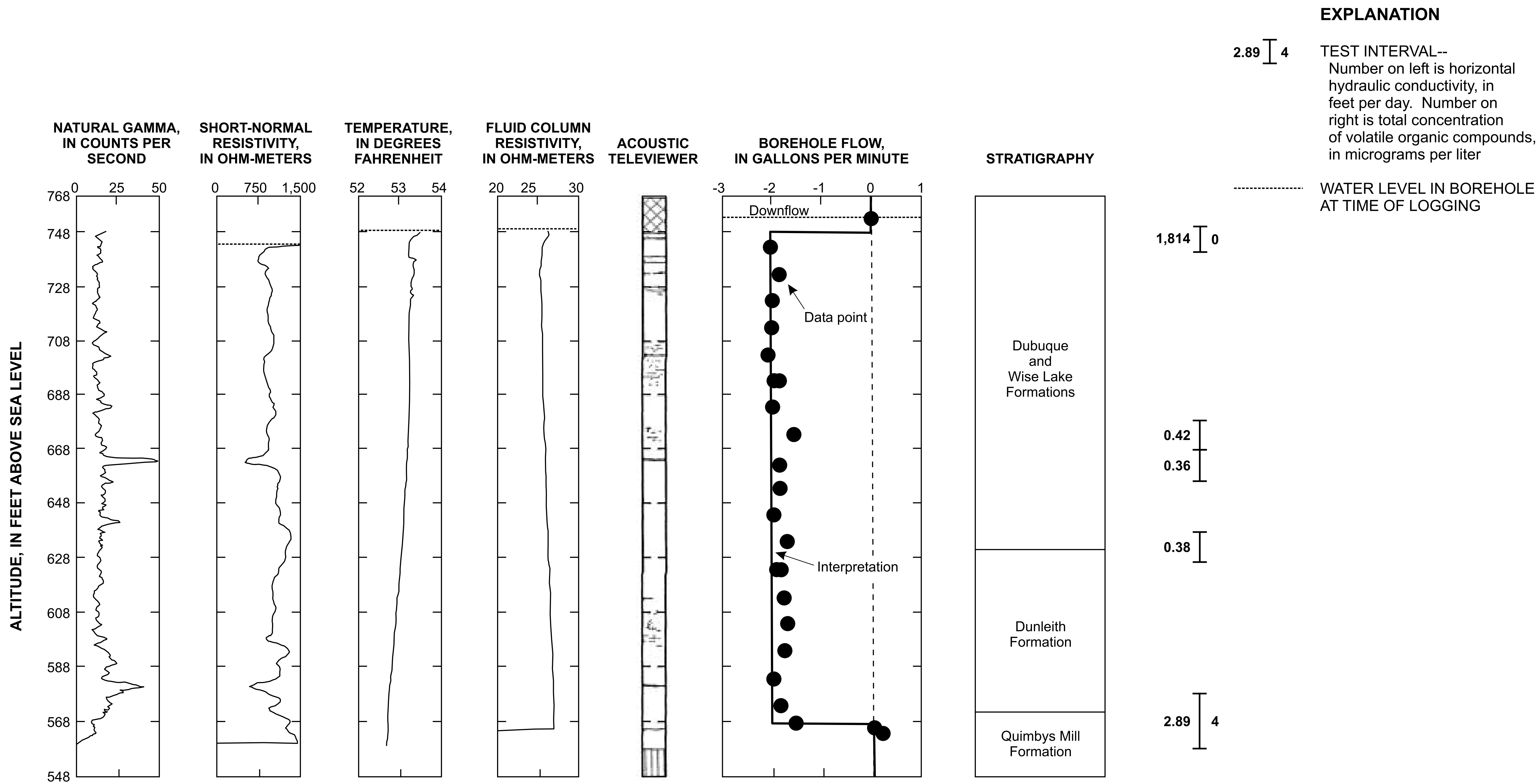

Figure 4. Natural-gamma, short-normal resistivity, fluid temperature, fluid-column resistivity, acoustic-televiewer, and flowmeter logs; stratigraphy; horizontal hydraulic conductivities; and total concentration of volatile organic compounds in the test intervals isolated with a packer assembly for borehole G130GP in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (See figure 1 for location of borehole.)

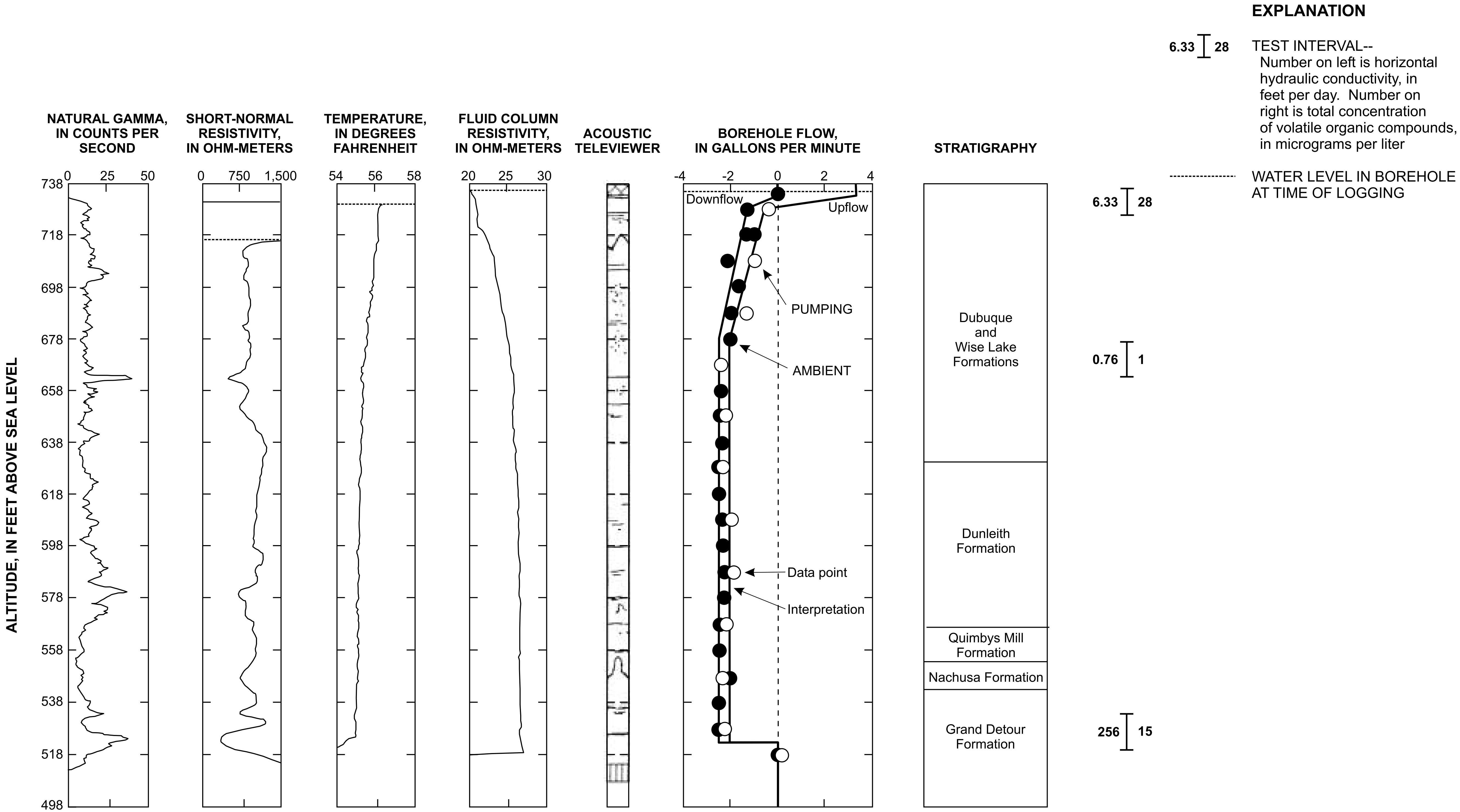

Figure 5. Natural-gamma, short-normal resistivity, fluid temperature, fluid-column resistivity, acoustic-televiewer, and flowmeter logs; stratigraphy; horizontal hydraulic conductivities; and total concentration of volatile organic compounds in the test intervals isolated with a packer assembly for borehole G133GP in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (See figure 1 for location of borehole.)

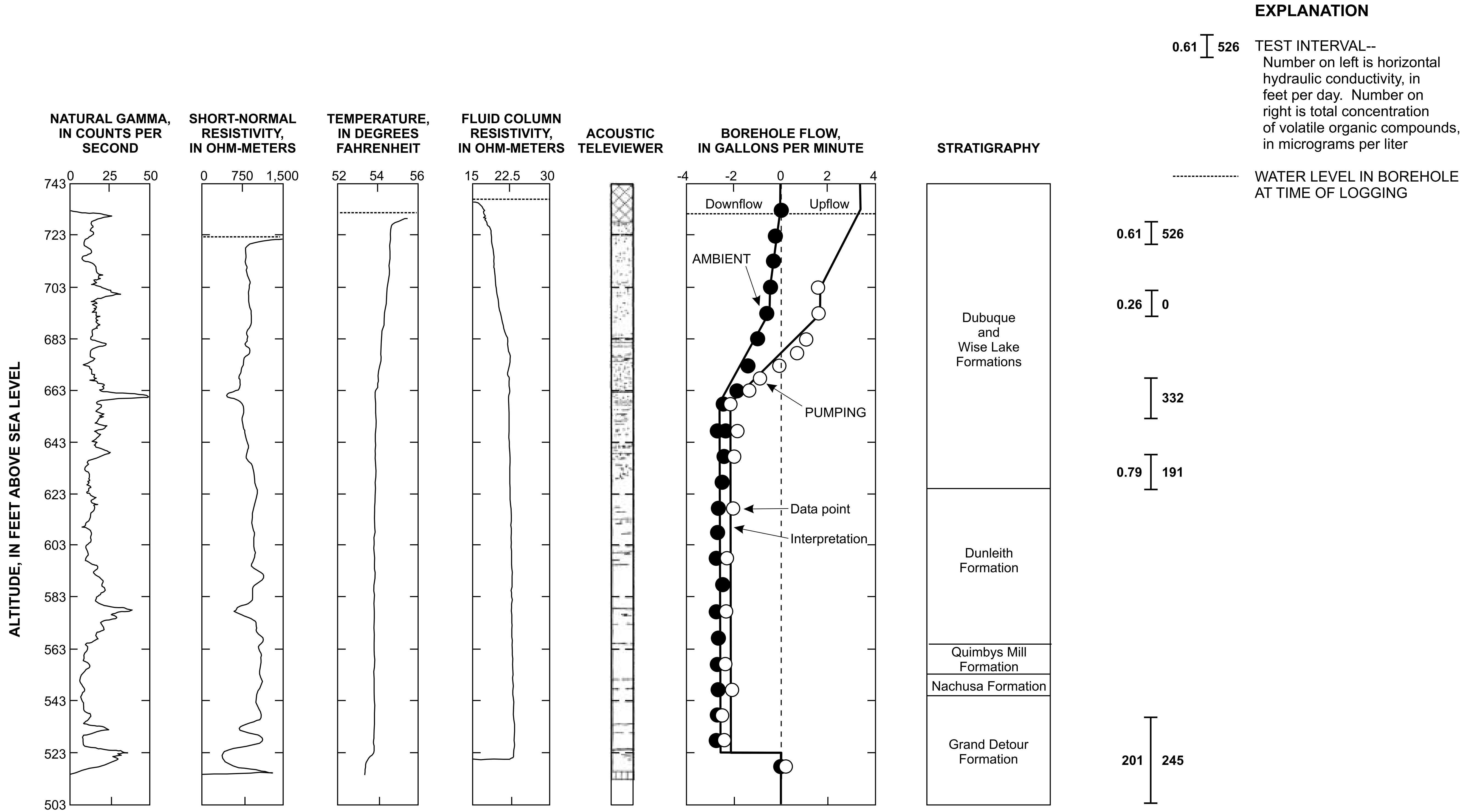

Figure 6. Natural-gamma, short-normal resistivity, fluid temperature, fluid-column resistivity, acoustic-televiewer, and flowmeter logs; stratigraphy; horizontal hydraulic conductivities; and total concentration of volatile organic compounds in the test intervals isolated with a packer assembly for borehole G134GP in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (See figure 1 for location of borehole.)

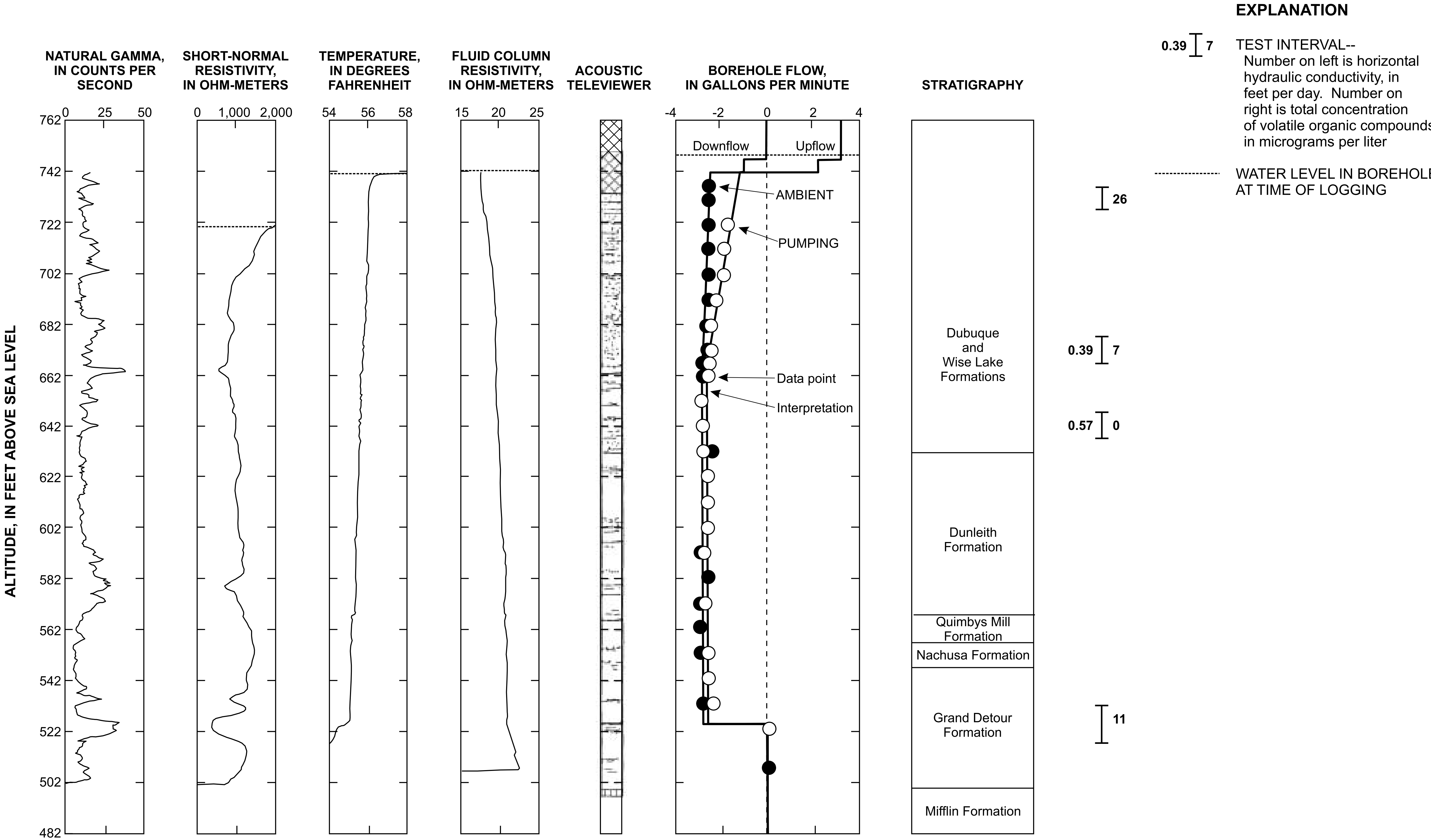

Figure 7. Natural-gamma, short-normal resistivity, fluid temperature, fluid-column resistivity, acoustic-televiewer, and flowmeter logs; stratigraphy; horizontal hydraulic conductivities; and total concentration of volatile organic compounds in the test intervals isolated with a packer assembly for borehole G136GP in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (See figure 1 for location of borehole.)

The basal deposit of the Galena Group in the study area is the Dunleith Formation (fig. 2). The Dunleith Formation is composed of cherty, gray-to-brown, medium to coarsely crystalline dolomite with some shale partings and mottling. The altitude of the Dunleith Formation is about 568-633 ft above sea level beneath the study area. The basal part of the Dunleith Formation can be identified on the natural-gamma logs by the elevated counts-per-second interval between about 572 and 597 ft (figs. 3-7). The Guttenburg Formation, which separates the Dunleith and Quimbys Mill Formations in much of Illinois, has been eroded away in the Belvidere area, and the Dunleith Formation unconformably overlies the Quimbys Mill Formation.

The Wise Lake Formation of the Galena Group overlies the Dunleith Formation and consists of tan and gray, vuggy, medium to thickly bedded, coarsely crystalline dolomite with some mottles. The Wise Lake Formation typically contains only small amounts of clay minerals (Willman and others, 1975). The contact between the Wise Lake Formation and the overlying Dubuque Formation (a brown to gray, medium to coarsely crystalline dolomite with shale partings) could not be identified in the cores collected during previous investigations at the PCHSS (Mills and others, 1998), and the two formations were not differentiated. The shaley layer at 662 ft above sea level is present throughout the study area.

Acoustic-televiewer logs measure the intensity of an acoustic signal reflected off the borehole wall (Keys, 1988). The log measures the amount of reflection of an oriented signal from the borehole wall over all 360 degrees at a given depth, providing an analog image of the borehole wall. Fractures, vugs, and other discontinuities in the borehole walls (such as a washout area where a shale parting has been eroded away) scatter the reflected signal and show up as dark areas on the logs (figs. 3-7). Because the signal is oriented, the depth, apparent thickness, and orientation of any fractures, vugs, and solution openings that intersect the borehole can be determined.

Vuggy intervals were detected at about 684-704 and 724-734 ft at borehole G124GP, between 693-708 ft at borehole G130GP, between 673-698 ft at borehole G133GP, above about 638 ft at borehole G134GP, and above about 662 ft at borehole G136GP (figs. 3-7). Televiewer logs run during previous investigations at the PCHSS indicate numerous vuggy intervals, including intervals at about 600-640 and 682-702 ft at borehole T7 (Kay and others, 2000) and 570-604, 624-654, 672-706 ft above sea level at well G127GP (Mills, 1993a). A televiewer log run during a previous investigation in borehole G128GP, located about 0.50 mi from the PCHSS and about 50 ft from Belvidere Municipal Well 6 (BMW6) (fig. 1), indicates the presence of vugs throughout the borehole, with some apparent concentration at about 500-510, 525-532, 540-560, 570-600, and 660-720 ft above sea level (Mills and others, 1998).

Acoustic-televiewer logs show numerous dark areas associated with subhorizontal fractures and perhaps washed out shale partings throughout the Galena-Platteville deposits (figs. 3-7, table 2). Almost all dark areas are associated with an increase in borehole diameter observed on the caliper logs (data not shown), which may be indicative of fractures. For the purposes of this discussion, all such features are assumed to be fractures. The subhorizontal fracture associated with the shaley bed at about 662 ft and the subhorizontal fracture near the bottom of the Dunleith and top of the Quimbys Mill Formations at about 564 ft were detected in each borehole drilled for this investigation, in addition to being detected at boreholes G127GP and G128GP. Subhorizontal fractures corresponding to argillaceous parts of the Grand Detour Formation were detected at about 524 ft above sea level in boreholes G124GP, G133GP, G134GP, and G136GP; and in boreholes G127GP, and G128GP (Mills and others 1998). Boreholes T7 and G130GP did not penetrate to 524 ft. Subhorizontal fractures were detected by televiewer logging at about 536, 579, 596, 648, 683, 702, 725, 732, and 738-745 ft above sea level in four or more boreholes in and near the study area (table 2). A subhorizontal fracture was detected in the middle of the Mifflin Formation at about 482 ft during previous investigations at the PCHSS (Mills and others, 1998).

Development of subhorizontal fractures in the Galena-Platteville deposits appears to be affected by a variety of processes. Subhorizontal fractures in the upper 10-20 ft of the bedrock are likely to be present because of weathering and erosion of the bedrock surface, particularly during the Quaternary system. The presence of some deeper, more areally extensive fractures appear to be affected by the stratigraphy and lithology of the Galena-Platteville deposits. The apparent fracture associated with the shaley bed at an altitude of 662 ft, for example, is located throughout the study area and may be due to a washout of the shale. The apparent fracture at about 564 ft, near the contact

Table 2. Altitude of subhorizontal fractures identified from televiewer logs in selected boreholes in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill.

[-, fracture not identified at this altitude; np, Galena-Platteville deposits not present at this altitude; bwl, below water level in borehole, presence of fracture cannot be verified by televiewer log]

Borehole name	Altitude of subhorizontal fracture, in feet above sea level																								
G124GP	744	-	-	-	723	703	684	-	-	662	-	-	-	-	-	-	-	608	596	-	564	563	-	538	524
G130GP	743	738	736	732	727	703	-	-	-	664	-	-	-	-	-	-	-	-	-	581	565	-	np	np	np
G133GP	np	np	np	734	726	704	684	-	-	665	-	653	-	-	-	-	-	-	598	578	569	558	-	536	524
G134GP	np	np	np	np	723	-	683	680	675	663	-	-	-	639	-	-	614	-	600	579	565	-	-	534	524
G136GP	np	bwl	bwl	732	-	702	-	-	-	662	660	-	648	-	630	624	-	-	596	576	566	-	-	534	522
G127GP	-	738	-	-	-	-	682	-	-	660	-	-	-	-	-	-	-	-	-	-	566	-	546	536	524
G128GP	744	742	-	-	-	707	682	-	-	660	-	-	645	643	-	-	-	-	-	579	562	-	-	534	521
T7	745	-	-	732	-	700	-	-	-	660	-	-	649	-	-	-	-	-	598	578	np	np	np	np	np

between the Quimbys Mill and Dunleith Formations, may be related to an unconformity during the Ordovician system. The fracture above the shale bed in the Grand Detour Formation, which also was observed at the Byron Salvage Yard Superfund site 30 mi west of the study area (Kay and others, 1997), may be related to enhanced dissolution associated with preferential ground-water flow above the shale layer.

Inclined fractures were detected at borehole G133GP at about 550 and 715 ft above sea level (fig. 5). The shallow inclined fracture had a measured dip of 86 degrees and a strike of 19 degrees west of north. The trend of this fracture is toward the western boundary of the PCHSS. The deeper inclined fracture at borehole G133GP has a dip of about 88 degrees and a strike of 79 degrees west of north. Inclined fractures at boreholes T1 and T6 on the PCHSS had a strike of about 30 degrees east of north (Kay and others, 2000). These trends are consistent with a vertical-fracture orientation of 30 degrees east of north and a second set oriented about 75 degrees west of north measured at a quarry about 5 mi from the study area in southeastern Boone County (Foote, 1982).

Short-normal resistivity logs were consistent between boreholes and tended to be inversely related to the natural-gamma logs (figs. 3-7). Resistivity values lower than the typical values for each log were measured at the shaley bed at about 662 ft and argillaceous dolomite units at about 522, 536, and 579 ft above sea level. Low normal-resistivity values are typical of porous and poorly consolidated deposits (Keys, 1988).

The top of the bedrock surface in the study area is highest (about 759 ft above sea level) west of the PCHSS and decreases toward the south and east to an estimated altitude of less than 650 ft beneath the Kishwaukee River (Berg and others, 1984). The highly weathered interval is restricted primarily to the upper 10-20 ft of the dolomite deposits.

Quaternary deposits unconformably overlie the bedrock throughout the study area. Quaternary deposits typically are less than 50 ft thick in the northern part of the study area, but thicken southward to an estimated 150 ft beneath the Kishwaukee River (Berg and others, 1984). Glaciofluvial sand-and-gravel deposits directly overlie the bedrock throughout most of the study area (Science Applications International Corporation, 1992, figs. 3-12 to 3-17). The sand-and-gravel deposits are overlain by silty clay with interspersed sand and gravel (Science Applications International Corporation, 1992, figs. 3-12 to 3-17).

HYDROLOGY

The hydrologic units of concern in the study area are the shallow unconsolidated aquifer, the unconsolidated semiconfining unit, the deep unconsolidated aquifer, the Galena-Platteville aquifer, the Glenwood semiconfining unit, and the St. Peter Sandstone aquifer (fig. 2). The shallow unconsolidated aquifer is composed of saturated sand-and-gravel deposits present in the southern part of the PCHSS (Science Applications International Corporation, 1992). This aquifer is not present in most of the study area. The unconsolidated semiconfining unit is composed of unconsolidated silt and clay deposits that overlie the deep unconsolidated aquifer. The deep unconsolidated aquifer is composed of saturated sand-and-gravel deposits that are in good hydraulic connection with the upper part of the underlying Galena-Platteville aquifer (Mills, 1993a). The Glenwood semiconfining unit is composed of argillaceous dolomite deposits in the upper part of the Glenwood Formation. The St. Peter Sandstone aquifer underlies the Glenwood semiconfining unit and is composed of the sandstones of the Glenwood and St. Peter Sandstone Formations. This investigation focused on the hydrology of the Galena-Platteville aquifer. The hydrology of the other units is not discussed in this report, except as it pertains to the hydrology and water quality of the Galena-Platteville aquifer.

Hydraulically Active Features

Temperature logs measure the temperature of the fluid column in the borehole. Water temperature in the Galena-Platteville aquifer typically was between 52 and 56°F and decreased with depth (figs. 3-7). Fluid-column-resistivity logs measure the capability of the water in the borehole to conduct electrical current and can show an inverse relation to the concentration of dissolved solids in the fluid column (Keys, 1988). Fluid-column-resistivity values for the Galena-Platteville aquifer ranged between 15 and 30 ohm-meters and increased overall with depth (figs. 3-7). Because variations in water quality with depth in a borehole can be caused by inflow (flow from the aquifer into the borehole) or outflow (flow from the borehole out to the aquifer), changes of temperature and fluid resistivity with depth in the borehole can indicate intervals of increased aquifer permeability. Both temperature and fluid-column-resistivity logs show abrupt changes at about 563 and 727 ft above sea level in borehole G124GP and possibly at about 743 ft in borehole G130GP. Both logs show a change in slope at about 660 ft in borehole G133GP and above about 663-673 ft in borehole G134GP. These logs also show abrupt changes at about 524 and 567 ft and possibly a slight change at about 597, 662, and 707 ft in borehole G136GP.

Heat-pulse flowmeter logs measure the rate and direction of ground-water flow within a borehole induced by the variations in hydrostatic pressure within that part of the aquifer penetrated by the borehole. Commonly, depths where changes in the rate of flow occur are associated with features that have increased permeability. Inflow is identified by an increase in flow rate in the direction of flow. Outflow is identified by a decrease in the flow rate in the direction of flow.

Flow direction and aquifer permeability were characterized on the basis of data from flowmeter logs run under ambient-flow conditions (no pumping in the boreholes) in boreholes G124GP, G130GP, G133GP, G134GP, and G136GP and during pumping near the top of the water column in boreholes G124GP, G133GP, G134GP, and G136GP (Frederick Paillet, U.S. Geological Survey, written commun., 1999) (figs. 3-7). Flowmeter logging indicates ground-water flow was directed downward in the Galena-Platteville aquifer at each borehole under ambient-flow conditions.

Flowmeter logging under ambient-flow conditions in borehole G124GP indicated gradually increasing inflow associated with subhorizontal fractures and vugs from about 662 to 739 ft, inflow associated with a subhorizontal fracture at about 564 ft, and outflow through the subhorizontal fracture at about 524 ft (fig. 3). Flowmeter logging during pumping identified the same hydraulically active features, but highlighted the flow contributions from the subhorizontal fractures at 662 and 739 ft above sea level.

Flowmeter logging under ambient-flow conditions in borehole G130GP indicated inflow associated with the subhorizontal fracture at about 746 ft and outflow through the subhorizontal fracture at about 564 ft (fig. 4). No other hydraulically active features were identified in this borehole.

Flowmeter logging under ambient-flow conditions in borehole G133GP indicated inflow associated with the subhorizontal fracture below the bottom of the casing at about 734 ft, gradually increasing inflow associated with vugs and subhorizontal and inclined fractures from about 665 to 734 ft and outflow through the subhorizontal fracture at about 524 ft (fig. 5). No flow was identified through the inclined fracture at about 550 ft. Flowmeter logging during pumping identified the same hydraulically active features.

Flowmeter logging under ambient-flow conditions in borehole G134GP indicated gradually increasing inflow associated with subhorizontal fractures and vugs from about 662 to 723 ft and outflow through the subhorizontal fracture at about 524 ft (fig. 6). Flowmeter logging during pumping identified the same hydraulically active features.

Water-level fluctuations in borehole G136GP prevented collection of acoustic-televiewer data from 732 to 754 ft, so the features in this interval (vugs, fractures) could not be identified. However, flowmeter logging under ambient-flow conditions in borehole G136GP indicated inflow associated with unidentified features between about 740 ft and the bottom of the well casing at 754 ft. The large increase in flow over a short distance indicates these features probably are fractures. Gradually increasing inflow is associated with subhorizontal fractures and vugs from about 662 to 740 ft above sea level. Outflow was through the subhorizontal fracture at about 524 ft (fig. 7). Flowmeter logging during pumping identified the same hydraulically active intervals but emphasized the presence of the flow contributions from the interval between about 662 and 740 ft.

Borehole flow values measured during pumping in boreholes G124GP, G133GP, G134GP, and G136GP were similar to values measured under ambient conditions below about 662 ft. Differences between the amount of flow under ambient and pumping conditions generally increased with increasing altitude above 662 ft, indicating that the amount of drawdown induced by pumping was sufficient to divert a substantial amount of the downflow above 662 ft but had little affect below 662 ft. This pattern indicates the hydraulic head within the Galena-Platteville aquifer above 662 ft is substantially greater than the hydraulic head below 662 ft and that vertical hydraulic gradients in the aquifer above 662 ft are lower than vertical hydraulic gradients in the aquifer below 662 ft.

The depths of the hydraulically active features identified by the flowmeter logs generally are consistent with the depths of the hydraulically active features indicated by the temperature and fluid-resistivity logs. Results of the flowmeter logging obtained during the current investigation are partially consistent with the results of flowmeter logging done as part of previous investigations in boreholes in and near the study area (Mills, 1993b; Mills and others, 1998; Kay and others, 2000). Flow was identified from shallow fractures near the top of the dolomite, vugs in the upper part of the bedrock, the shaley interval at 662 ft, and the subhorizontal fracture at about 524 ft during previous investigations at the PCHSS and at borehole G128GP. However, flow through the vugs in the upper part of the bedrock, where present, tended to be restricted to about 682-692 ft in boreholes logged for previous investigations, and the amount of flow through the fracture at about 662 ft was higher for previous investigations than detected during the current investigation. In addition, flow measured through a vuggy interval between 640 and 590 ft at boreholes T1-T7 during a previous investigation (Kay and others, 2000) was not detected in the boreholes drilled for this investigation. The results of the flowmeter logging indicate hydraulically active features consistently are present near the bedrock surface and at about 524 ft in the study area, but the presence and extent of hydraulic activity in the vuggy intervals and the other fractures is variable in the study area.

Water Levels

In September 1999, vertical variations in water levels within the Galena-Platteville aquifer were measured in discrete test intervals isolated with a packer assembly (table 3). The packer assembly consists of two 4-ft-long inflatable nitrile packers separated by 10 ft of stainless-steel screen (fig. 8). The packer assembly was constructed so that water levels could be measured above, within, and below the test intervals after the packers were inflated and the water levels had equilibrated. Water levels above, within, and below the test intervals were not equal, which indicates that the packers were effectively isolating the test intervals from the rest of the borehole.

Test intervals isolated with the packer assembly consisted of representative intervals of boreholes G124GP, G130GP, G133GP, G134GP, and G136GP (table 3). The water-level altitude decreased consistently above, within, and below the packed intervals in each borehole, indicating the potential for downward flow within the Galena-Platteville aquifer throughout the study area. This interpretation is consistent with the results of the flowmeter logging. This interpretation also is consistent with the results of previous investigations in and near the study area, although transient upward flow occasionally was indicated during previous investigations (Mills and others, 1998; Kay and others, 2000).

Water levels in the test intervals open to the fracture at about 524 ft in boreholes G124GP, G133GP, G134GP, and G136GP typically were substantially lower than the water levels in the overlying intervals. Vertical variation of water levels in the test intervals at borehole G130GP, which does not penetrate the fracture at 524 ft, are substantially less than the vertical variation of water levels in the remaining boreholes. The low water levels near the bottom of the boreholes indicate pumping effects from Belvidere Municipal Well 4 (BMW4) and BMW6, and possibly other water-supply wells, are being transmitted through the fracture at 524 ft and also may indicate low vertical hydraulic interconnection within the Galena-Platteville aquifer.

Water levels in the test intervals open at or near the shaley layer at about 662 ft in boreholes G124GP,

Table 3. Water levels measured during testing with a packer assembly under approximately hydrostatic conditions in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., September 1999

[na, not applicable; <, less than; nt, measurement not taken]

Borehole name	Date of measurement	Altitude of test interval (feet above sea level)	Water-level altitude (feet above sea level)			
			Open borehole before packer inflation	Above test interval	In test interval	Below test interval
G124GP	September 10, 1999	737-747	742.75	na	757.03	<754
G124GP	September 10, 1999	716-747	nt	na	748.68	745.87
G124GP	September 10, 1999	658-668	747.25	760.38	758.40	743.87
G124GP	September 10, 1999	556-566	nt	758.11	752.51	731.49
G124GP	September 10, 1999	518-540	nt	756.23	726.45	na
G124GP	September 11, 1999	518-540	nt	758.95	731.55	na
G130GP	September 8, 1999	742-747	nt	na	763.48	761.72
G130GP	September 10, 1999	626-636	nt	763.41	756.79	751.15
G130GP	September 10, 1999	558-576	751.46	nt	750.07	na
G133GP	September 14, 1999	726-733	732.57	na	756.35	747.41
G133GP	September 14, 1999	667-677	735.80	752.26	751.05	732.16
G133GP	September 15, 1999	667-677	736.22	757.11	755.93	728.62
G133GP	September 15, 1999	522-532	nt	751.58	730.18	nt
G134GP	September 16, 1999	718-728	nt	na	753.12	748.35
G134GP	September 16, 1999	692-702	nt	753.28	753.02	748.30
G134GP	September 17, 1999	628-638	nt	753.89	743.51	732.81
G134GP	September 17, 1999	516-537	748.07	752.24	728.41	na
G136GP	September 20, 1999	742-754	749.30	na	763.61	<759
G136GP	September 20, 1999	667-677	nt	763.83	761.5	732.81
G136GP	September 21, 1999	637-647	nt	763.57	741.33	733.17
G136GP	September 21, 1999	520-530	736.57	759.55	729.18	729.12

G133GP, and G136GP were within 2.5 ft of the water levels above the test interval but were more than 14 ft higher than the water levels below the test interval (table 3). The small difference in water levels above 662 ft and the large difference in water levels below 662 ft may indicate substantial pumping effects are not transmitted up to this altitude in these wells and vertical hydraulic interconnection (perhaps because of an increased density of vertical fractures or an extensive network of interconnected vugs) within the Galena-Platteville aquifer is greater above the shaley layer than below the shaley layer.

Previous investigations in the vicinity of the PCHSS have established that water levels in the lower parts of the Galena-Platteville aquifer can fluctuate by more than 20 ft in response to individual pumping cycles at BMW4 and BMW6 (Mills and others, 1998; Kay and others, 2000) and perhaps other water-supply wells in Belvidere. Water levels were monitored in wells G133GP, G134GPS, G134GPD, G136GPS, and G136GPD from February 4-28, 2000, and in wells G124GPS and G124GPD from February 14-28, 2000, to establish the effects of pumping from water-supply wells on water levels and flow directions in the Galena-Platteville aquifer (figs. 9-12). Wells G124GPD, G133GP, G134GPD, and G136GPD are open to the subhorizontal fracture at about 524 ft above sea level. Wells G124GPS, G134GPS, and G136GPS are open near the top of the Galena-Platteville aquifer. Water levels in each well were measured simultaneously with calibrated pressure transducers and recorded with a datalogger every 15 minutes. Periodic water-level measurements using electric tapes indicated the transducers were giving accurate water-level readings.

Pumping schedules during the monitoring period are not representative of typical conditions. During periods of normal operations, BMW4 is pumped frequently for periods of tens of minutes, whereas BMW6 is pumped less frequently but often for more than 100 minutes. BMW4 was not in operation during the monitoring period, whereas BMW6 was pumped frequently each day for periods of tens of minutes. Industrial-supply wells 00295 and 00296 south of the

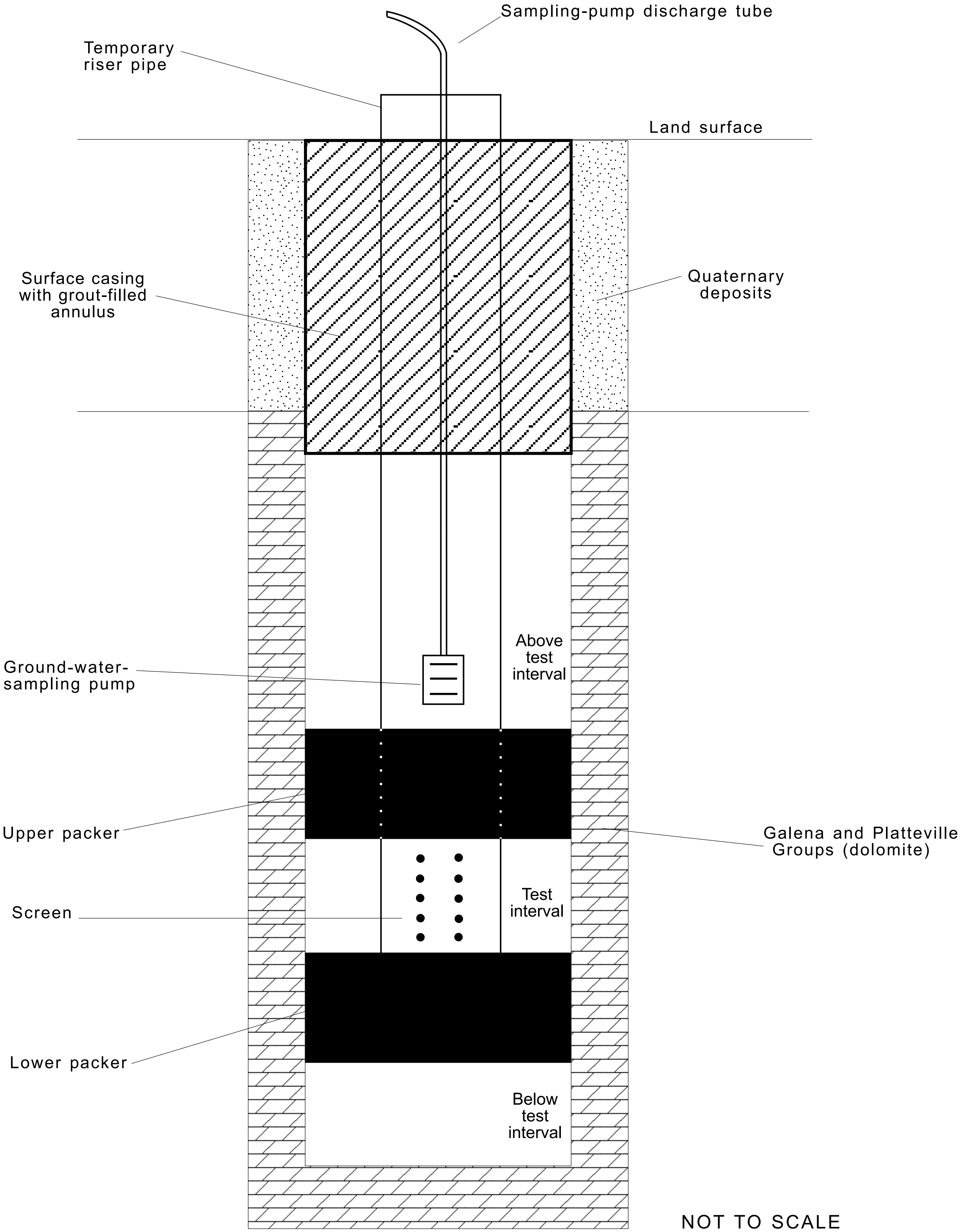

Figure 8. Packer assembly and ground-water sampling pump in a borehole.

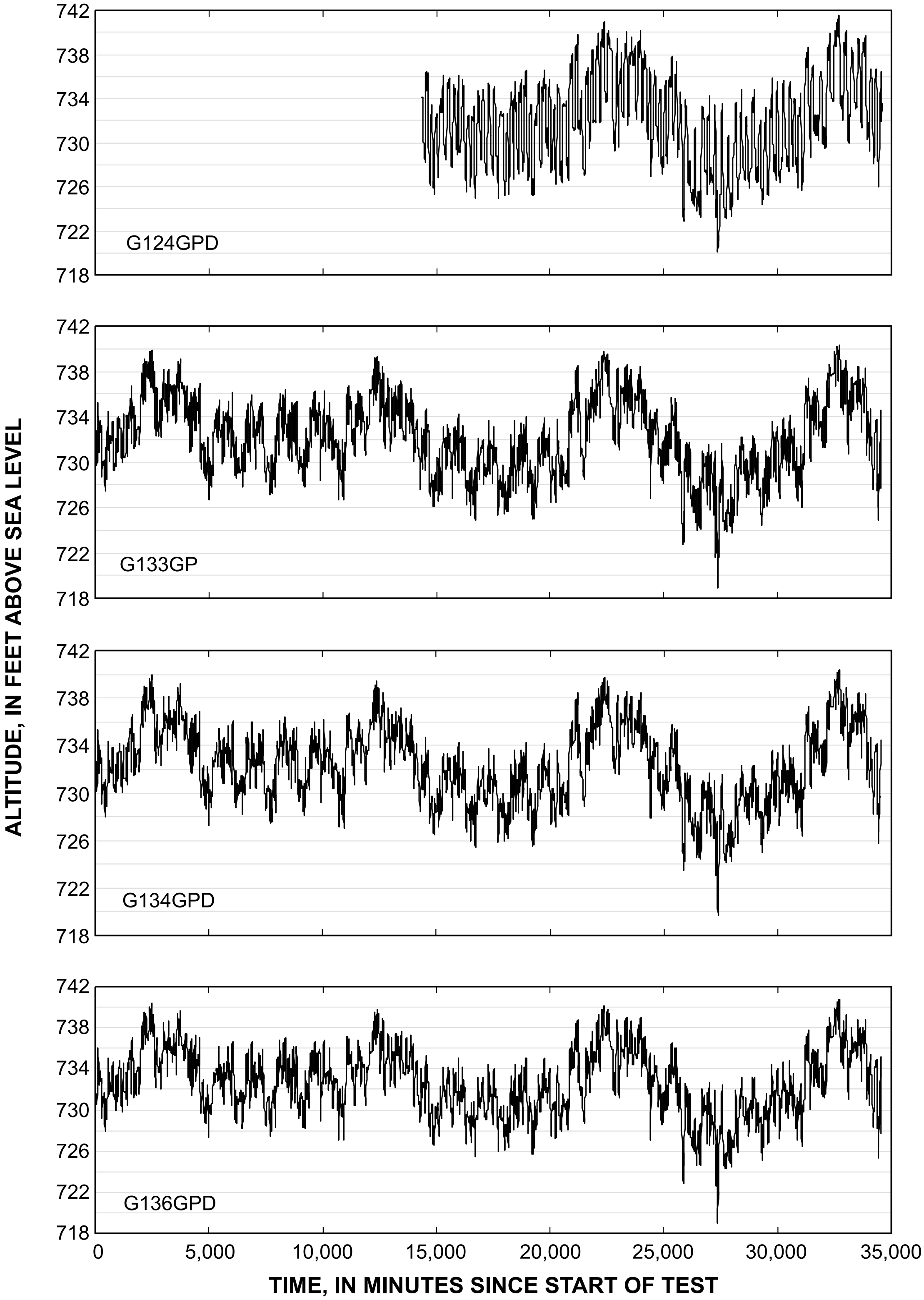

Figure 9. Water-level altitude in wells G124GPD, G133GP, G134GPD, and G136GPD in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., February 4-28, 2000.

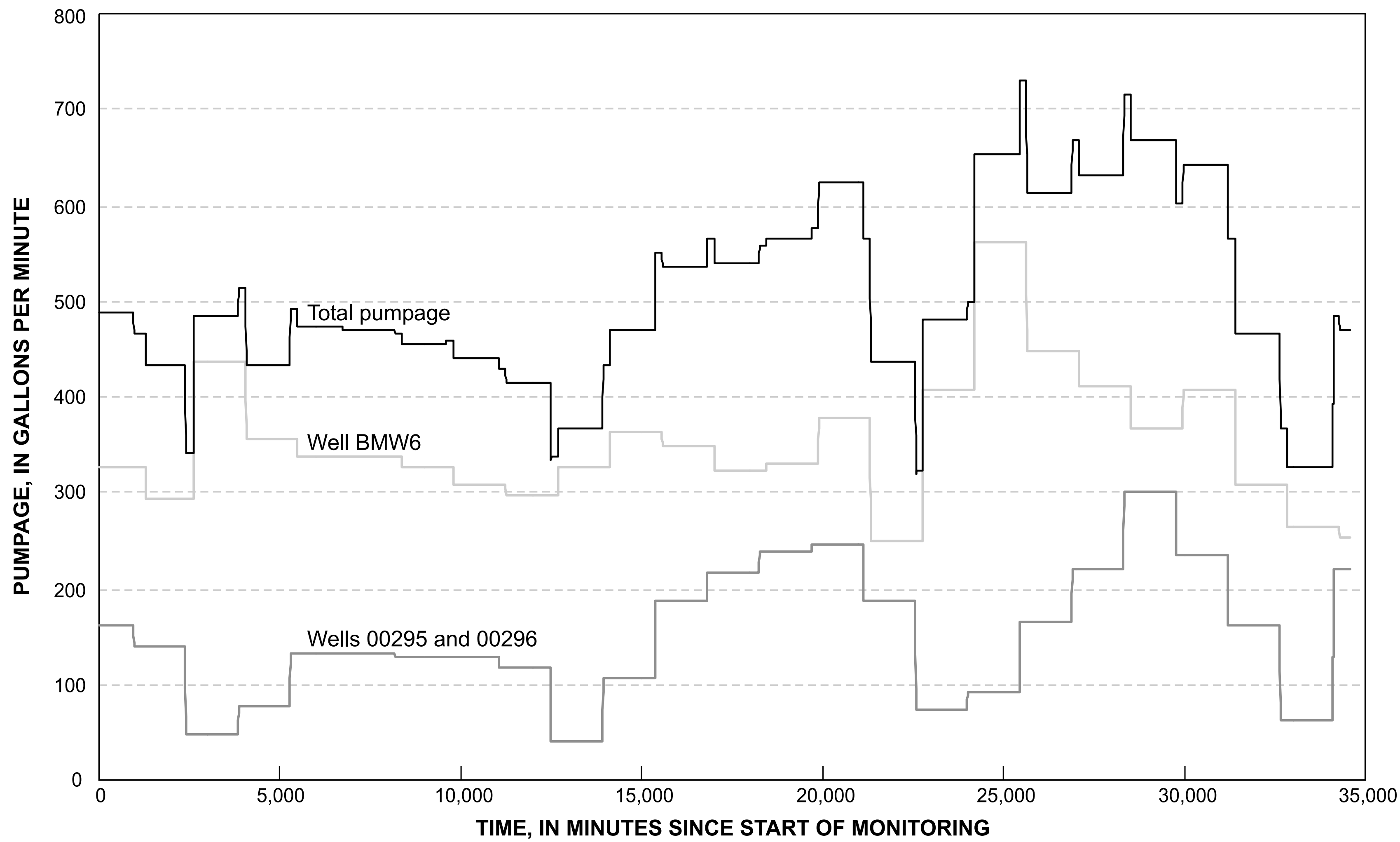

Figure 10. Pumping totals for wells 00295 and 00296 combined and well BMW6 in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., February 4-28, 2000.

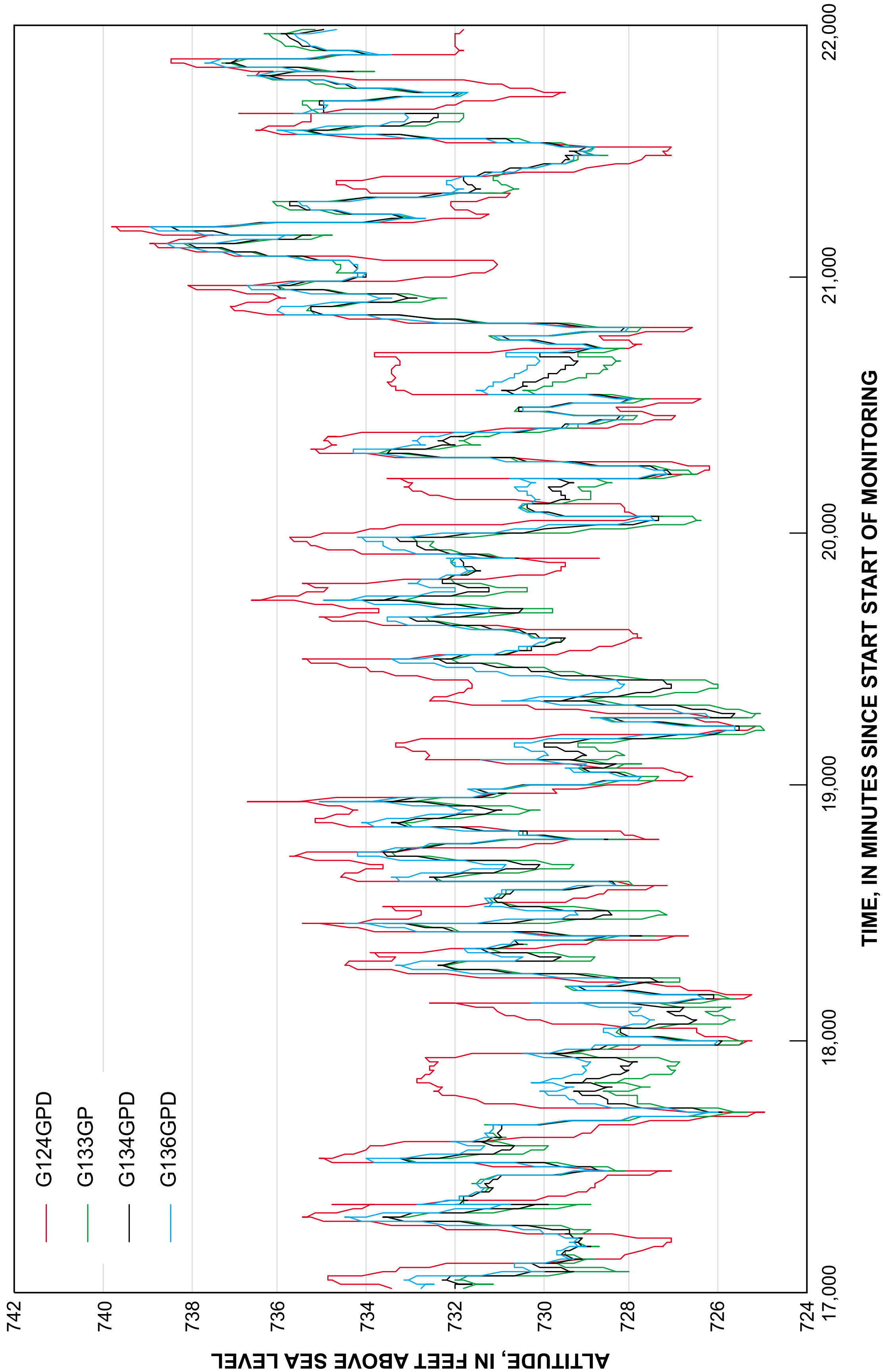

Figure 11. Water-level altitude in wells G124GPD, G133GP, G134GPD, and G136GPD in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., February 6-19, 2000.

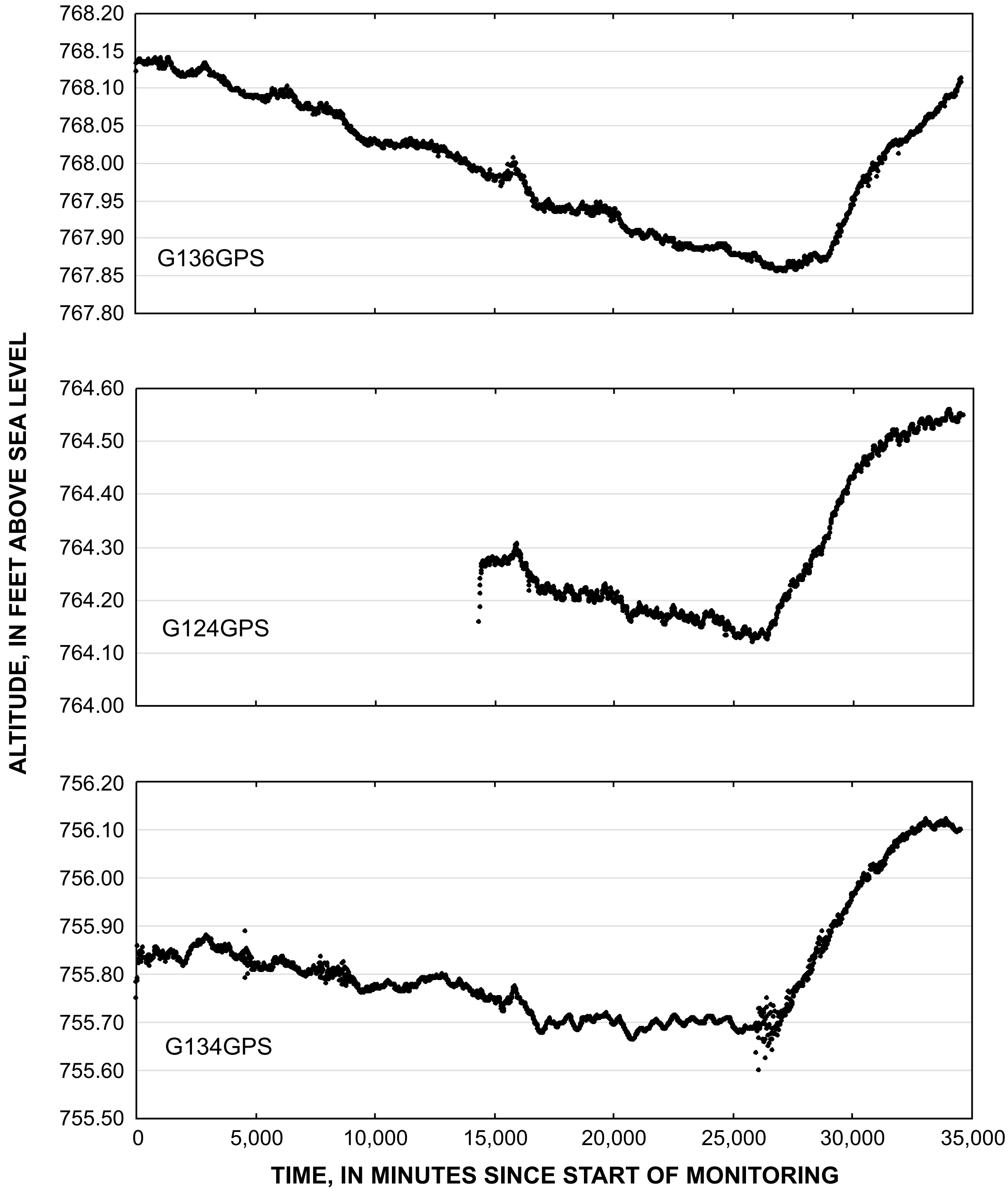

Figure 12. Water-level altitude in wells G124GPS, G134GPS, and G136GPS in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., February 4-28, 2000.

river (fig. 1) are pumped continuously during the week but pump less water during the weekend. All water-supply wells are open from the upper part of the Galena-Platteville aquifer to a depth of 550 ft for well 00296, 627 ft for well 00295, 868 ft for well BMW6, and 1,800 ft for well BMW4 (table 1). Water is pumped from primarily the St. Peter Sandstone aquifer in wells 00296 and 00295. Water is pumped from primarily the St. Peter Sandstone and Ironton-Galesville aquifers in well BMW6. Water is pumped from primarily the St. Peter Sandstone, Ironton-Galesville, and Mt. Simon aquifers in well BMW4. The subhorizontal fracture at about 524 ft appears to be present at well BMW6 (Mills, 1993b; Mills and others, 1998). Data are unavailable to determine if this fracture is present at well BMW4 or wells 00295 and 00296.

Water-level trends were similar in wells G124GPD, G133GP, G134GPD, and G136GPD (figs. 9, 11). Changes in water level in the wells in the 15 minutes between measurements were often greater than 1 ft. During the monitoring period, water levels in each well varied from about 719 to 741 ft above sea level. Water-level changes of this magnitude cannot be attributed to natural phenomena and likely are caused by the effects of pumping and the cessation of pumping in the water-supply wells.

Data from a USGS streamflow-gaging station (number 05438500) on the Kishwaukee River about 2 mi downstream from the study area indicate the stage of the river ranged from about 739.5 to 742.5 ft above sea level during February 2000. The station is about 0.5 mi downstream from a dam with about 5 ft of fall (Patrick Mills, U.S. Geological Survey, written commun., 2000). During February 2000, the stage of the Kishwaukee River at the study area upstream from the dam, therefore, must have been at least 5 ft higher than the stage measured at the streamflow-gaging station or about 744.5 to 747.5 ft above sea level. The stage of the Kishwaukee River was higher than the water-level altitude in the subhorizontal fracture at about 524 ft, indicating water in the deeper part of the Galena-Platteville aquifer near the PCHSS does not discharge to the Kishwaukee River.

Water levels were compared to daily pumping totals measured at wells 00295 and 00296 combined and well BMW6 (Gary Yunto, Pillsbury Corporation, written commun., 2000; James Grimes, city of Belvidere, written commun., 2000)(fig. 10). Although the wells were not pumped continuously for the entire monitoring period, pumping is assumed to be continuous. Comparison of water levels (fig. 9) and pumpage (fig. 10) indicate water levels typically decreased during periods of increased pumping in the water-supply wells and typically increased during periods of decreased pumping. No clear differentiation can be made between the effects of pumping in wells 00295 and 00296, and BMW6.

Comparison of the water-level altitude in the wells open to the fracture at 524 ft above sea level indicates water-level fluctuations within a given time span tended to be largest at well G124GPD and more moderate in wells G133GP, G134GPD, and G136GPD (figs. 9, 11). Because of the variability in the water-level fluctuations, the relative water-level altitude in these wells changed frequently during the monitoring period and, therefore, flow directions through the fracture were variable.

During periods of high water levels, the water-level altitude in well G124GPD was often more than 0.5 ft higher than in well G136GPD and the water-level altitude in well G136GPD was often about 0.5 ft higher than in wells G133GP and G134GPD, which tended to have similar water levels. These water-level trends indicate that during periods when pumping from the water-supply wells had a smaller effect on water levels, flow through the fracture in the Galena-Platteville aquifer at about 524 ft typically was from the PCHSS south toward the Kishwaukee River and wells 00295 and 00296.

At 27,375 minutes into the monitoring period, when the lowest water levels were recorded, the water-level altitude in wells G124GPD, G133GP, G134GPD, and G136GPD were 720.13, 718.91, 719.70, and 719.01 ft above sea level, respectively, indicating overall flow toward the Kishwaukee River at this time. During most of the periods of low water levels, however, the water-level altitude in well G136GPD was 0.5-3 ft higher than in well G124GPD and less than 1.5 ft higher than the water-level altitude in wells G134GPD and G133GP (fig. 11). These trends in water level indicate that during periods of pumping from well BMW6, a cone of depression is transmitted through the fracture at 524 ft. The magnitude of the cone of depression is large enough to overcome the natural gradient in this fracture at well G124GPD and perhaps well G136GPD, reversing the (presumed) natural direction of flow toward the south and inducing flow to the north toward BMW6. The extent of the area of reversal in the flow direction would likely be affected by the duration of pumping in well BMW6 and the pumping cycles in the other nearby water-supply wells but could potentially include all of the area beneath the PCHSS. It is possible that flow would be induced toward well BMW4 when well BMW4 is pumped.

The large water-level response in the wells open to the fracture at about 524 ft above sea level to the pumping cycles observed during the current and previous investigations indicates this fracture is hydraulically connected to wells BMW4 and BMW6 and may be hydraulically connected to wells 00295 and 00296 and other water-supply wells south of the river. During periods of comparatively high water levels, flow through the fracture appears to be toward the Kishwaukee River and wells 00296 and 00295. Comparatively high water levels in the fracture at about 524 ft appear to result from smaller amounts of pumping in well BMW6, and perhaps other water-supply wells. During periods of comparatively low water levels associated with larger amounts of pumping in well BMW6, flow through the fracture at about 524 ft appears to be toward well BMW6.

Water levels near the top of the Galena-Platteville aquifer in wells G124GPS, G134GPS, and G136GPS varied by less than 1 ft during the monitoring period (fig. 12). Water levels in these wells showed a less than 0.30 ft of decline from the start of the monitoring until about 27,000 minutes, then rose by more than 0.2 ft, presumably in response to recharge from precipitation and snowmelt. Water levels in the wells open near the top of the aquifer showed no correlation with pumping in the water-supply wells and typically were 15 to 25 ft higher than water levels in the wells open to the fracture at about 524 ft. This result is consistent with the results of the water-level monitoring using the packer assembly and indicates the potential for downward flow within the aquifer and poor vertical hydraulic connection between the upper part of the aquifer and the fracture at 524 ft above sea level. Water levels in the shallow part of the Galena-Platteville aquifer were greater than the estimated stage of the Kishwaukee River during the monitoring period, indicating the potential for water in the shallow part of the aquifer to discharge to the river.

Hydraulic Properties

The transmissivity of the Galena-Platteville aquifer at boreholes G130GP, G133GP, G134GP, and G136GP was calculated to range from 270 to 5,400 ft^2/d on the basis of an analysis of the specific-capacity data obtained during purging of the boreholes (Walton, 1962) (table 1). These transmissivity values are based on numerous simplifying assumptions and should be considered rough estimates of the aquifer as a whole at the location of the boreholes. Details of the assumptions and methods used for analysis of the specific-capacity data are described in Kay and others (1994).

Transmissivity and horizontal hydraulic conductivity were calculated from data collected during slug testing in 16 discrete intervals isolated with a packer assembly at boreholes G124GP, G130GP, G133GP, G134GP, and G136GP (figs. 3-7; table 4). Packer assemblies (fig. 8) were used to isolate an interval of the borehole from the rest of the aquifer so that the hydraulic properties of the features (fractures and vugs) in the isolated intervals could be determined.

Slug-test data for the 742-747 ft test interval in borehole G130GP and the 522-532 ft test interval in borehole G133GP were analyzed on the basis of the oscillatory-response technique of van der Kamp (1976). Slug-test data from the remaining test intervals were analyzed on the basis of the technique of Bouwer and Rice (1976). Details of the methods used for collection and analysis of the slug-test data are described in Kay and others (2000). Horizontal-hydraulic-conductivity values are estimated from the transmissivity values by assuming an aquifer thickness equal to the thickness of the packed interval.

In the boreholes drilled for this investigation, calculated values for horizontal hydraulic conductivity of the test intervals within the upper 20 ft of the bedrock surface (742-747 ft in borehole G130GP, 726-733 ft in borehole G133GP, and 718-728 ft in borehole G134GP) ranged from 0.61 to 360 ft/d. These values generally are consistent with the range of 0.054-170 ft/d for this interval calculated during previous investigations within the study area (Mills and others, 1998; Kay and others, 2000). The geometric mean horizontal hydraulic conductivity for the 12 slug tests done in the upper 20 ft of the bedrock for current and previous investigations in the study area is calculated to be 3.5 ft/d.

Horizontal-hydraulic-conductivity values calculated for the five test intervals open to the Galena-Platteville aquifer from more than 20 ft below the bedrock surface to the base of the shaley bed at about 662 ft ranged from 0.26 to 0.92 ft/d. These values are consistent with the range of 0.067-10 ft/d for this

Table 4. Results of slug testing in test intervals isolated with a packer assembly in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill.

[nc, not calculated]

Borehole name	Altitude of test interval (feet above sea level)	Depth of test interval (feet below land surface)	Horizontal hydraulic conductivity (feet per day)	Transmissivity (feet squared per day)
G124GP	556-566	218-228	21	nc
G124GP	518-540	243-267	5.26	nc
G130GP	742-747	41-46	360	1,800
G130GP	668-678	110-120	.92	nc
G130GP	658-668	120-130	.36	nc
G130GP	626-636	152-162	.38	nc
G130GP	558-576	212-230	2.9	nc
G133GP	726-733	45-52	6.33	nc
G133GP	667-677	101-111	.76	nc
G133GP	522-532	246-256	5.7	570
G134GP	718-728	55-65	.61	nc
G134GP	692-702	81-91	.26	nc
G134GP	628-638	145-155	.79	nc
G134GP	516-537	246-266	200	nc
G136GP	667-677	105-115	.39	nc
G136GP	637-647	135-145	.57	nc

interval calculated during previous investigations (Mills, 1993b; Kay and others, 2000). The calculated geometric mean of the horizontal-hydraulic-conductivity values for the 28 slug tests done in this interval for current and previous investigations in the study area is 0.36 ft/d.

Horizontal-hydraulic-conductivity values calculated from three slug tests done in the 525-662 ft interval of the boreholes drilled for this investigation, excluding the fracture at about 564 ft in boreholes G124GP and G130GP, ranged from 0.38 to 0.79 ft/d. These values are consistent with a range of 0.036-0.80 ft/d calculated from this interval during previous investigations. The mean horizontal hydraulic conductivity for the 29 slug tests done in this interval within the study area was calculated to be 0.29 ft/d.

During this investigation, horizontal-hydraulic-conductivity values calculated from the two slug tests done in the 564-ft fracture were 2.9 and 21 ft/d. These values are consistent with the values of 0.036 and 15 ft/d calculated from this interval during previous investigations. The mean horizontal-hydraulic-conductivity value calculated from the four slug tests open to the fracture at about 564 ft within the study area was calculated to be 2.4 ft/d.

Horizontal-hydraulic-conductivity values calculated from the three slug tests done in the fracture at about 524 ft during this investigation were 5.3, 5.7, and 200 ft/d. These values generally are consistent with the values of 0.13 and 180 ft/d calculated from this interval during previous investigations (Mills and others, 1998). The mean horizontal-hydraulic-conductivity value for the five slug tests done in this interval within the study area was calculated to be 11 ft/d.

Geophysical logging and aquifer testing done during the current investigation, combined with the results of previous investigations (Mills, 1993b; Mills and others, 1998; Kay and others, 2000) indicate horizontal flow in the Galena-Platteville aquifer can be divided into five zones in the vicinity of the PCHSS. Zone 1 is present in the upper 20 ft of the bedrock throughout the study area. Flow in zone 1 is through the weathered fractures in the upper part of the bedrock surface. This zone, as a whole, is highly permeable. Zone 2 is about 60-80 ft thick and extends from the bottom of the most weathered part of the bedrock to the top of the shaley layer at about 662 ft above sea level. This zone corresponds to undifferentiated parts of the Dubuque and Wise Lake Formations in the study area. Horizontal flow in zone 2 is through primarily low-permeability fractures and vugs, with the exception of the fracture at 662 ft, which has variable permeability. Zone 3 extends from the bottom of the shaley layer at 662 ft to immediately above the fracture at about 524 ft above sea level and corresponds to the lower part of the undifferentiated Dubuque and Wise Lake Formations to the upper part of the Grand Detour Formation. Horizontal flow in zone 3 is through primarily low-permeability vugs and fractures, with the exception of the fracture at about 564 ft, which has variable permeability in the study area. Zone 4 corresponds to the subhorizontal fracture near the argillaceous part of the Grand Detour Formation at about 524 ft. This permeable fracture appears to be present throughout the study area and appears to be hydraulically well connected to wells BMW4 and BMW6. Zone 5 corresponds to the interval from the bottom of zone 4 to the top of the Glenwood semiconfining unit. Zone 5 has not been extensively investigated, but flow appears to be through low-permeability vugs and fractures, with the exception of a subhorizontal fracture in the lower part of the Mifflin Formation at about 480 ft above sea level (Mills and others, 1998). The permeability of this fracture is highly variable within the study area.

In addition to the horizontal flow, vuggy intervals appear to transmit vertical flow in the aquifer. Some inclined fractures in the Galena-Platteville aquifer provide pathways for vertical flow within and between zones 1-4, and perhaps zone 5. Inclined fractures appear to be less permeable with depth (Kay and others, 2000), which in combination with the distribution of vugs in the upper part of the aquifer may explain why the aquifer above the shaley bed at 662 ft appears to have more vertical hydraulic interconnection than the aquifer below 662 ft.

GROUND-WATER QUALITY

In each borehole, water samples were collected from test intervals isolated with the packer assembly (tables 5, 6). An attempt to collect a sample from the 560-570 ft interval of borehole G136GP was unsuccessful because of the low permeability of this interval. Temperature, pH, oxidation-reduction potential (ORP), specific conductance, and dissolved oxygen concentration were measured during purging using a calibrated water-quality monitor with an attached flow-through cell. Using a Hach colorimeter, iron(II) concentrations were measured in the field immediately after sample collection. All samples were analyzed for concentrations of VOC's and monitored natural attenuation (MNA) parameters. The MNA parameters analyzed are methane, ethane, ethene, nitrate, alkalinity, chloride, total organic carbon, and iron. The samples were collected in September 1999 using a low-capacity sampling pump constructed with Teflon and stainless-steel parts. All samples were collected after at least three packed-interval volumes were purged from the sample interval, and the samples were preserved, stored, shipped, and analyzed in accordance with the approved Sampling and Analysis Plan (SAP) for the investigation (U.S. Geological Survey, written commun., 1999). Quality-assurance and quality control samples; duplicates; and matrix-spike, trip-blank, and pump-blank samples were collected as required by the SAP. All equipment was decontaminated as required by the SAP. Compounds considered to be present because of field or laboratory contamination are not presented in this report. Where a duplicate sample was collected, the highest reported concentration is presented. Results of analysis of duplicate samples typically were similar to the results of the original-sample analysis. Results of analysis of samples collected in April 2000 from the monitoring wells completed in boreholes G124GP, G130GP, G133GP, G134GP, and G136GP (Ray Mastrolonardo, Tetra Tech EM, Inc., written commun., 2000) were consistent with the results of the analyses of the samples collected using the packer assembly.

Volatile Organic Compounds

The total concentration of volatile organic compounds (TVOC's) in water samples collected for this investigation ranged from below the practical detection limit of about 1 μg/L to 526 μg/L (table 5). VOC's were detected over the entire thickness of the aquifer accessible by the boreholes.

The highest concentrations of VOC's were detected at borehole G134GP, near the lateral center of the plume in the deep unconsolidated aquifer (fig. 13). Lower VOC concentrations were detected around the periphery of the plume at boreholes G124GP, G130GP, G133GP, and G136GP. The distribution of VOC's in the Galena-Platteville aquifer indicates the bulk of the plume is migrating to the southeast toward the Kishwaukee River. This distribution of VOC's and the results of the water-level monitoring indicate there also are components of flow to the north, east, and possibly west in the Galena-Platteville aquifer.

Trichloroethene (TCE) was the VOC detected at the highest concentration in the samples from boreholes G124GP, G130GP, and G134GP and most of the test intervals in borehole G133GP (table 5). Tetrachloroethene (PCE) was the VOC detected at

Table 5. Results of analysis for volatile organic compounds in samples from test intervals isolated with a packer assembly in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., September 1999

[Compound detected: C2S, carbon disulfide; TCA, 1,1,1-trichlorethane; TCE, trichloroethene; PCE, tetrachloroethene; TOL, toluene; 1,2DCE, total 1,2-dichloroethene; 1,1DCE, 1,1-dichloroethene; 1,1DCA, 1,1-dichloroethane; 4M2P, 4-Methyl-2-Pentone; EB-ethylbenzene; XYL, xylene; J, estimated concentrations below detection limit; <, less than; ND, not detected]

Borehole name	Altitude of test interval (feet above sea level)	Volatile organic compound detected/concentration (micrograms per liter)	Total concentration of volatile organic compounds (micrograms per liter)
G124GP	716-747	C2S/17J, TCA/6J, TCE/19, PCE/2J, TOL/2J	46
	658-668	TCE/7J	7
	556-566	TCE/4J	4
	518-540	TCA/1J, TCE/6J	7
G130GP	742-752	ND	<1
	558-576	TCE/4J	4
G133GP	726-733	1,2DCE/5J, TCA/4J, TCE/8J, PCE/11	28
	667-677	TCE/1J	1
	522-532	1,2DCE/3J, TCA/2J, TCE/6J, PCE/4J	15
G134GP	718-728	1,1DCE/11J, 1,1DCA/13J, 1,2DCE/9J, TCA/72, TCE/390, 4M2P/15J, PCE/12J, TOL/4J	526
	692-702	ND	<1
	662-672	1,1DCE/6J, 1,1DCA/7J, 1,2DCE/5J, TCA/46, TCE/240, 4M2P/17J, PCE/8J, TOL/3J	332
	628-638	1,1DCE/4J, 1,1DCA/4J, 1,2DCE/4J, TCA/23, TCE/150, PCE/6J	191
	516-537	1,1DCE/4J, 1,1DCA/4J, 1,2DCE/4J, TCA/26, 4M2P/10, TCE/180, PCE/6J, TOL/7J, EB/1J, XYL/3J	245
G136GP	742-754	1,2DCE/6J, TCA/1J, TCE/3J, PCE/16	26
	667-677	1,1DCE/2J, PCE/5J	7
	637-647	ND	<1
	520-530	1,2DCE/3J, TCE/1J, PCE/6J, XYL/1J	11

Table 6. Results of monitored natural attenuation parameter analyses in samples from test intervals isolated with a packer assembly in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill., September 1999

[U, compound not detected and detection limit; J, estimated concentration; na, not analyzed]

Borehole name	Altitude of test interval (feet above sea level)	Total organic carbon (milligrams per liter)	Temperature (degrees Celsius)	Specific conductance (microSiemens per centimeter)	pH (standard units)	Oxidation-reduction potential (millivolts)	Dissolved oxygen (milligrams per liter)	Total nitrogen as nitrate (milligrams per liter)
G124GP	716-747	0.62U	12.56	759	6.96	19	2.71	3.0
	658-668	.62U	11.85	745	6.88	-35	.60	.21
	556-566	.62U	11.87	669	7.00	-39	.59	.042J
	518-540	.62U	11.74	700	6.83	-2	1.00	.37
G130GP	742-747	.62U	12.47	899	6.78	95	8.34	11.5
	558-576	.62U	12.04	811	6.84	-8	.63	8.8
G133GP	726-733	.62U	13.98	741	6.87	68	6.35	4.8
	667-677	.62U	12.82	599	6.95	-53	.40	.011U
	522-532	.62U	13.02	646	6.90	-4	1.72	2.3
G134GP	718-728	.62U	14.26	801	7.00	-90	.56	.011U
	692-702	.62U	13.5	635	6.96	-86	.66	.011U
	662-672	.62U	12.63	764	7.00	-54	.30	1.2
	628-638	.62U	12.63	743	7.01	-4	.18	1.1
	516-537	.62U	12.5	648	6.95	-40	.26	.18
G136GP	742-754	.62U	13.89	913	6.81	102	7.55	6.4
	667-677	.62U	13.43	901	6.77	68	.44	3.8
	637-647	.62U	12.81	551	6.76	11	.52	.011U
	520-530	.62U	13.25	723	6.79	68	4.57	4.1

Borehole name	Altitude of test interval (feet above sea level)	Iron (II) (milligrams per liter)	Sulfate (milligrams per liter)	Methane (milligrams per liter)	Alkalinity (milligrams per liter)	Chloride (milligrams per liter)	Ethane (milligrams per liter)	Ethene (milligrams per liter)
G124GP	716-747	0.50	74.1	0.075U	366	11.9	0.075U	0.075U
	658-668	.90	95.0	.075U	366	17.8	.075U	.075U
	556-566	.60	61.9	.075U	363	13.8	.075U	.075U
	518-540	.70	81.2	.075U	363	14.4	.075U	.075U
G130GP	742-747	.10	26.4	.075U	324	26.9	.075U	.075U
	558-576	.60	31.2	.075U	304	21.7	.075U	.075U
G133GP	726-733	.80	44.4	.075U	324	49.9	.075U	.075U
	667-677	.75	44.7	.075U	337	16.2	.075U	.075U
	522-532	.50	41.1	.075U	332	30.0	.075U	.075U
G134GP	718-728	1.80	103.0	.075U	388	47.7	.075U	.075U
	692-702	1.40	59.8	.075U	338	27.4	.075U	.075U
	662-672	.60	78.0	.075U	398	47.6	.075U	.075U
	628-638	na	85.0	.075U	378	48.1	.075U	.075U
	516-537	.80	63.0	.075U	352	27	.075U	.075U
G136GP	742-754	.20	41.9	.075U	342	93.5	.075U	.075U
	667-677	.10	78.8	.075U	354	80.4	.075U	.075U
	637-647	.10	36.9	.075U	349	15.8	.075U	.075U
	520-530	.25	51.1	.075U	342	69.4	.075U	.075U

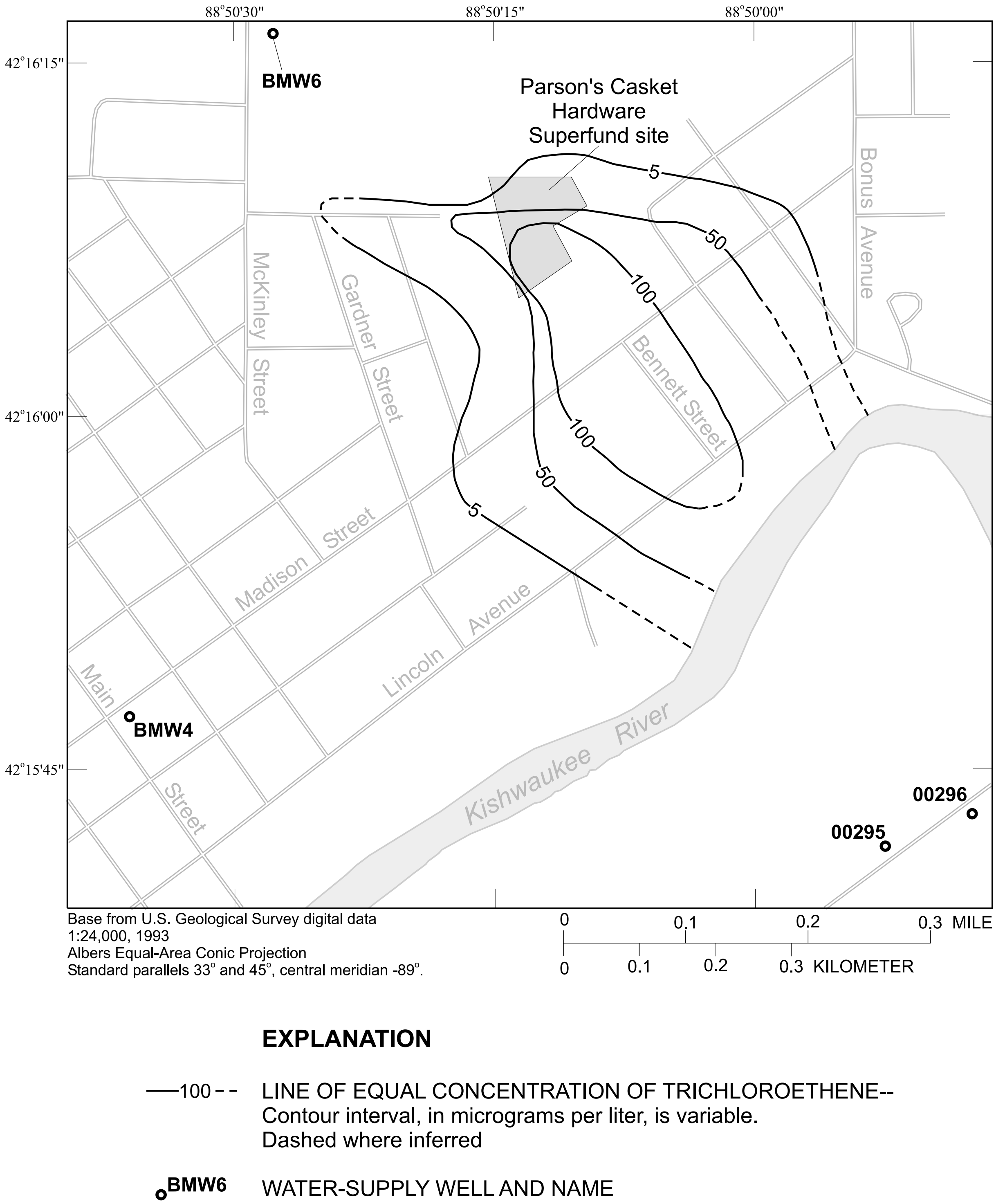

Figure 13. Concentration of trichloroethene in the deep unconsolidated aquifer in the vicinity of the Parson's Casket Hardware Superfund site, Belvidere, Ill. (modified from Science Applications International Corporation, 1993, fig. 3-15).

the highest concentrations at borehole G136GP and the shallowest test interval in borehole G133GP. Trichloroethane (TCA) was detected in samples from every borehole except G130GP. Concentrations of TCE or PCE exceed the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) of 5 µg/L (U.S. Environmental Protection Agency, 1996) in at least one sample from every borehole except G130GP. Both 1,1- and 1,2-dichloroethene (collectively referred to as DCE) and dichloroethane (DCA) compounds were detected in the samples from boreholes G133GP, G134GP, and G136GP. DCE and DCA compounds were not detected in the samples from boreholes G124GP and G130GP.

TCE was detected in soils at the PCHSS, whereas PCE was absent (Science Applications International Corporation, 1998), indicating that much of the TCE in the ground water is derived from the source material at the PCHSS. The presence of PCE in ground water in the study area indicates that the PCHSS is not the only source of VOC's in the study area. The predominance of PCE over TCE in boreholes G133GP and G136GP in the western part of the study area may indicate a source of VOC's in ground water west of the PCHSS.

Natural Attenuation Parameters

One important mechanism for natural attenuation of chlorinated ethenes and ethanes is biodegradation through the process of reductive dechlorination. Reductive dechlorination is the microbiologically mediated removal of a chlorine atom from the chlorinated ethene or chlorinated ethane molecule and replacement of the chloride atom with a hydrogen atom (fig. 14). Reductive dechlorination typically occurs by sequential dechlorination from PCE to TCE to DCE to vinyl chloride, to ethene or water, carbon dioxide, and chloride (fig. 14). Ethene may break down into ethane or methane. The reductive dechlorination process for the chlorinated ethane compounds is analogous with sequential dechlorination from TCA to DCA to chloroethane to ethanol to carbon dioxide.

DCE, DCA, vinyl chloride, and chloroethane were detected in ground-water samples collected during the current or previous investigations in the study area (Science Applications International Corporation, 1992; Mills and others, 1998; and Kay and others, 2000). DCE and DCA were detected in the unconsolidated and Galena-Platteville aquifers throughout the study area, whereas vinyl chloride and chloroethane were detected only in the shallow unconsolidated aquifer and only beneath the PCHSS. The absence of DCA, vinyl chloride, and chloroethane in the soils at the PCHSS (Science Applications International Corporation, 1998) indicates biodegradation of TCE, TCA, and perhaps PCE by reductive dechlorination is occurring within the study area. The absence of PCE in the soils at the PCHSS indicates most of the TCE in ground water in the study area is derived from dissolution of TCE in soils and waste materials.

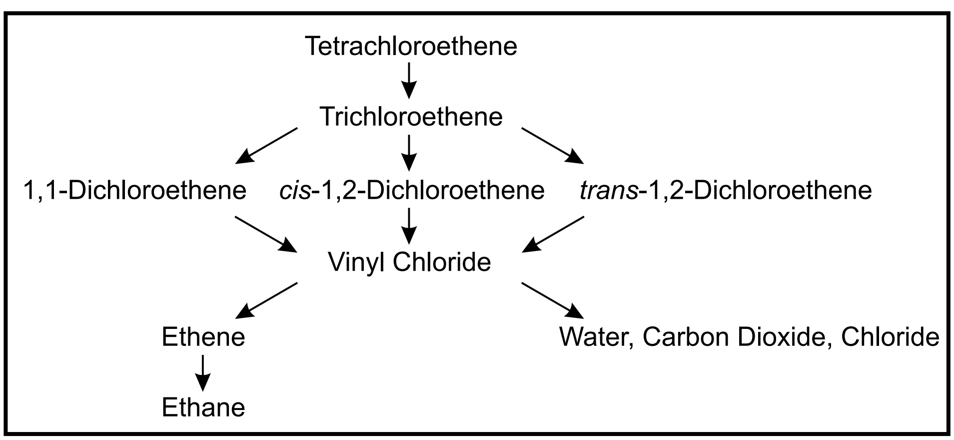

Figure 14. Reductive dechlorination sequence for chlorinated ethenes.

Reductive dechlorination requires both electron acceptors and an adequate supply of electron donors. In an uncontaminated aquifer, native organic carbon is used as an electron donor and dissolved oxygen is used first as an electron acceptor. After dissolved oxygen is consumed, anaerobic organisms typically use nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide as electron acceptors. Chlorinated ethenes and ethanes compete as electron acceptors in aquifers where chlorinated ethenes and ethanes are present in sufficient concentrations. The rate of dechlorination decreases as the degree of chlorination decreases so that PCE is more readily degraded than TCE. TCE is more readily degraded than DCE compounds. DCE compounds are more readily degraded than vinyl chloride. Reductive dechlorination occurs under nitrate- and iron-reducing conditions but is most rapid and affects the widest range of compounds under sulfate reducing and methanogenic conditions. In addition to degradation by reductive dechlorination, vinyl chloride can be used as an electron donor and broken down to produce carbon dioxide, water, and chloride ion. Use of vinyl chloride as an electron donor can occur under iron-reducing conditions (Bradley and Chapelle, 1997).

Samples from the Galena-Platteville aquifer were analyzed for a variety of chemical parameters that affect the degree of biodegradation or indicate the presence of biodegradation. These parameters were used to indicate if biodegradation of chlorinated ethenes and ethanes by reductive dechlorination is occurring, the locations where biodegradation may be occurring, and the degree to which the compounds are being degraded.

Organic carbon, the primary electron donor in a ground-water system, was not detected in the test intervals isolated with a packer assembly (table 6). The absence of detectable concentrations of organic carbon is likely to be limiting the amount of biodegradation of the chlorinated ethenes and ethanes in the Galena-Platteville aquifer. However, the small amounts of toluene, xylene, and ethylbenzene (table 5) also may be serving as electron donors in the aquifer (Wiedemeier and others, 1998).

Water temperatures in the test intervals isolated with a packer assembly ranged from 11.74 to 14.26°C (table 6). These values are below 20°C. Above 20°C, the biochemical process is accelerated (Wiedemeier and others, 1998). Temperatures tended to decrease with increasing depth in the aquifer. Temperatures were lowest overall in boreholes G124GP and G130GP, were intermediate in borehole G134GP, and were highest in boreholes G133GP and G136GP. These patterns are consistent with the information obtained from the temperature logging.

Specific conductance is a measure of the capability of a solution to conduct electricity. Although specific conductance is not directly correlated to the potential for natural attenuation, specific conductance typically is related directly to the concentration of ions in a solution. Specific conductance of the water in the test intervals isolated with a packer assembly ranged from 551 to 913 μS/cm (table 6), the mean value (the geometric mean value of the geometric mean values from each borehole) was 737 μS/cm. Specific-conductance values generally decreased with increasing depth. Specific-conductance values at borehole G133GP averaged nearly 75 μS/cm below the mean and specific conductance values at borehole G130GP averaged more than 110 μS/cm above the mean.

pH values of water samples in the test intervals isolated with a packer assembly ranged from 6.76 to 7.01 units (table 6) with a geometric mean value of 6.88. These values are within the optimal range of 6-8 pH units for microbial degradation of chlorinated ethenes and ethanes (Wiedemeier and others, 1998). pH values showed no clear correlation with TVOC concentrations. However, the five test intervals with the highest concentrations of TVOC’s had higher pH values than most of the other test intervals.

The ORP of ground water is a measure of electron activity and an indicator of the relative tendency of a solution to accept or transfer electrons. Reductive dechlorination is possible at ORP values below 50 millivolts and is likely at ORP values below -100 millivolts (Wiedemeier and others, 1998). These values are not absolute but reflect the tendency for reductive dechlorination to occur more readily under increasingly reducing conditions. ORP values of the water in the test intervals isolated with a packer assembly ranged from -90 to 102 millivolts (table 6). All values at borehole G134GP were negative, whereas all values at borehole G136GP were positive. For the remaining boreholes, the shallowest interval was positive and all of the deeper intervals were negative. With the exception of borehole G134GP, ORP values were highest in the shallowest packed interval. ORP concentrations in the water from the Galena-Platteville aquifer tested for this investigation showed no clear correlation with concentrations of TVOC’s; however, ORP values decreased as TVOC concentrations increased above 40 μg/L.

The anaerobic bacteria required for reductive dechlorination cannot function at dissolved oxygen concentrations greater than about 0.5 mg/L (Wiedemeier and others, 1998). Therefore, dissolved-oxygen concentrations greater than 0.5 mg/L tend to suppress reductive dechlorination. Concentrations of dissolved oxygen in water from the test intervals isolated with a packer assembly ranged from 0.18 to 8.34 mg/L (table 6). The highest concentrations of dissolved oxygen tended to be present in the shallowest test intervals within a given borehole, and the lowest overall concentrations were observed at borehole G134GP. Dissolved oxygen concentrations showed no clear correlation with TVOC concentrations; however, dissolved oxygen concentrations decreased as TVOC concentrations increased above 40 μg/L.

After dissolved oxygen has been depleted from the aquifer, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon, including VOC's. Nitrate concentrations greater than 1 mg/L may reduce the amount of dechlorination by competing with the chlorinated ethenes and ethanes as an electron acceptor (Wiedemeier and others, 1998). Concentrations of nitrogen as nitrate in samples from the test intervals isolated with a packer assembly ranged from below the detection limit of 0.011 mg/L to 11.5 mg/L (table 6). Except for borehole G134GP, nitrogen as nitrate concentrations were highest in the uppermost interval of the boreholes, lowest in the intermediate intervals, and intermediate in the lowermost interval. The geometric mean of the concentrations of nitrogen as nitrate were as much as an order of magnitude higher in borehole G130GP (10.6 mg/L) than concentrations in the other boreholes (less than 1.0 mg/L) and exceeded the USEPA MCL of 10 mg/L in the shallowest sample (U.S. Environmental Protection Agency, 1996). Concentrations of nitrogen as nitrate were substantially lower in borehole G134GP than in the other boreholes. Nitrate concentrations showed no clear correlation with TVOC concentrations; however, nitrate concentrations decreased as TVOC concentrations increased above 40 μg/L.

Iron(III) may be used as an electron acceptor during anaerobic biodegradation of VOC's and other forms of organic carbon, resulting in the reduction of iron(III) to iron (II), which may be soluble in water (Wiedemeier and others, 1998). Concentrations of iron(II) in excess of 1 mg/L may be used as indicators of anaerobic degradation of vinyl chloride. Concentrations of iron(II) in samples collected with the packer assembly for this investigation ranged from near the detection limit of 0.1 mg/L to 1.8 mg/L and showed no clear trends with depth (table 6). Iron(II) concentrations were highest in borehole G134GP, intermediate at boreholes G124GP and G133GP, and lowest in boreholes G130GP and G136GP. Iron(II) concentrations in the water from the Galena-Platteville aquifer tested for this investigation showed no clear correlation to TVOC concentrations but were highest in the sample with the highest TVOC concentrations.

Sulfate may be used as an electron acceptor for anaerobic biodegradation after dissolved oxygen and nitrate have been depleted from the VOC plume. Sulfate concentrations greater than 20 mg/L may reduce the amount of dechlorination by competing with the chlorinated ethenes and ethanes as an electron acceptor (Wiedemeier and others, 1998). Sulfate concentrations in the samples collected from the test intervals isolated with the packer assembly ranged from 26.4 to 103 mg/L and showed no clear trends with depth (table 6). Sulfate concentrations were highest in boreholes G124GP and G134GP, intermediate in boreholes G133GP and G136GP, and lowest in borehole G130GP. Sulfate concentrations showed an overall increase with increasing TVOC concentrations.

Concentrations of methane in samples collected from the test intervals isolated with a packer assembly were below the detection limit of 0.075 mg/L (table 6). The absence of methane indicates strongly reducing conditions, which are most favorable for reductive dechlorination, are not present in the aquifer. In addition, methane is one of the ultimate breakdown products from reductive dechlorination and the absence of methane in the aquifer indicates reductive dechlorination is not resulting in the breakdown of the chlorinated ethenes and ethanes to their nontoxic end products.

Concentrations of alkalinity in the samples collected from the test intervals isolated with a packer assembly varied from 304 to 398 mg/L (table 6). Alkalinity concentrations show no clear trends with depth or location. Carbon dioxide, one of the end products produced from the complete degradation of chlorinated ethenes and ethanes, can interact with carbonate minerals in the aquifer to increase ground-water alkalinity; therefore, alkalinity concentrations that are more than twice the background concentrations may indicate areas where biodegradation is occurring (Wiedemeier and others, 1998).

Alkalinity concentrations showed a general increase with increasing concentrations of TVOC's but increased by less than a factor of two.

Chloride concentrations in the samples collected from the test intervals isolated with a packer assembly ranged from 11.9 to 93.5 mg/L, nearly an order of magnitude (table 6). Chloride concentrations show no clear trends with depth but were highest in borehole G136GP; intermediate in borehole G134GP; and lowest in boreholes G133GP, G124GP, and G130GP. Chloride is one of the end products of reductive dechlorination and tends to be elevated relative to background concentrations at an aquifer in which dechlorination of substantial amounts of VOC's is occurring. Chloride concentrations in the samples collected for this investigation did not show a correlation with TVOC concentrations. Concentrations of TVOC's are less than 1.0 mg/L, and concentrations of chloride exceed 10 mg/L. Therefore, the lack of correlation between concentrations of TVOC's and chloride does not necessarily indicate that dechlorination is not occurring in the aquifer.

Concentrations of ethane and ethene in samples collected from the test intervals isolated with a packer assembly were below the detection limit of 0.075 mg/L. Ethane and ethene concentrations greater than 0.01 mg/L (which is less than the detection limit) are considered indicative of dechlorination of the less chlorinated compounds (Wiedemeier and others, 1998).

Data from previous investigations indicate reductive dechlorination of TCE to DCE to vinyl chloride and TCA to DCA to chloroethane is occurring in the shallow unconsolidated aquifer beneath the PCHSS. The VOC and MNA parameters indicate reductive dechlorination of PCE, TCE, and TCA to DCE and DCA is occurring under either nitrate or iron-reducing conditions in the unconsolidated aquifer and, perhaps, the upper part of the Galena-Platteville aquifer hydraulically upgradient of borehole G134GP. This borehole monitors the approximate center of the VOC plume emanating from the PCHSS and, apparently, another source area. Whether substantial reductive dechlorination is occurring in the Galena-Platteville aquifer in the vicinity of borehole G134GP is not clearly indicated. Oxidizing conditions appear to be present at least in the upper part of the Galena-Platteville aquifer at boreholes G124GP, G130GP, G133GP, and G136GP, and reductive dechlorination in the Galena-Platteville aquifer at these boreholes is not clearly indicated. Reductive dechlorination appears to be limited by a lack of organic carbon in the Galena-Platteville aquifer.

Although the data collected during this investigation do not clearly indicate DCE or DCA are degrading by reductive dechlorination in the Galena-Platteville aquifer, it is possible that DCE is being dechlorinated to form vinyl chloride and vinyl chloride is being mineralized to carbon dioxide through electron donor reactions in the iron-reducing part of the unconsolidated deposits and, perhaps, the Galena-Platteville aquifer. The absence of detectable concentrations of vinyl chloride in the samples collected for this investigation may be attributed to a lack of production of this compound or, less likely, rapid degradation of this compound that prevents its accumulation.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey, in cooperation with the Illinois Environmental Protection Agency, used packer assemblies in conjunction with geophysical logging to characterize the geology, hydrology, and distribution of contaminants in the fractured-bedrock aquifer in the vicinity of the Parson's Casket Hardware Superfund site in northeastern Belvidere, Ill. The bedrock aquifer beneath this part of Belvidere is composed of dolomite of the Galena and Platteville Groups and is referred to as the Galena-Platteville aquifer. This information will be used to assess possible remediation scenarios at the site.

Horizontal flow in the Galena-Platteville aquifer in the study area can be divided into five zones. Flow in zone 1 is through the weathered fractures in the upper 20 ft (feet) of the bedrock surface. These fractures tend to be highly permeable. Zone 2 ranges from about 60 to 80 ft thick and extends from the bottom of the most weathered part of the bedrock to the top of the shaley layer at about 662 ft above sea level. This zone corresponds to undifferentiated parts of the Dubuque and Wise Lake Formations in the study area. Horizontal flow in zone 2 is through primarily low-permeability fractures and vugs, with the exception of the fracture at 662 ft, which has variable permeability. Zone 3 extends from just below the shaley layer at 662 ft to immediately above the fracture at 524 ft and corresponds to the lower part of the undifferentiated Dubuque and Wise Lake Formations through the upper part of the Grand Detour Formation. Horizontal flow in zone 3 is through primarily low-permeability vugs and fractures, with the exception of the fracture at about 564 ft, which has variable permeability in the study area. Zone 4 corresponds to the subhorizontal fracture in the argillaceous part of the Grand Detour Formation at about 524 ft. This permeable fracture appears to be present throughout the study area and is hydraulically well connected to wells BMW4 and BMW6. Zone 5 corresponds to the interval from the bottom of zone 4 to the top of the Glenwood semiconfining unit. Zone 5 has not been extensively investigated but flow appears to be through low-permeability vugs and fractures, with the exception of a subhorizontal fracture in the lower part of the Mifflin Formation at about 480 ft. This fracture has highly variable permeability in the study area. Vugs and inclined fractures provide pathways for vertical flow within the Galena-Platteville aquifer.

The fractures in the upper 10-20 ft of the bedrock at any borehole are likely to be present because of weathering and erosion of the bedrock surface. The presence of most of the deeper subhorizontal fractures appears to be affected by the stratigraphy and lithology of the Galena-Platteville deposits.

Water-level data indicate the potential for downward flow within the Galena-Platteville aquifer throughout the study area. The direction of flow in the fracture at about 524 ft above sea level is variable. Flow through the fracture is toward the south during periods of higher water levels in the fracture that appear to occur when pumping in well BMW6 is minimal or absent. Flow through the fracture is to the north during periods of low water levels in the fracture that appear to occur when BMW6 is being pumped and may be toward the southwest when well BMW4 is being pumped. Water levels in the upper part of the Galena-Platteville aquifer do not appear to be affected by pumping in any of the water-supply wells. Water-level data indicate water in the shallow part of the Galena-Platteville aquifer has the potential to flow into the Kishwaukee River and water in the deeper part of the aquifer will flow beneath the river.

The total concentration of VOC's in water samples collected from the test intervals isolated with the packer assembly ranged from below the practical detection limit of 10 μg/L (micrograms per liter) to 526 μg/L. Chlorinated ethenes were the VOC's detected most often and at the highest concentration. VOC's were detected over the entire sampled depth of the aquifer. The lateral center of the VOC plume in the Galena-Platteville aquifer is migrating from the PCHSS and, apparently, another source area southeast toward the Kishwaukee River. There appear to be components of plume movement in the aquifer to the north and west.

Reductive dechlorination appears to be occurring under either nitrate or iron-reducing conditions in the overlying unconsolidated deposits and, perhaps, the upper part of the Galena-Platteville aquifer hydraulically upgradient of borehole G134GP. However, there is no clear indication that reductive dechlorination is occurring in the Galena-Platteville aquifer in the area of the boreholes drilled for this investigation. Reductive dechlorination in the Galena-Platteville aquifer appears to be limited by a lack of organic carbon in the aquifer.

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