GROUND-WATER CONTAMINATION AND MOVEMENT AT THE DEFENSE GENERAL SUPPLY CENTER, RICHMOND, VIRGINIA

By John D. Powell, Winfield G. Wright, David L. Nelms and Richard J. Ahlin

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4113

Prepared in cooperation with the

U.S. DEPARTMENT OF DEFENSE,
DEFENSE LOGISTICS AGENCY

Richmond, Virginia

1990

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Gary S. Anderson, Chief
Virginia Office
U.S. Geological Survey
3600 W. Broad Street, Room 606
Richmond, VA 23230

Copies of this report can
be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Box 25425
Federal Center, Building 810
Denver, CO 80225

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS–Continued

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	*By*	*To obtain*
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per year (Mgal/yr)	3,785.0	cubic meter per year (m^3/yr)

Chemical concentration, temperature, and specific conductance are given in metric units. Chemical concentration is expressed in milligrams per liter (mg/L). Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F), and vice versa, as follows:

$$°F = (1.8 \times °C) + 32$$
$$°C = (°F - 32) \times 0.5555$$

Specific conductance is expressed in microsiemens per centimeter (µS/cm) at 25 degrees Celsius.

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.*"

GROUND-WATER CONTAMINATION AND MOVEMENT AT THE DEFENSE GENERAL SUPPLY CENTER, RICHMOND, VIRGINIA

By John D. Powell, Winfield G. Wright,
David L. Nelms, and Richard J. Ahlin

ABSTRACT

Analyses of ground water from 68 monitoring wells installed downgradient from the eastern boundary of the Defense General Supply Center indicate that volatile-organic compounds are present in both the upper unconfined aquifer and the lower confined aquifer. The principal contaminants in the aquifers are trichloroethene and 1,2-trans-dichloroethene. Chemical analyses and water-level data indicate that the unnamed creek flowing along the eastern boundary of the Federal property acts as a hydrologic discharge boundary and prevents eastward movement of contaminated ground water beyond the creek in the upper aquifer. Analyses of water in lower aquifer wells during 1985-89 indicated that contaminants in the lower aquifer had moved downgradient about 200 feet beyond the boundary of the Federal property. Subsequent analyses during 1989-90 indicate that contaminants have moved as much as 400 feet beyond the boundary of the property in the lower aquifer.

The rate of movement of contaminated ground water in the lower aquifer cannot be determined accurately because of natural degradation processes that deter the downgradient migration of the plume; in addition, precise locations and dates of disposals and spills are not available. Aquifer-test data indicate that ground water flows at about 90 feet per year in the upper aquifer and at about 200 feet per year in the lower aquifer. On the basis of the distance the contaminants have moved from their possible sources, contaminant migration is about 80 percent slower than ground-water flow, indicating that the contaminants are being degraded by natural processes.

INTRODUCTION

The Defense General Supply Center (DGSC) is participating in the U.S. Department of Defense Installation Restoration Program (IRP) to comply with current policy on hazardous-waste issues. This effort is designed to identify, evaluate, and remedy potential problems caused by past handling and disposal of hazardous materials. U.S. Geological Survey (USGS) participation is intended to provide hydrologic information necessary to assess the ground-water contamination problem and to support evaluations of the feasibility of proposed remedial actions.

Purpose and Scope

This report documents the efforts of the USGS in support of the quantification phase of the IRP to determine the degree of contamination of a site that has been identified as requiring study. The report describes the extent, concentration, direction, and rate of movement of contaminants in ground water beyond the boundaries of the DGSC.

Hydrologic and geologic data were collected during 1984-90 from wells located upgradient from the DGSC, upgradient from the Area 50 landfill located on the DGSC, in the landfill, in the National Guard Area (NGA) downgradient from the landfill, and downgradient from the NGA beyond the

eastern boundary of the DGSC (fig. 1). Lithologic data were collected during drilling of wells installed downgradient of the NGA by the USGS during 1984-86. Water from wells located downgradient of the NGA was analyzed for volatile-organic compounds, major cations and anions, priority-pollutant trace metals, and total organic carbon. Aquifer-test wells were installed by the USGS and aquifer testing was performed during 1985.

History of Site

The DGSC (fig. 1), constructed during 1940-41, serves as a depot for general supplies for the Department of the Defense. The DGSC occupies about 1 mi^2 (square mile) and is located about 5 mi (mile) south of the city of Richmond, Virginia.

During the 1960's and early 1970's, leaking containers and bulk chemicals were dumped into a topographically low area about 800 ft (feet) long, 200 ft wide, and 10 ft deep (Ludeman and others, 1981). The area–now called the former Area 50 landfill–was graded and seeded during the 1970's and is a grassy area today. During January 1981, the Commander, Defense Logistics Agency, recommended that an investigation be made to determine if evidence existed indicating the possibility of contamination of ground water at the DGSC. The subsequent records search prompted concern because of the disposal of chemicals in the landfill; further study was recommended. Ground-water contamination by volatile-organic compounds was discovered in March 1982 during an investigation by the U.S. Army Environmental Hygiene Agency (1982a). This study evaluated the hydrologic setting and identified potential sources of ground-water contamination. Six monitoring wells (no. 2 - no. 7) were installed in the upper unconfined aquifer of the landfill (fig. 2). One well (no. 1) was installed upgradient from the landfill near the western boundary of the DGSC and sampled to identify the quality of ground water moving onto the DGSC. During October 1982, a study was conducted to determine how far contaminants had moved from the landfill. Ten additional wells were drilled in pairs (no. 12 - no. 16) around the perimeter of the adjoining NGA located downgradient from the landfill (U.S. Army Environmental Hygiene Agency, 1982b). Five of these wells were finished in the upper unconfined aquifer (labeled as "A" wells) and five penetrated into a deeper confined aquifer (labeled as "B" wells). Chemical analyses of water from these wells indicated that contamination probably extended downgradient beyond the boundaries of the DGSC (U.S. Army Environmental Hygiene Agency, 1982b). In November 1983, 18 additional well pairs (no. 17 - no. 34) of shallow and deeper wells were drilled and sampled to identify the contaminated area in more detail and to confirm the movement of contamination beyond the boundaries of the DGSC (U.S. Army Environmental Hygiene Agency, 1983). The USGS began the recommended investigation in May 1984.

ENVIRONMENTAL SETTING

Physical Geography

The DGSC is located on the western edge of the eastward-thickening wedge of unconsolidated sediments of the Virginia Coastal Plain physiographic province, about 2 mi east of the Fall Line. Land-surface elevations range from 140 ft above sea level along the western edge of the DGSC to approximately 100 ft above sea level in the southeastern part of the DGSC. Surface drainage is to the east. The northern part of the DGSC drains toward the unnamed creek east of the NGA; the southern part drains toward Kingsland Creek (fig. 1).

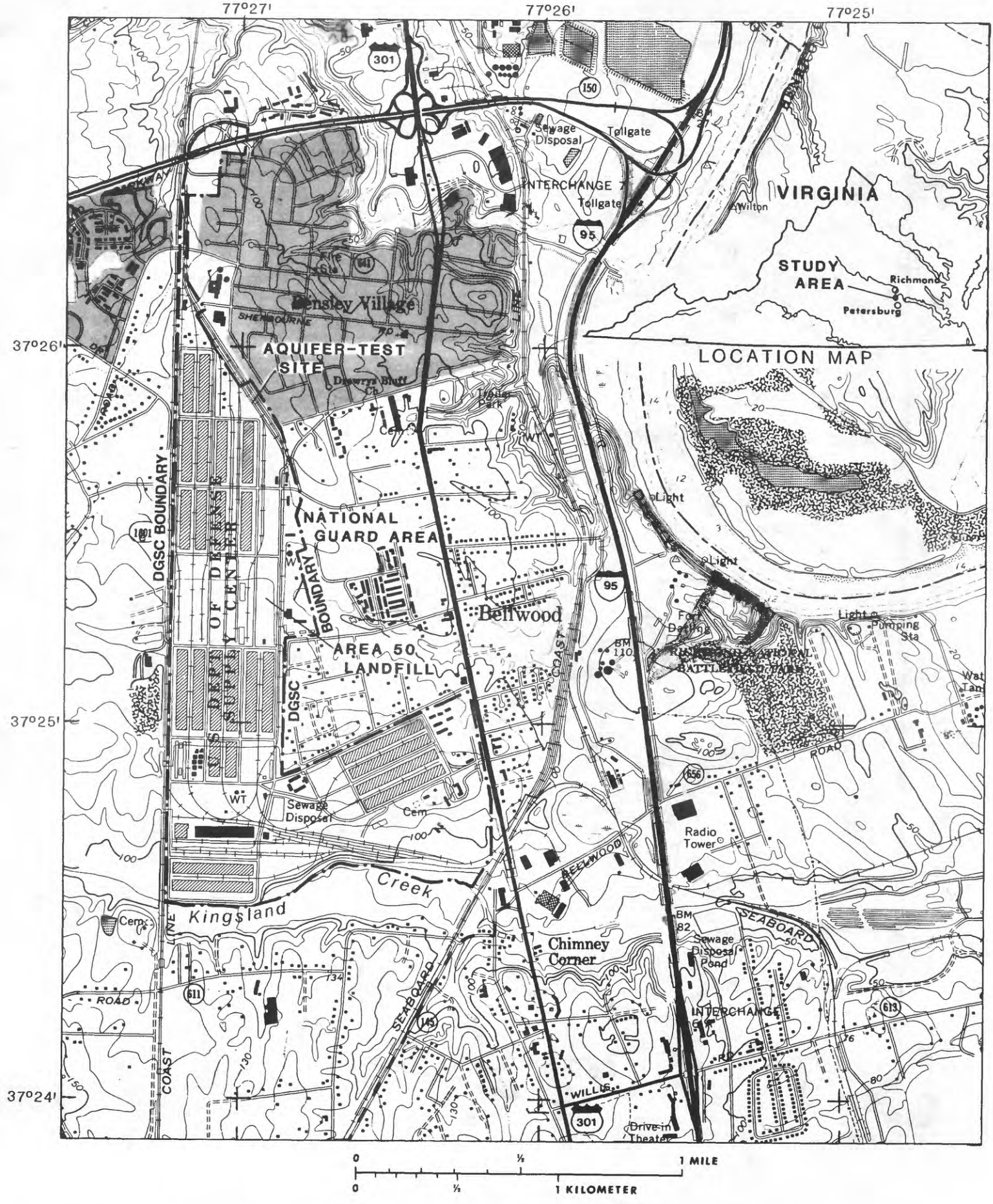
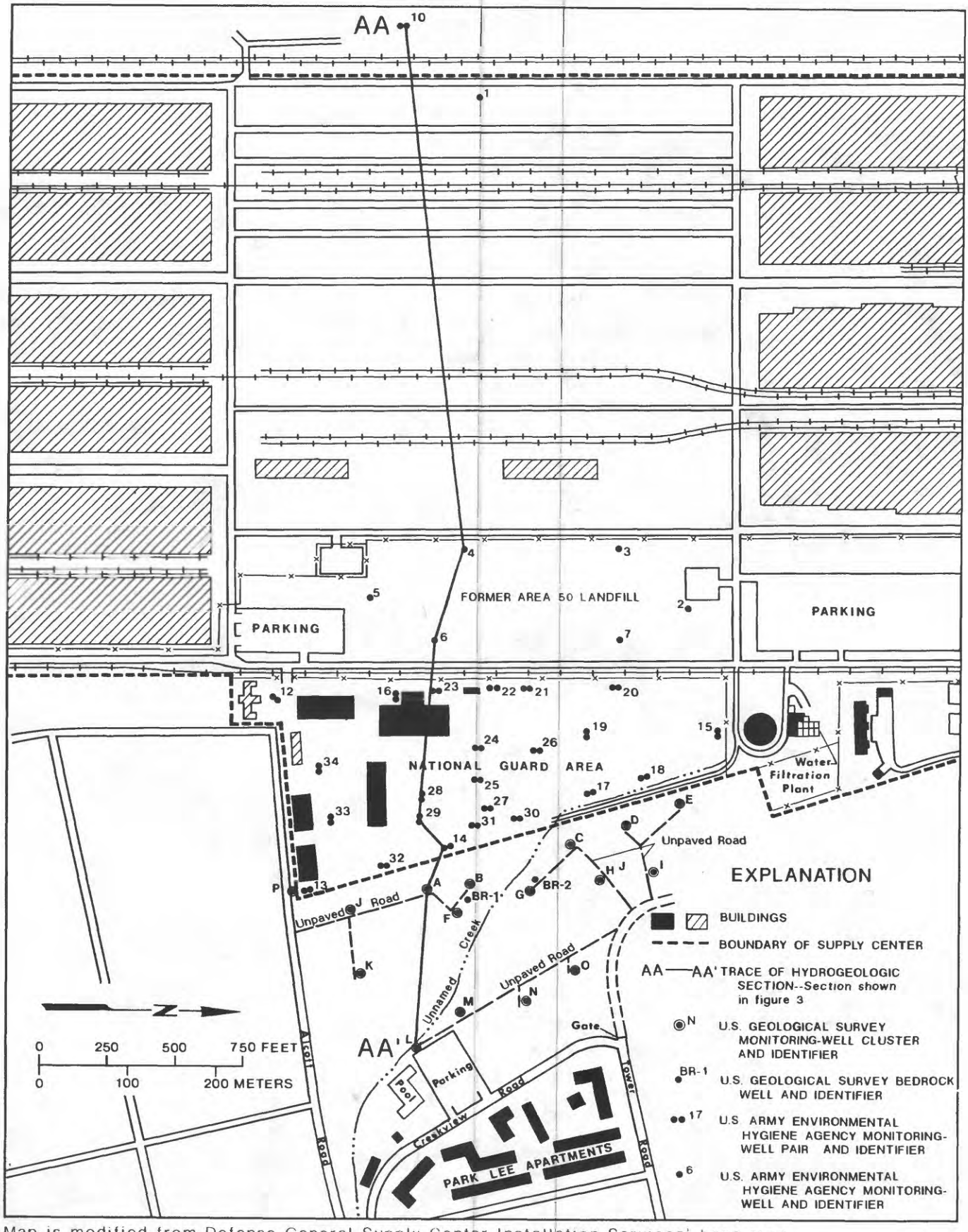


Figure 1.-- Defense General Supply Center and surrounding area.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 2.-- Location of U.S. Geological Survey monitoring-well clusters and selected U.S. Army Environmental Hygiene Agency wells.

Hydrogeologic Framework

A hydrogeologic framework was developed for the DGSC area using data from lithologic logs, geophysical logs, and core samples. The framework consists of an upper unconfined aquifer (Eastover Formation), an intervening confining unit (Calvert and Aquia Formations), and a lower confined aquifer (Potomac Formation) that overlies bedrock (Petersburg Granite) (fig. 3).

Core samples were collected from all USGS wells using a split-spoon sampler. The samples were used to determine the depth and thickness of hydrogeologic units, and were analyzed by sieve analysis to define sediment-size distribution, by petrographic microscope to define mineral content, and by laboratory testing of core samples to determine vertical hydraulic conductivity (table 1). An example lithologic log in table 2 shows textural characteristics of the strata.

Natural-gamma-radiation logs were recorded in selected wells. Comparison of these logs with respective lithologic logs recorded during drilling enabled the identification of characteristics of each hydrogeologic unit in the study area. An example natural-gamma log for well BR-1 is presented in figure 4. This well is finished in bedrock and is located among the well clusters immediately east of the NGA (fig. 2).

Upper Unconfined Aquifer

The upper unconfined aquifer is composed of alluvial sediments of the Eastover Formation. The aquifer varies in color, lithology, and thickness. It is generally rust to orange in color and is a clayey to silty, fine- to medium-grained sand. It overlies a basal gravel stratum. The aquifer generally thins to the east, and ranges from about 6 to 32 ft in thickness because of erosion and excavations by human activities. Attempts to collect core samples for laboratory analysis of vertical hydraulic conductivity were unsuccessful. Hydraulic conductivity of the Eastover Formation probably differs greatly throughout the study area because of variations in the composition of the sediments.

Confining Unit

The confining unit is composed of marine sediments of the Calvert and Aquia Formations. The Calvert Formation is a dark-gray deposit of silt and fine sand. The base of this formation consists of clay intermixed with sand and gravel, and contains sharks' teeth and wood fragments. Laboratory analysis of a core sample indicates a vertical hydraulic conductivity of approximately 0.098 ft/yr (feet/year) (table 1). The Aquia Formation is a fining-upward, well-sorted, dark green, glauconitic sand with a basal gravel stratum. The thickness of the confining unit ranges from 14 to 27 ft. Contours of the approximate altitude of the top of the confining unit are shown in figure 5.

Lower Confined Aquifer

The lower confined aquifer is composed of alluvial sediments of the Potomac Formation. This formation is a grayish-green, medium- to very coarse-grained sand, and gravel, interbedded with clay layers. Attempts to collect core samples for laboratory analysis of vertical hydraulic conductivity were unsuccessful. The thickness of the unit ranges from about 24 to 43 ft. Contours of the approximate altitude of the top of the lower aquifer are shown in figure 6.

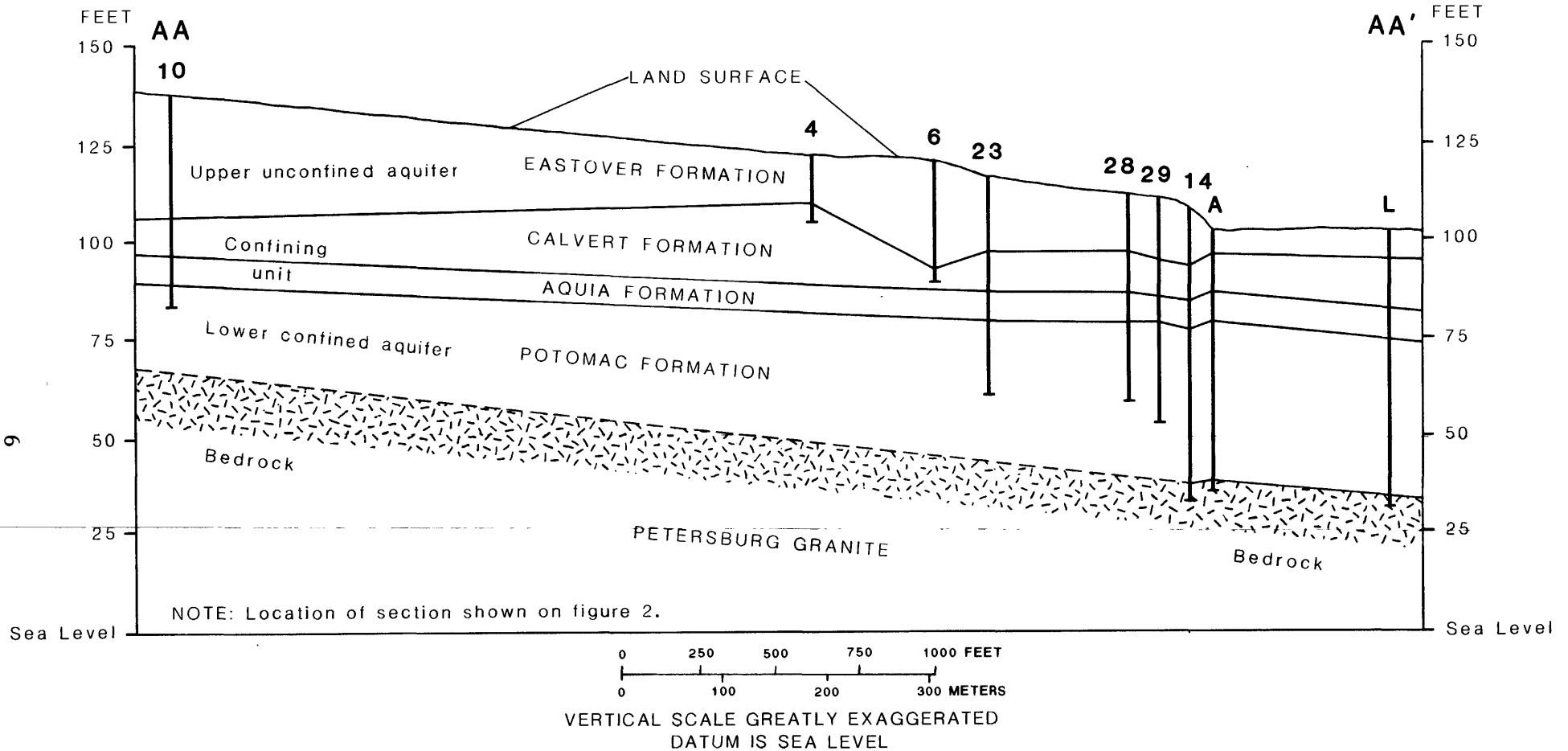


Figure 3.--Hydrogeologic section showing relations among formations.
(view looking north: trace of section is shown in figure 2.)

Table 1.–*Hydrogeologic characteristics of core samples*

[Vertical hydraulic conductivities were determined by laboratory technique using deaired water; clay types were determined by X-ray diffraction analysis; abbreviations in parentheses under lithologic descriptor refer to soil types of the Unified Soil Classification System of the U.S. Army Corps of Engineers; mineralogic percentages were determined by petrographic analysis; –, indicates data are not available]

Formation	Hydrogeologic unit	Vertical hydraulic conductivity, in feet per per year	Clay type	Total organic carbon content, in milligrams per kilogram	Lithologic descriptor	Mineralogy, in percent by volume
Eastover	Upper confined aquifer	–	Smectite, kaolinite, illite	5,200	Silty sand, (SM)	Quartz - 99 Feldspar - trace Glauconite - trace Weathered rock fragments - trace Opaque minerals - trace
Calvert	Confining unit	0.098	Smectite, kaolinite, illite, chlorite(trace)	32,700	Organic sandy silt, (OL)	Quartz - 53 Feldspar - 2 Clay - 41 Illite - 4 Opaque minerals - trace
Aquia	Confining unit	10.2	Smectite, kaolinite, glauconite, chlorite (trace)	20,500	Silty sand, (SM)	Quartz - 82 Feldspar - trace Clay - trace Glauconite - 13 Opaque minerals - 5
Potomac	Lower confined aquifer	–	Smectite, kaolinite, illite	19,500	Sandy gravel, (GP-GM)	Quartz - 85 Feldspar - 10 Clay - 2 Chert - 1 Illite - 1 Weathered rock fragments - trace
Petersburg Granite	Bedrock	–	–	–	Chloritized-granite, saprolite	Quartz - – Feldspar - – Muscovite - – Chlorite - –

Table 2.–*Lithologic log for well BR-1*

Depth in feet		Description of material	Remarks
From	To		
0.0	0.3	Top soil.	
0.3	5.0	Sand and gravel, clayey, grayish-brown, coarse-to very fine-grained, angular to subangular; cobbles at 3.5 feet.	Moist. No water in the hole.
5.0	5.9	Sand and gravel, clayey, greenish-white, very fine-to medium-grained.	Tight and dry.
5.9	8.0	Clay, orange, laminated.	
8.0	17.0	Clay, dark gray, high plasticity; basal layer has sand, pebbles, shell fragments, and sharks' teeth.	
17.0	24.0	Sand, silty, dark green, very fine- to fine-grained, glauconitic; basal gravel unit.	
24.0	53.0	Sand and gravel, grayish-green, coarse-to very fine-grained; interbedded clayey sand layers.	
53.0	67.0	Sand, clayey, grayish-green; basal layer of pea gravel.	
67.0	71.0	Saprolite; decomposed rock.	
71.0	96.0	Granite; hard rock.	

Bedrock

The chlorite-rich granodiorite of the Petersburg Granite underlies the sediments in the study area. This formation has a well-weathered saprolite of variable thickness that grades into unweathered rock. Hydraulic conductivity in this fractured-crystalline rock is not known, but it probably differs locally with the number and size of fractures. Contours of the approximate altitude of the top of bedrock are shown in figure 7.

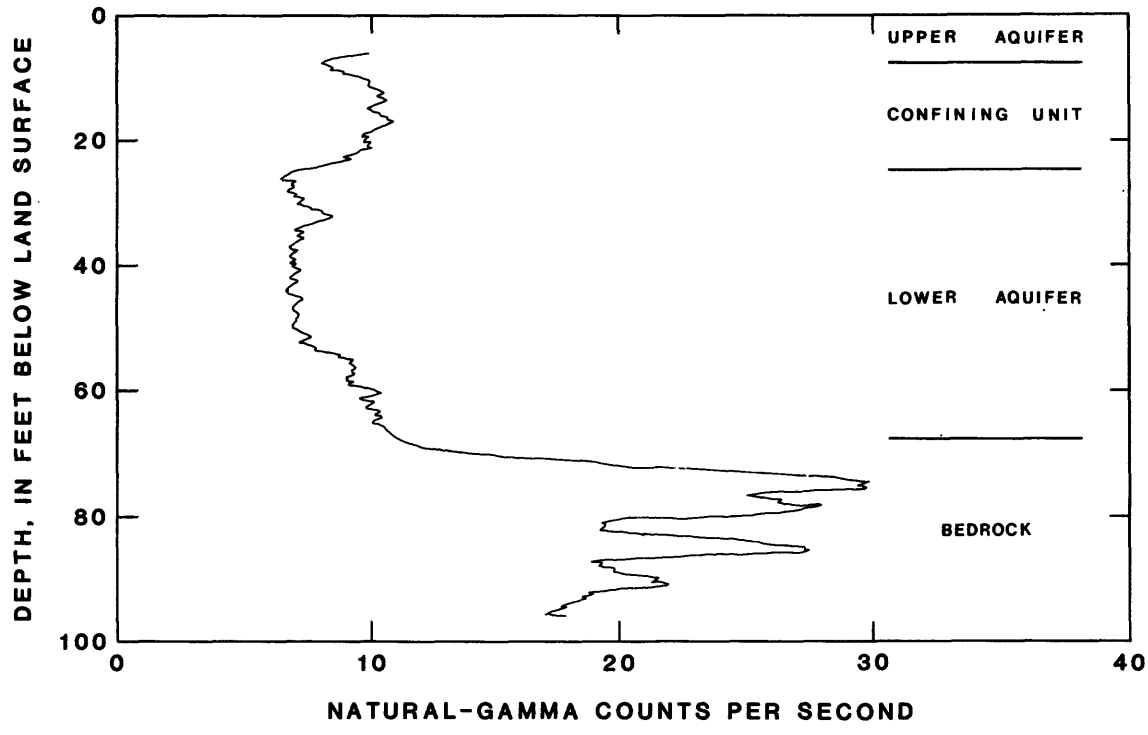
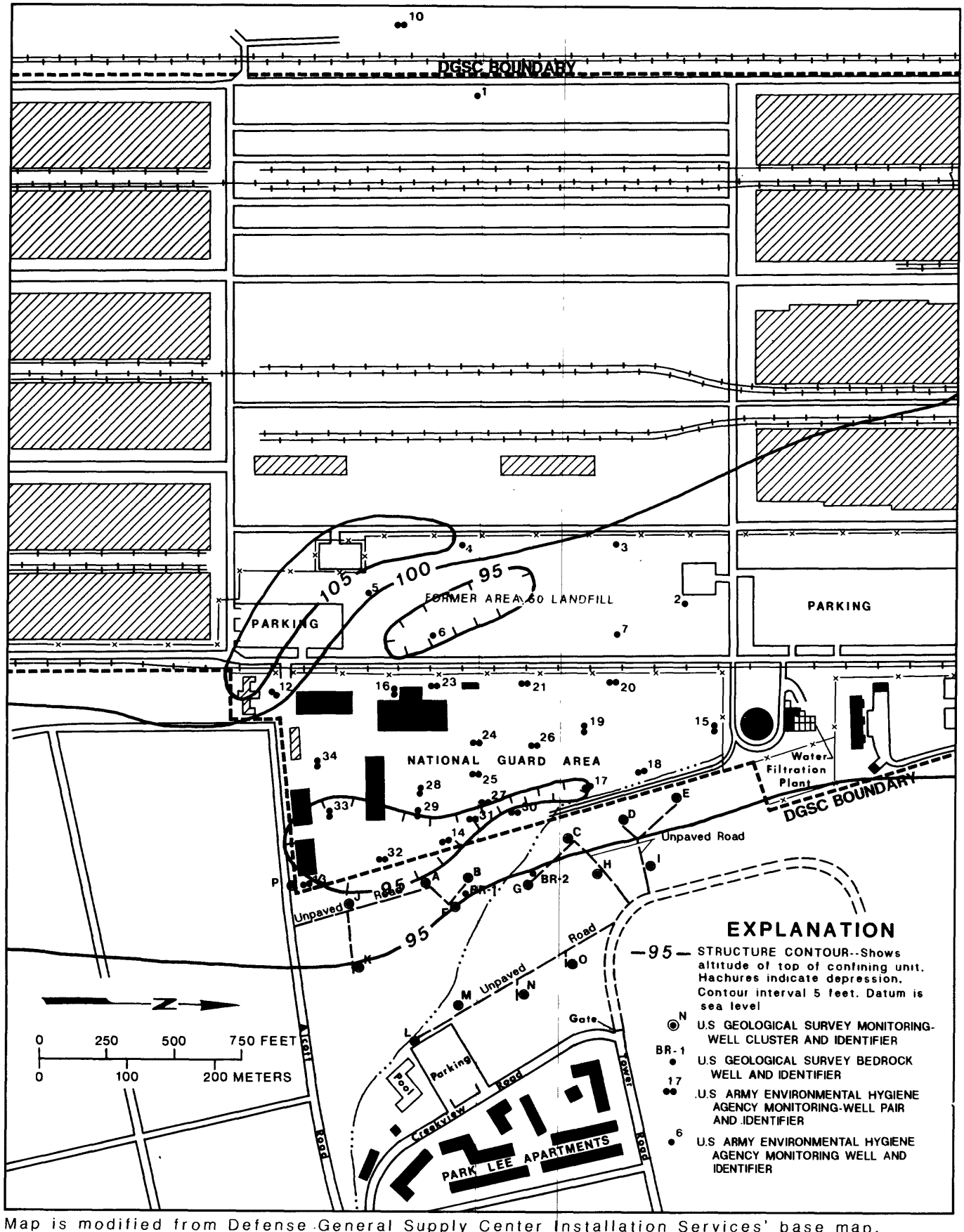


Figure 4.-- Natural-gamma log for well BR-1.

FIELD PROGRAM

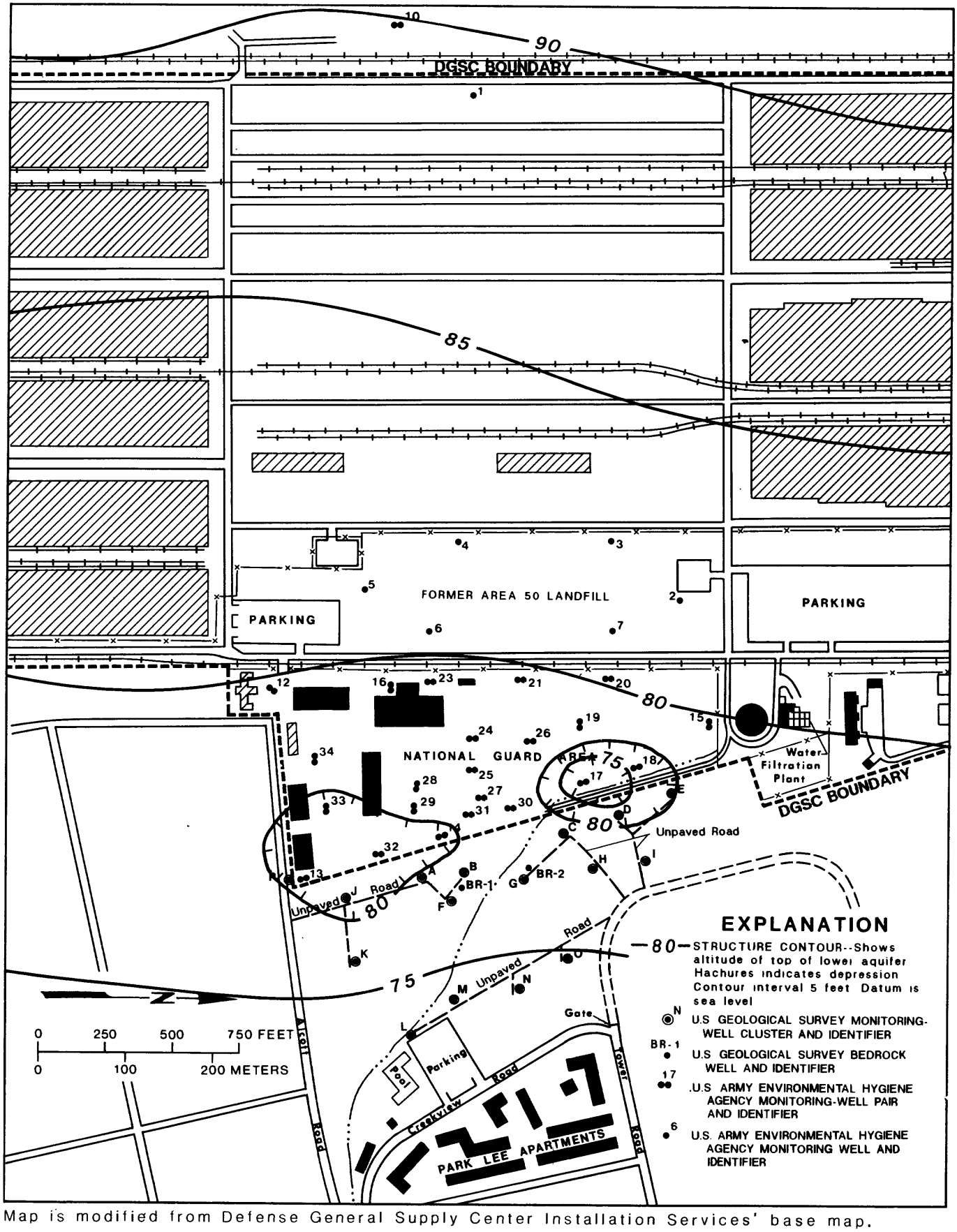
Monitoring-Well Design and Installation

Monitoring-well sites were selected by the USGS based on surficial geology, analyses of core samples, and previous investigations of contamination within the DGSC and NGA. Sixteen well clusters (fig. 8) that contain 68 wells were installed to define the areal extent of contamination. A line of 10 well clusters (lettered A to J) was placed 50 to 150 ft from and parallel to the eastern boundary of the DGSC. These clusters were used to locate the zone of contaminated water moving downgradient beyond the boundaries of the DGSC. A second line of well clusters was then placed about 200 ft farther downgradient. These clusters (lettered K to O) were used to investigate the downgradient extent of contaminated ground water.



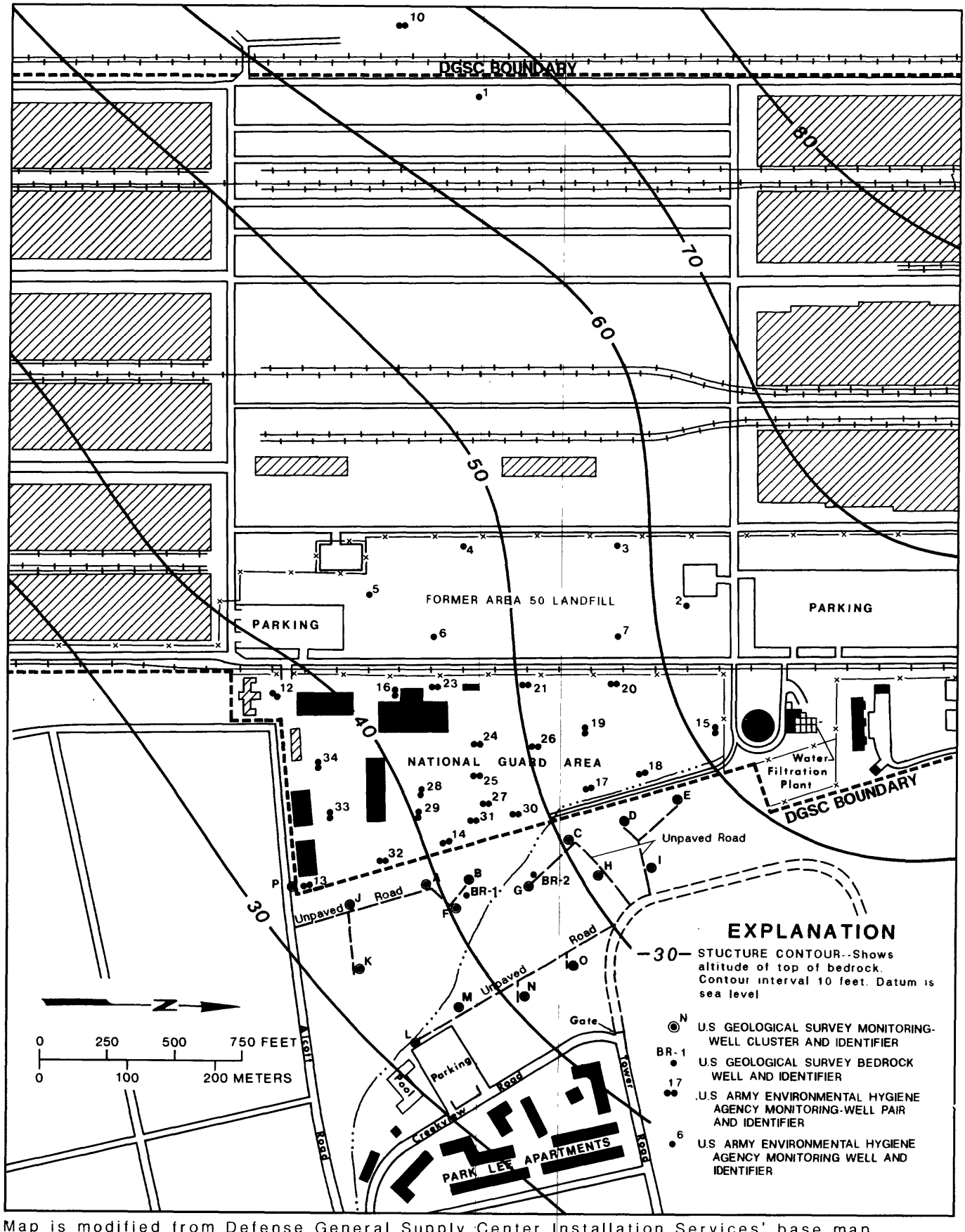
Map is modified from Defense General Supply Center Installation Services' base map.

Figure 5.-- Approximate altitude of the top of the confining unit.



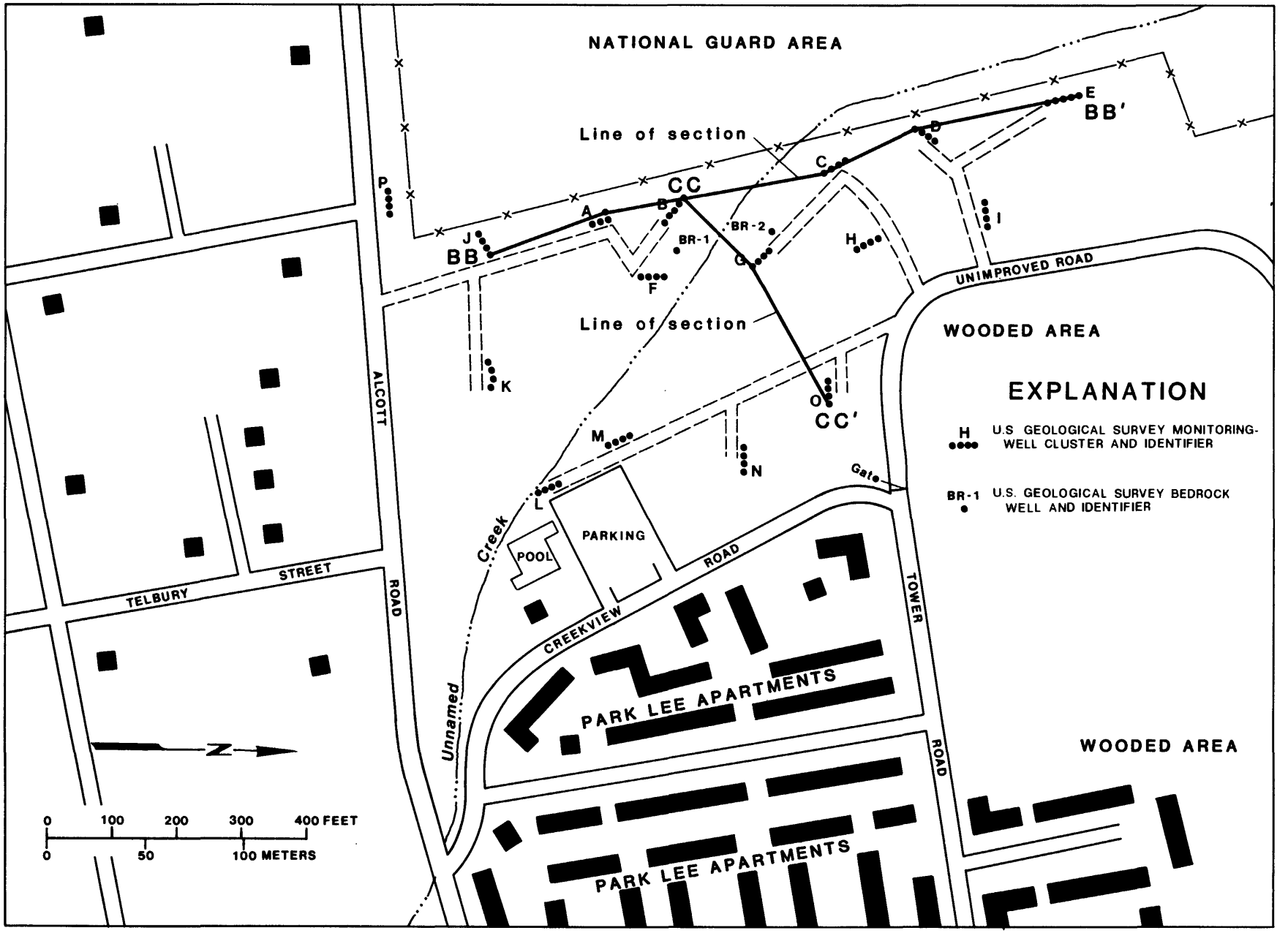
Map is modified from Defense General Supply Center Installation Services' base map.

Figure 6.-- Approximate altitude of the top of the lower aquifer.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 7.--Approximate altitude of the top of the Petersburg Granite.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 8.-- Location of U.S. Geological Survey monitoring-well clusters. (Sections BB-BB' and CC-CC' are shown in figures 14 and 13, respectively.)

Wells were installed at different depths within a cluster to define vertical variations within the contaminated zone. At least one well in a cluster was finished in the upper aquifer. If the thickness of the saturated zone of the upper aquifer exceeded 6 ft, separate wells were finished in the upper and lower halves of the upper aquifer. Separate wells were finished in the bottom, middle, and upper thirds of the lower aquifer. At each cluster, the wells were numbered consecutively from the deepest (A-1, for example) to the shallowest (A-4). The general arrangement of cluster wells is shown in figure 9. Samples of aquifer material were collected at the planned depth of each screened interval and visually examined in the field before installation of the screen; this assured placement of the screen in a productive zone of the aquifer.

All monitoring wells installed by the USGS were constructed with 3-in.-inside-diameter flush-threaded polyvinylchloride (PVC) casing and screens 2 ft long with 0.01-in. slots. Screens 2 ft long were used so that a narrow discrete altitude within the aquifer could be sampled. A diagram showing the construction of monitoring wells installed by the USGS is provided in figure 10.

Monitoring wells in the upper aquifer were constructed by placing 14-in.-inside-diameter steel surface casing in 18-in.-diameter auger holes and grouting the annular space between the surface casing and the hole to land surface. The PVC screen and casing were installed inside the surface casing with a 12-in.-diameter hollow-stem auger. Gravel was used to enclose the well screen; a minimum of 2 ft of bentonite pellets was introduced into the the hole above the gravel packing. After removal of the auger, the remaining annular space between the well casing and the surface casing above the bentonite was filled with gravel.

To auger the lower aquifer without introduction of contaminated water from the upper aquifer, an 18-in. diameter hole was augered to the confining unit and 14-in.-inside-diameter steel surface casing was driven into the confining unit. Drilling was continued using 12-in.-diameter augers inside the steel surface casing. The PVC screen and casing were inserted into the drill hole through the center of the hollow-stem augers, the augers were lifted 5 ft, gravel packing and bentonite were emplaced through the center of the augers, then the augers were lifted out of the hole. The remaining annular space between the well casing and the hole was grouted using a tremie pipe. Locking well caps were welded onto the surface casing to secure the wells.

Two wells were drilled into the bedrock to determine if contamination was present in the fractured granitic bedrock. These wells were drilled by mud-rotary method. The upper aquifer was sealed off using 14-in.-diameter steel surface casing driven into the confining unit. The lower aquifer was sealed off using 6-in.-diameter PVC casing grouted into the bedrock. The wells were finished as 4-in.-diameter open holes drilled 25 ft into the bedrock.

All wells installed by the USGS were purged approximately 20-30 well volumes after installation– a process called well development– to remove fines from the gravel packing and well screen and to remove aquifer water disturbed by drilling.

Ground-Water Sampling

Wells were purged 3-well volumes before sampling using an air-driven positive-displacement pump. Purged water was placed in a specially-designed steel tank and disposed of–with official written permission–in the sanitary sewer system.

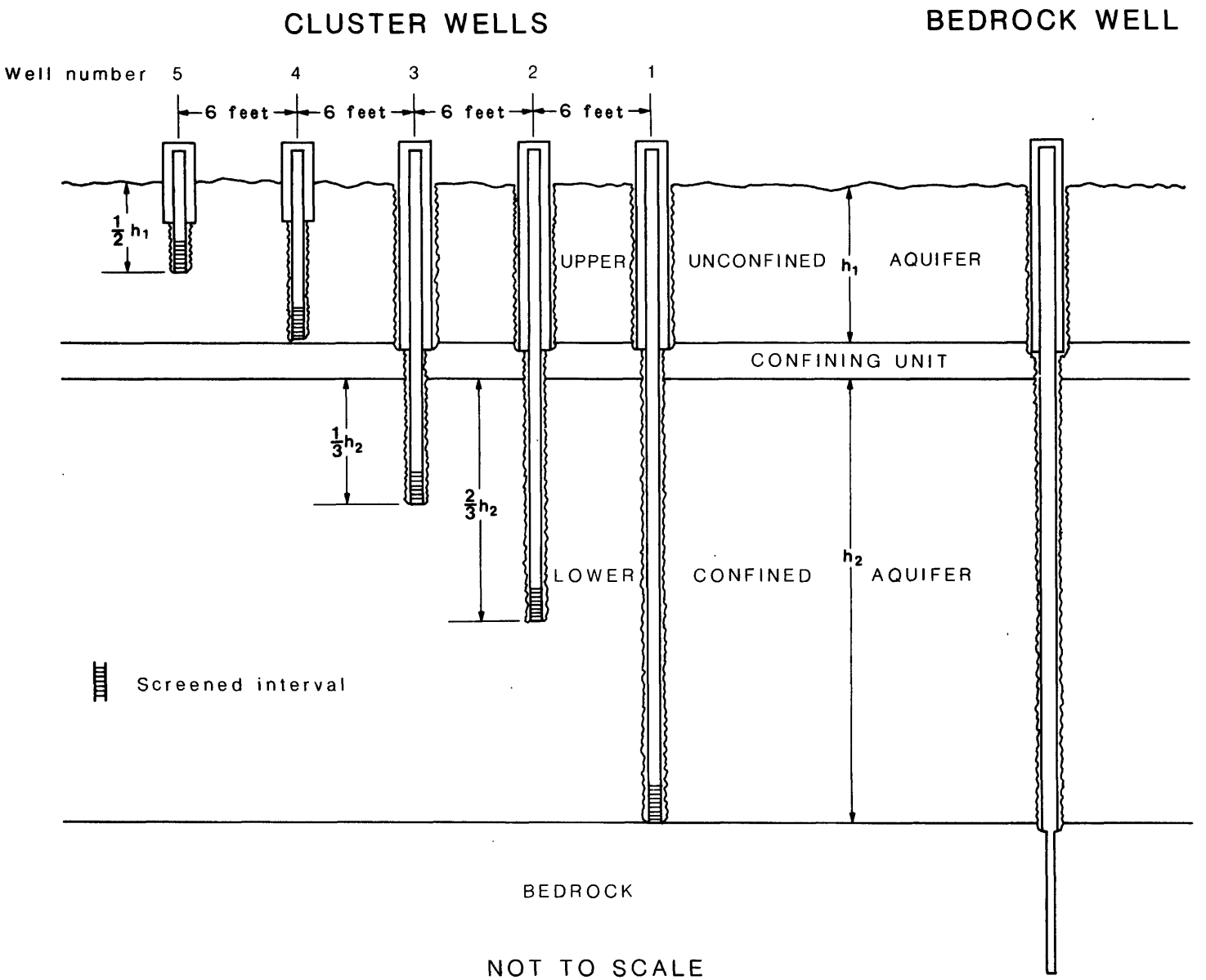


Figure 9.-- General arrangement of cluster wells and bedrock well.

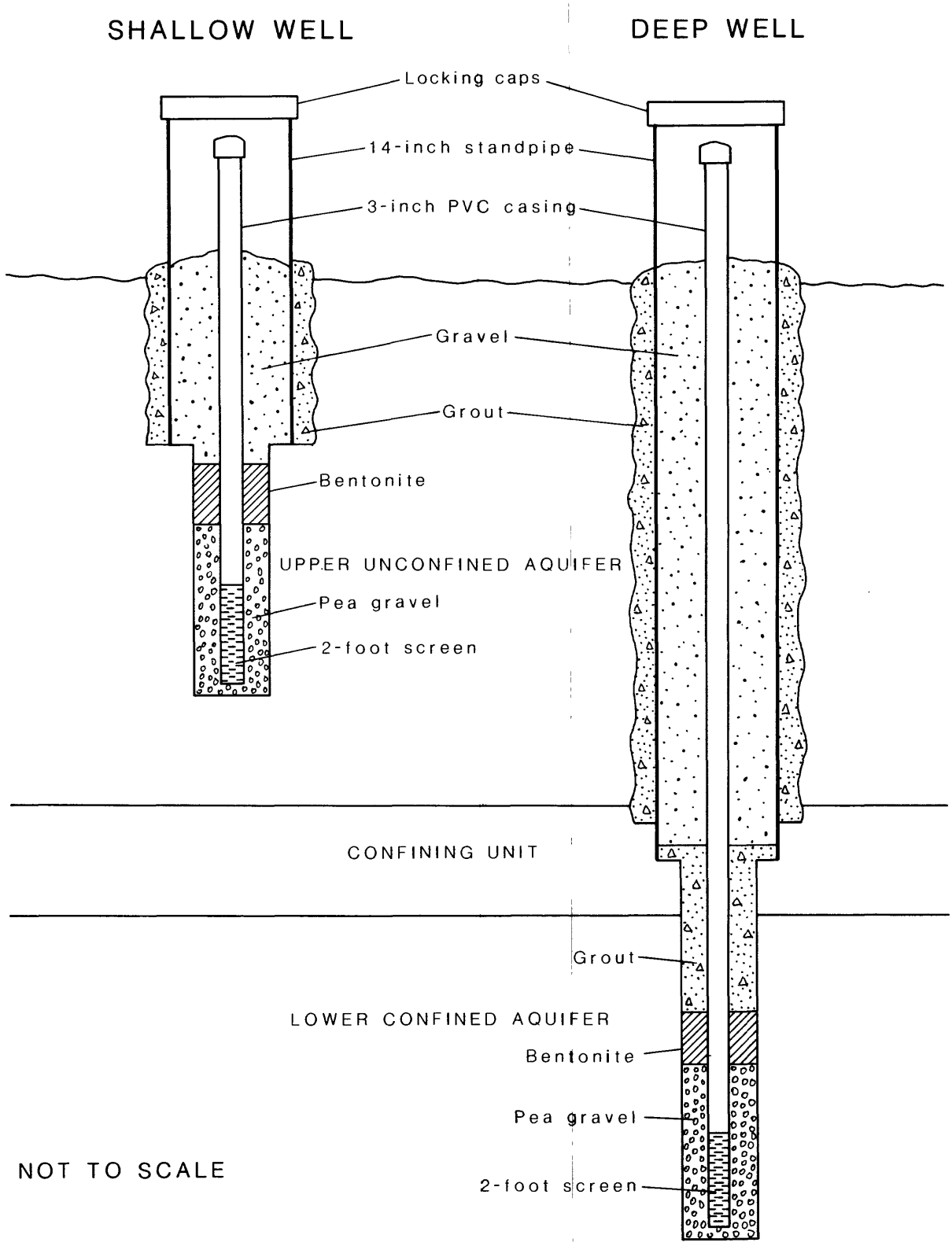


Figure 10.-- Design of monitoring wells installed by the U.S. Geological Survey.

All ground-water samples were collected from the middle of the 2-ft screened interval using Teflon[1] bailers. The 2.5-in.-diameter bailers were equipped with check valves at both the top and bottom of the bailer to insure collection of an undisturbed point sample. A bottom-emptying device with a valve facilitated extracting the sample from the bailer without aerating the sample. A Teflon-coated wire was attached to the ball in the upper check valve to open the check valve during sample extraction to prevent buildup of a vacuum and preclude aeration from the bottom when extracting water through the bottom-emptying device. Water for analysis of volatile-organic compounds was placed in 40-ml (milliliter) glass Teflon-septum vials.

All samples were stored in an ice-filled cooler immediately upon collection and shipped to the laboratory by overnight delivery at the end of each workday.

RESULTS OF STUDY

Ground-Water Contamination

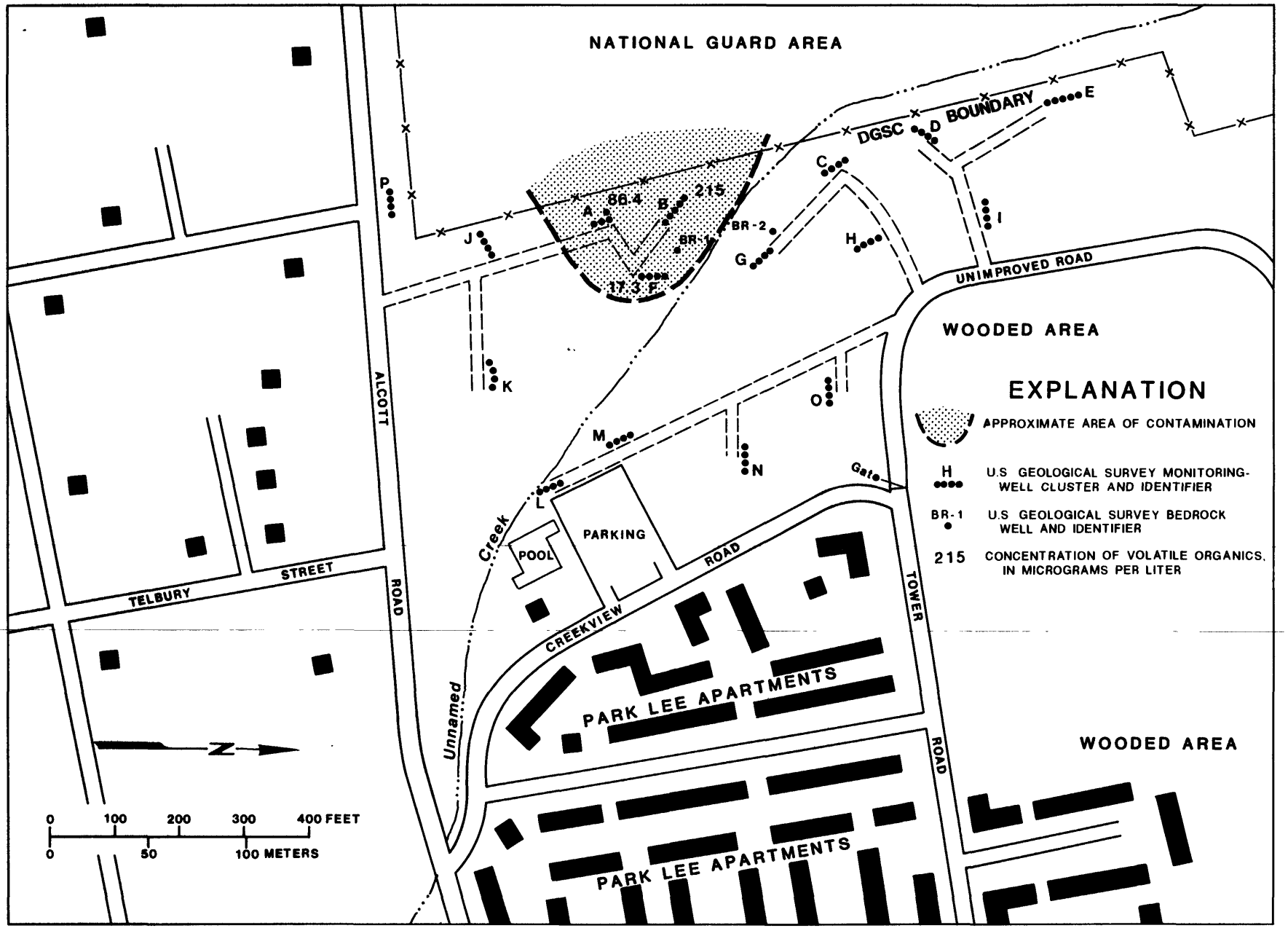
Chemical analyses were performed by the USGS central laboratories located in Atlanta, Georgia, and Denver, Colorado. Volatile-organic-compound concentrations were analyzed using gas chromotography and mass spectrometry. Total organic-carbon concentrations were determined using a carbon analyzer. Field measurements were performed for pH, specific conductance, dissolved oxygen, and alkalinity.

Areal maps and cross-sectional views of data showing field measurements and analyses of major cations and anions, priority-pollutant metals, and total organic carbon do not indicate any relation to the zones of volatile-organic contamination. The suspected cause of this nonrelation is probably from the excavated landscape of the DGSC where fill was transported in from other areas, and from the many parking lots and roads that contribute urban contaminants to the ground-water system.

Ground-water contamination data collected and compiled by the U.S. Army Environmental Hygiene Agency indicate elevated concentrations of volatile-organic compounds in water from wells in the former Area 50 landfill and in the NGA (U.S. Army Environmental Hygiene Agency, 1982a; 1982b). The sources of contamination have not been completely identified. Since the objective of this report is to describe the distribution of ground-water contaminants beyond the boundaries of the DGSC, distribution of volatile-organic compounds within the boundaries of the DGSC are not shown.

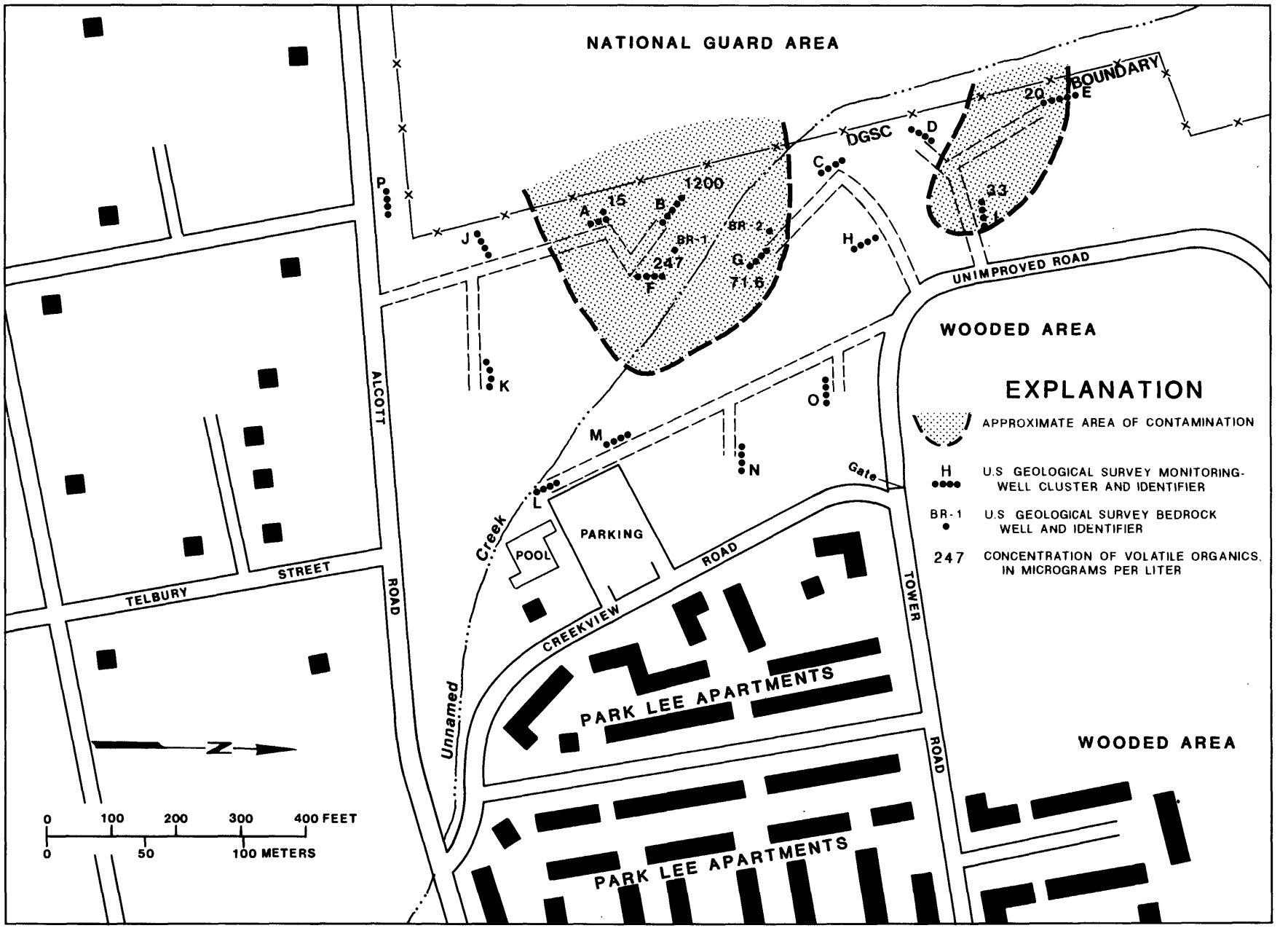
For the purposes of this report, total volatile compounds were determined by summing the concentrations, in micrograms per liter, of each of the concentrations of the individual volatile-organic compounds detected. The extent of total volatile compounds beyond the boundaries of the DGSC for the upper and lower aquifers during September 1986 is shown in figures 11 and 12; concentrations shown in figure 12 are from the middle zone of the lower aquifer (A-2, B-2, *etc.*). Longitudinal and lateral profiles of the contaminated ground water are shown in figures 13 and 14. Similar areal distributions of total volatile compounds are evident for the sampling periods covering 1986-89.

[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.



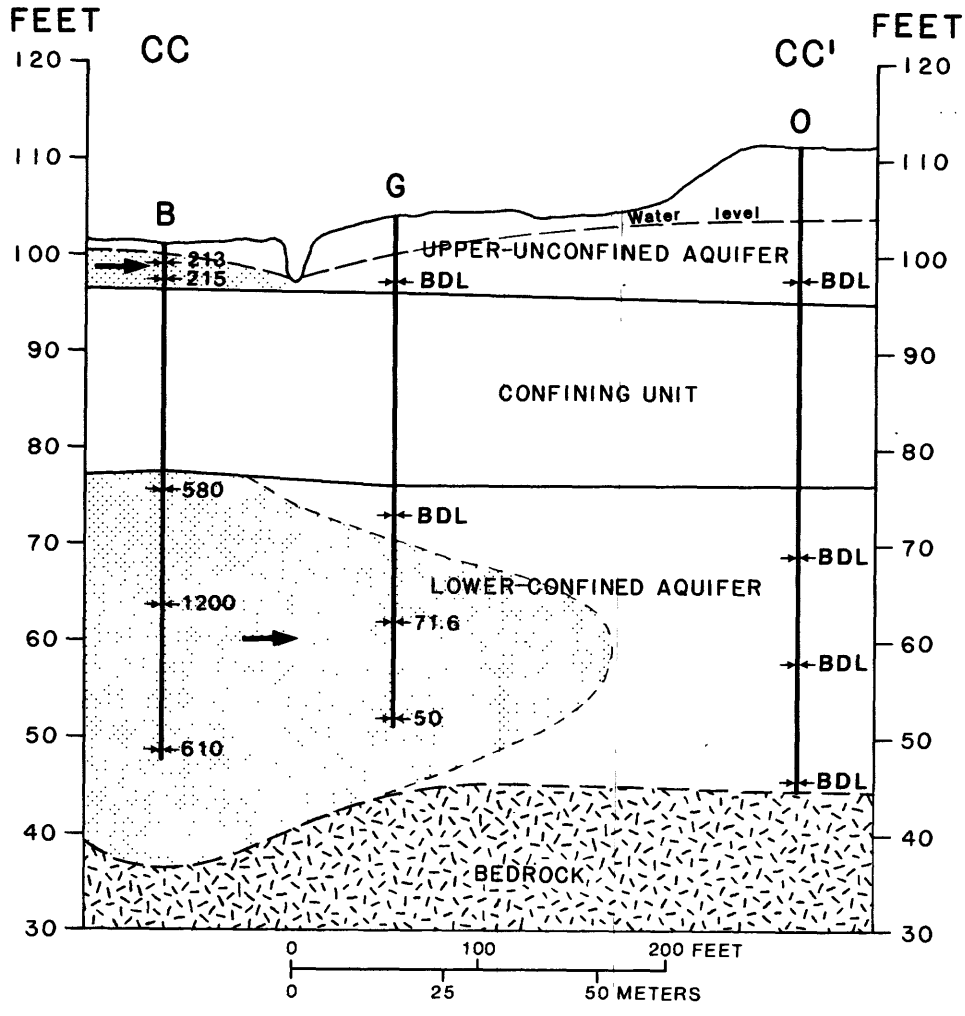
Map is modified from Defense General Supply Center Installation Services' base map.

Figure 11.--Area of ground-water contamination in the upper unconfined aquifer beyond the boundaries of the Defense General Supply Center, September 1986.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 12.--Area of ground-water contamination in the middle part of the lower confined aquifer beyond the boundaries of the Defense General Supply Center, September 1986.



EXPLANATION

	AREA OF CONTAMINATION
B	U.S. GEOLOGICAL SURVEY MONITORING-WELL CLUSTER
- -	MIDDLE OF SCREENED INTERVAL
610	CONCENTRATION OF VOLATILE-ORGANIC COMPOUNDS, IN MICROGRAMS PER LITER
BDL	BELOW DETECTION LIMITS
→	DIRECTION OF GROUND-WATER FLOW

Figure 13.--Longitudinal hydrogeologic section of zone of contamination within the upper and lower aquifers, September 1986.

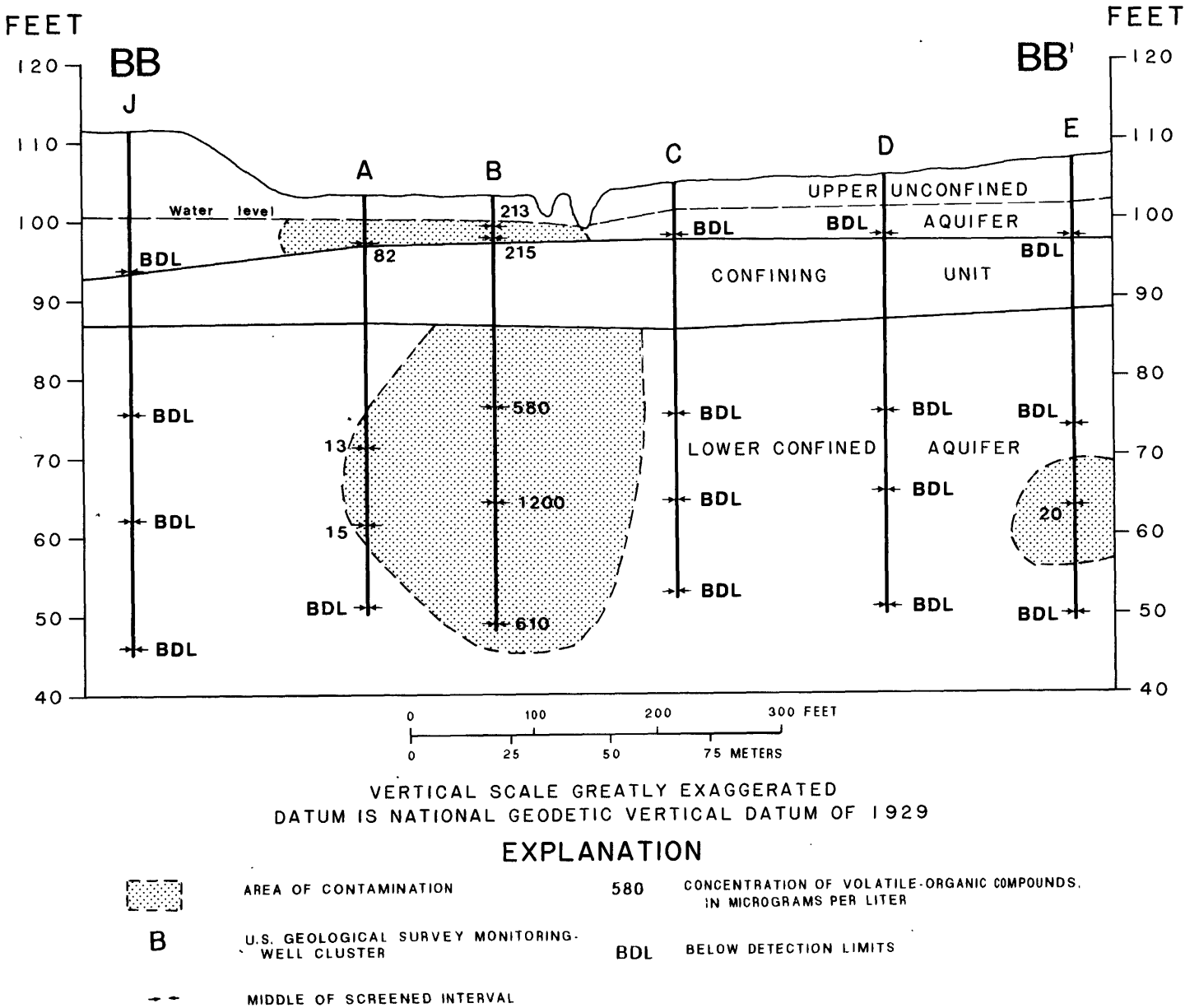


Figure 14.--Lateral hydrogeologic section of zone of contamination within the upper and lower aquifers looking upgradient, September 1986.

For data covering the 1984-89 sampling period, two areas of ground-water contamination are evident downgradient from the DGSC. The major area of contamination, located in the vicinity of clusters A, B, and F (fig. 2), is characterized by the presence of trichloroethene and 1,2-trans-dichloroethene. Chlorobenzene, tetrachloroethene, and toluene occur at relatively low concentrations in water from these wells. A lesser contaminated area, located in the vicinity of clusters E and I (fig. 2), is characterized by the presence of toluene.

Ground-water contamination in the upper aquifer in the vicinity of clusters A, B, and F does not seem to extend downgradient beyond the unnamed creek, possibly indicating that the unnamed creek acts as a hydrologic boundary to the transport of contaminants in the upper aquifer. Ground-water contamination in the lower confined aquifer does extend downgradient beyond the unnamed creek, but, as of the June 1989 sampling, did not reach clusters L, M, N, and O located farther downgradient. Contamination in O cluster was first reported in the analyses from the June 1989 sampling. The distribution of total volatile compounds in the upper and lower aquifers for March 1990 is shown in figures 15 and 16. Longitudinal and lateral profiles of the contaminated ground water are shown in figures 17 and 18.

Ground-water contamination in the vicinity of clusters E and I is present in both the upper and lower aquifers. Concentrations of toluene in this area generally are significantly lower than the concentrations at clusters A, B, F, and G.

Direction and Rate of Ground-Water Movement

Direction

Estimates of direction of ground-water movement, based on monthly water-level measurements in the upper and lower aquifers, are presented in figures 19 and 20. Ground water in the upper aquifer moves toward and discharges into the unnamed creek from both the east and west and probably moves slowly downward through the confining unit into the lower aquifer. Ground water in the lower aquifer, however, moves eastward under the creek.

Four analog digital water-level recorders were operated to provide hourly records of water levels at B cluster, east of the NGA. These records show the reaction of each aquifer to recharge by precipitation and demonstrates the interconnection of the upper and lower aquifers. Hydrographs for well B-4 (finished in the upper aquifer) and well B-1 (finished in the lower aquifer) are shown in figure 21. Rainfall data collected at the DGSC for the period of record of the hydrographs are also shown in figure 21. An immediate response of water levels in the upper aquifer to rainfall is evident; the response of the water levels in the lower aquifer is more subdued.

Rate

Hydraulic conductivity, hydraulic gradient, and storage control the rate of ground-water flow. These hydraulic characteristics were determined by aquifer tests of both the upper and lower aquifers. A production well and four observation wells were used in a test of the lower aquifer. The arrangement of wells at the test site is shown in figure 22. Three observation wells were completed in the lower aquifer, each at a different depth and at a radius of 50 ft from the production well. One observation well was finished in the lower aquifer at a distance of 100 ft from the production well to determine leakance of the confining unit. Water levels were measured at each well over a 24-hour pumping period. The second test involved a production well and one observation well in the

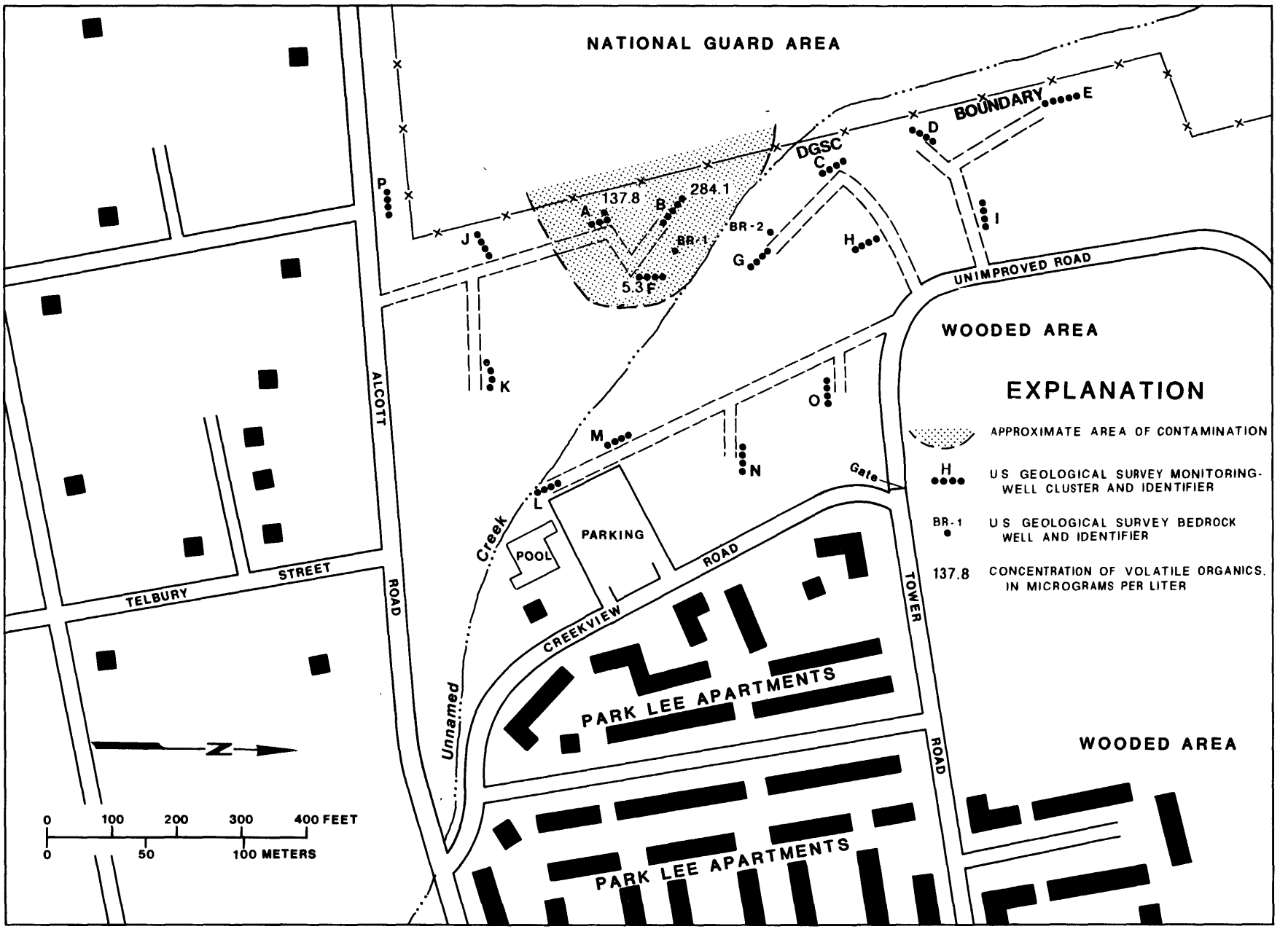


Figure 15.--Area of ground-water contamination in the upper unconfined aquifer beyond the boundaries of the Defense General Supply Center, March 1990.

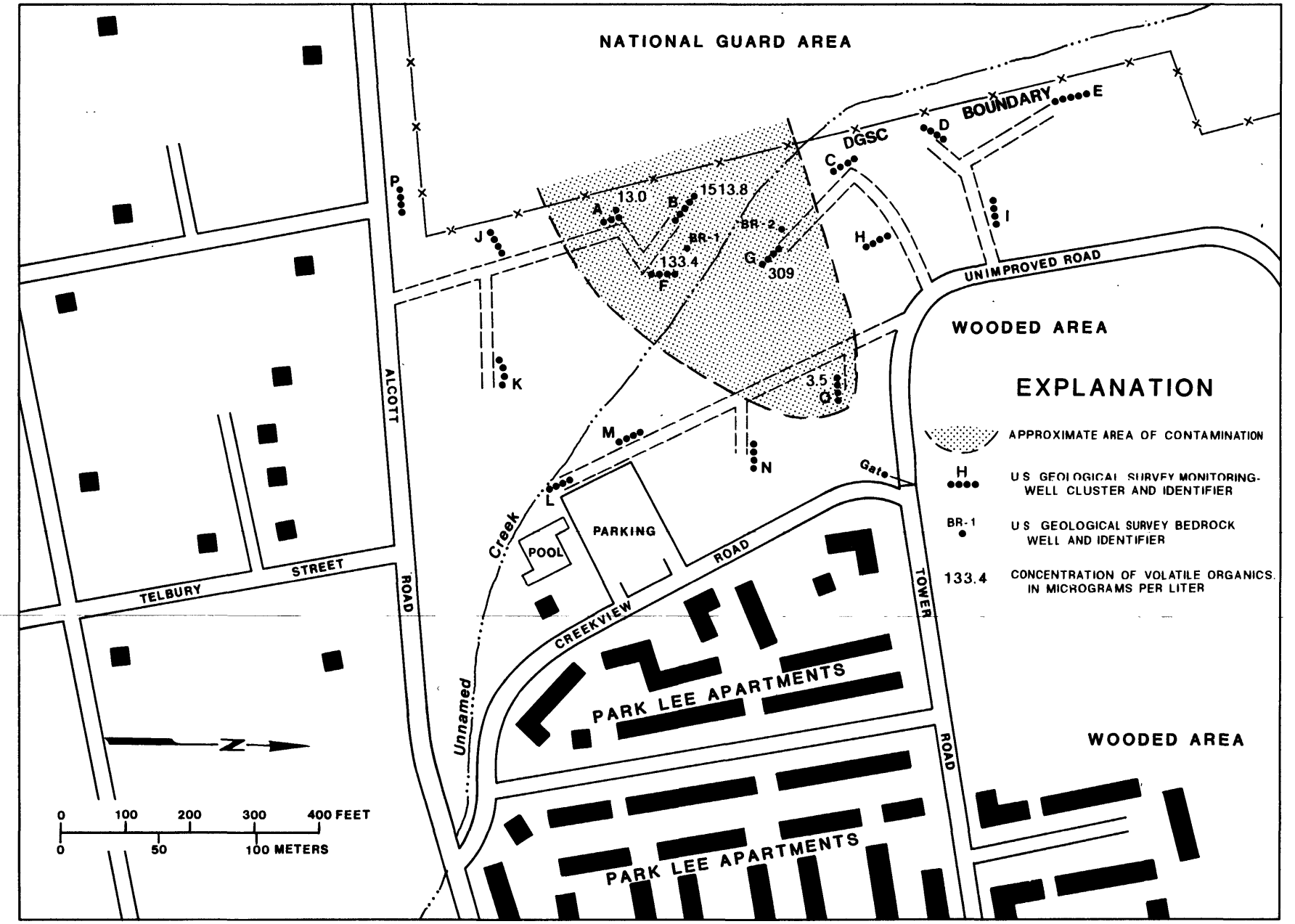
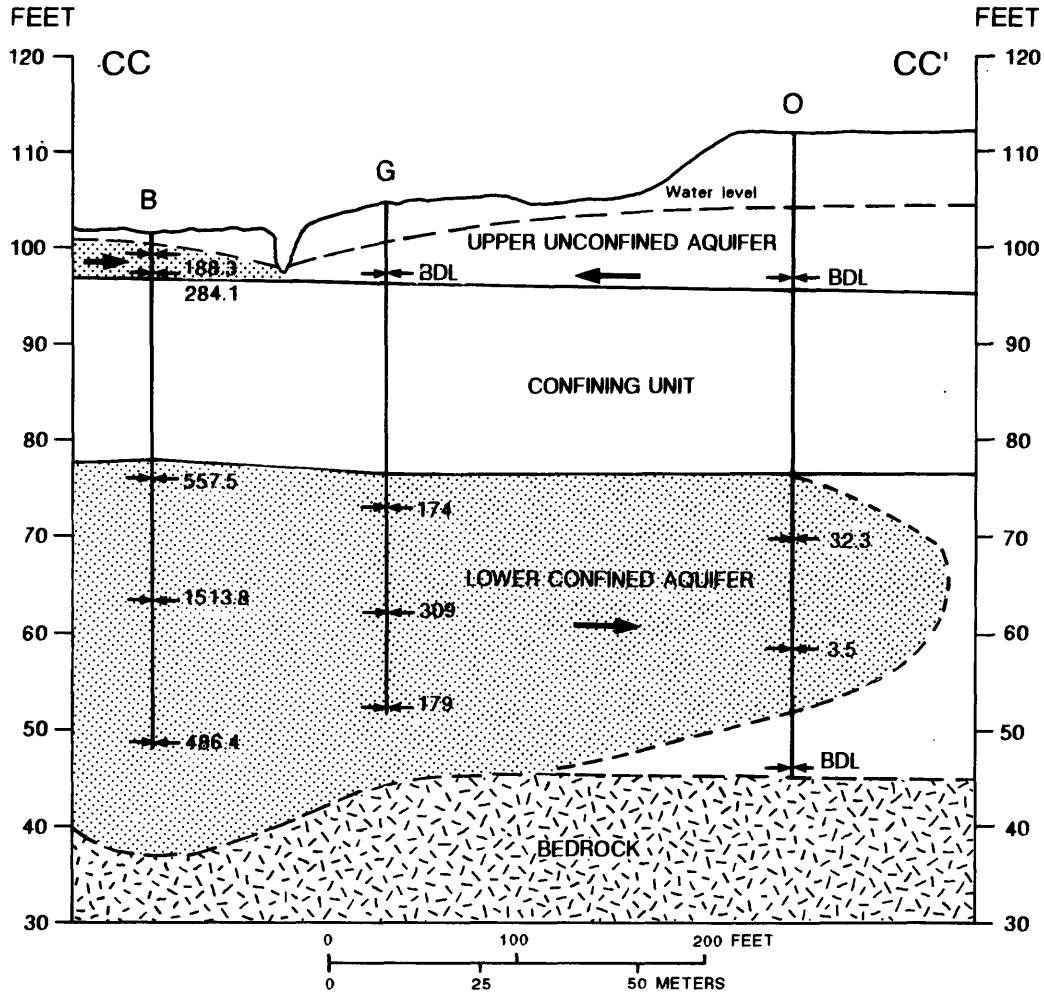


Figure 16.--Area of ground-water contamination in the middle part of the lower confined aquifer beyond the boundaries of the Defense General Supply Center, March 1990.



VERTICAL SCALE GREATLY EXAGERATED
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

	AREA OF CONTAMINATION
B	U.S. GEOLOGICAL SURVEY MONITORING-WELL CLUSTER
→ ←	MIDDLE OF SCREENED INTERVAL
309	CONCENTRATION OF VOLATILE-ORGANIC COMPOUNDS, IN MICROGRAMS PER LITER
BDL	BELOW DETECTION LIMITS
→	DIRECTION OF GROUND-WATER FLOW

Figure 17.--Longitudinal hydrogeologic section of zone of contamination within the upper and lower aquifers, March 1990.

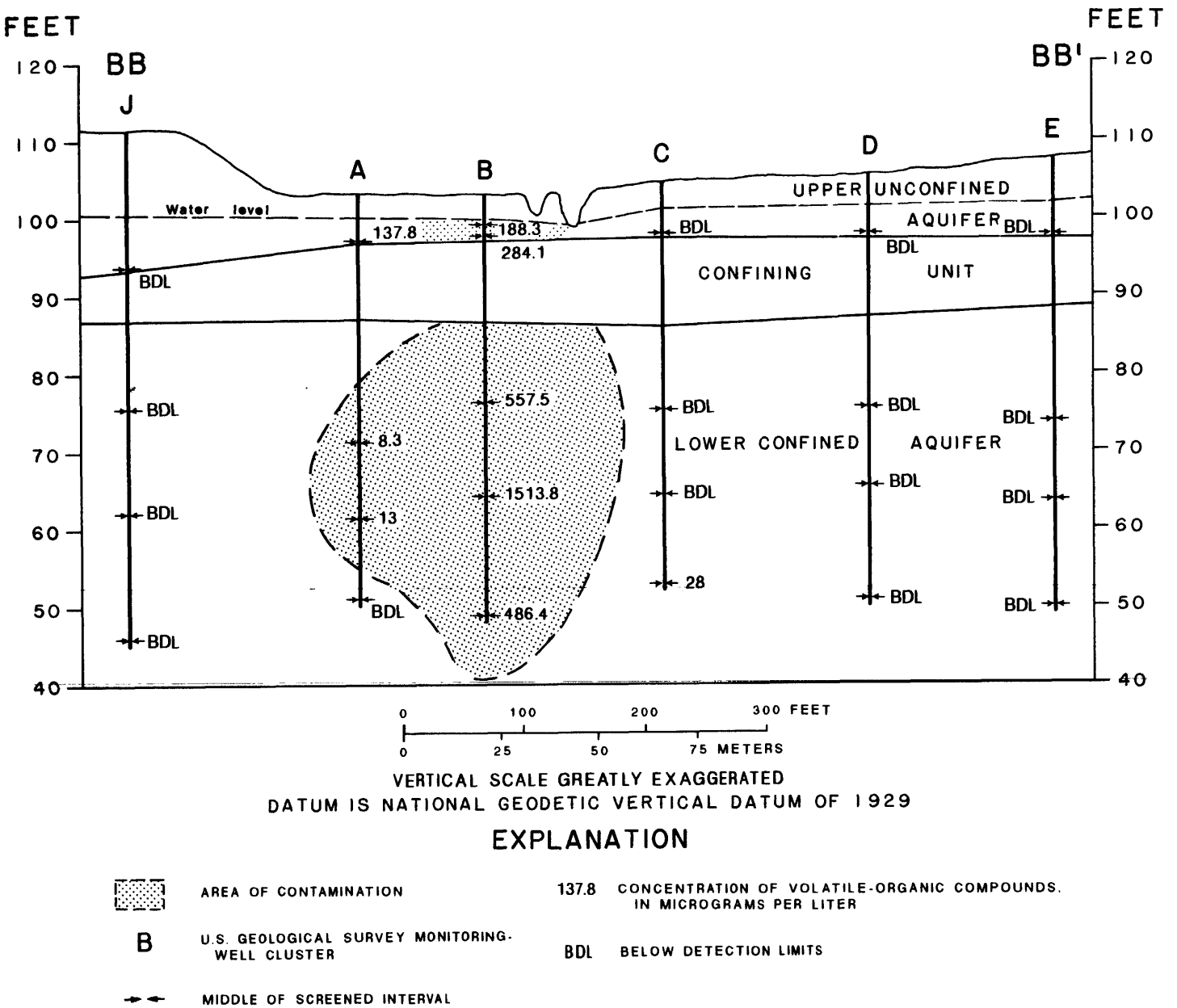
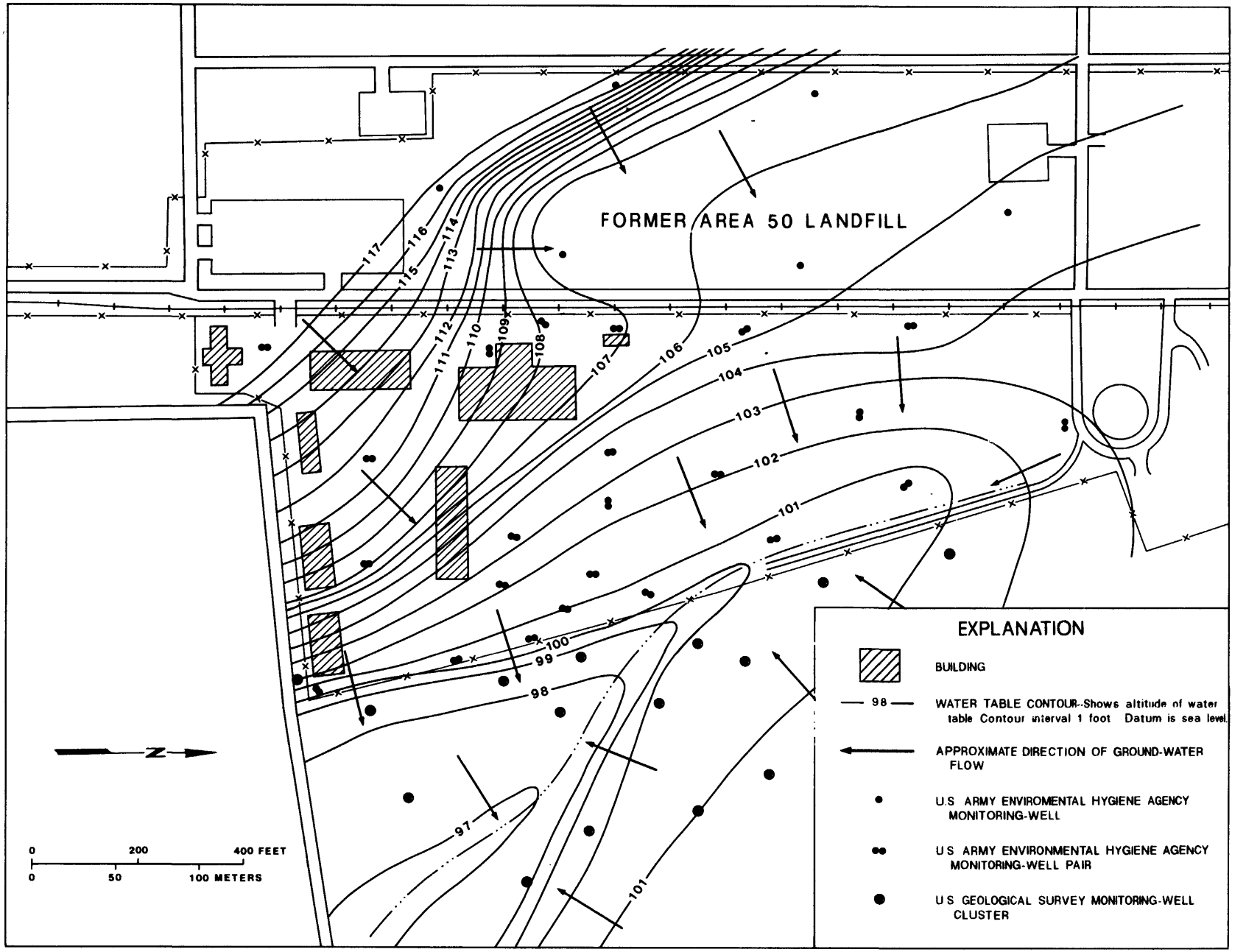
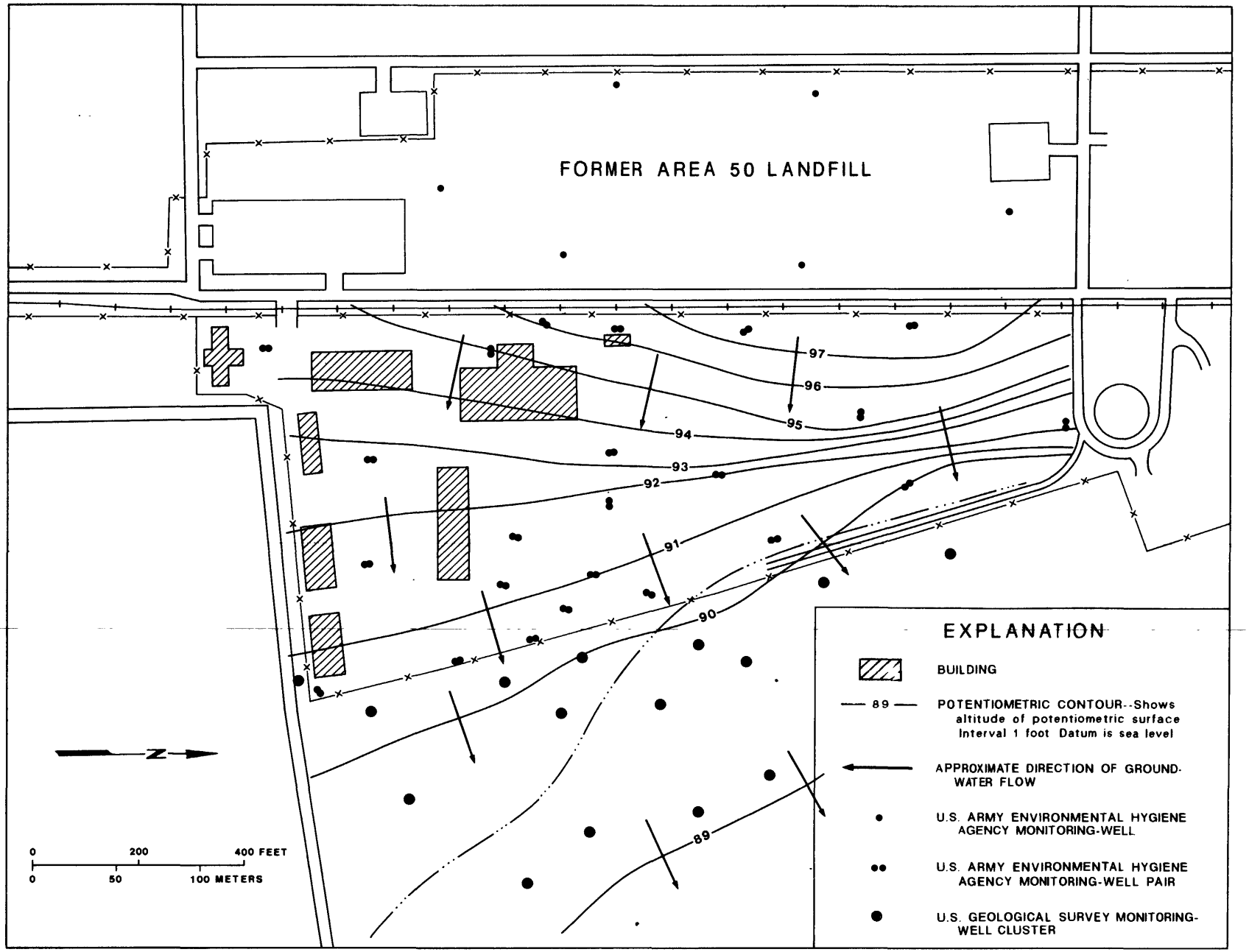


Figure 18.--Lateral hydrogeologic section of zone of contamination within the upper and lower aquifers looking upgradient, March 1990.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 19.--Water-table contours and approximate directions of ground-water movement in the upper aquifer, June 1986.



Map is modified from Defense General Supply Center Installation Services' base map.

Figure 20.--Potentiometric contours and approximate direction of ground-water movement in the lower aquifer, June 1986.

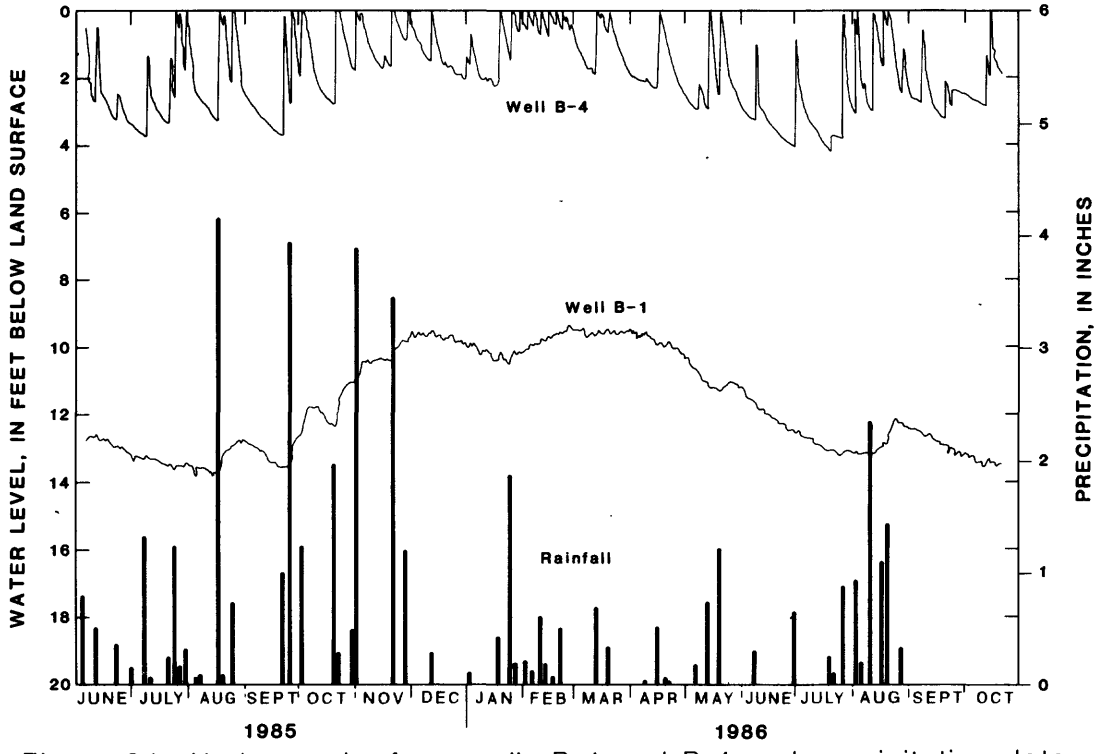


Figure 21.--Hydrographs from wells B-1 and B-4 and precipitation data, January 1985 through October 1986.

upper aquifer at a distance of 25 ft from the production well. Water levels were measured over a 3-hour period.

Storage coefficient and transmissivity of the lower aquifer were estimated using type-curve matching (Theis, 1935). The hydraulic properties determined from aquifer-test results were used in a radial-flow model (Weeks, E.P., U.S. Geological Survey, written commun., 1986) to refine these characteristics for the upper, middle, and lower parts of the lower aquifer. The radial-flow model incorporates vertical leakage (Hantush and Jacob, 1955), delayed yield from drainage (Lohman, 1979, p. 34), conversion of artesian conditions to water-table conditions, and well-bore storage (Walton, 1970). Hydraulic characteristics were adjusted in the model until simulated drawdown curves matched actual drawdown. Actual and simulated drawdown curves for each lower aquifer well are shown in figure 23. Final estimates of aquifer characteristics are given in table 3.

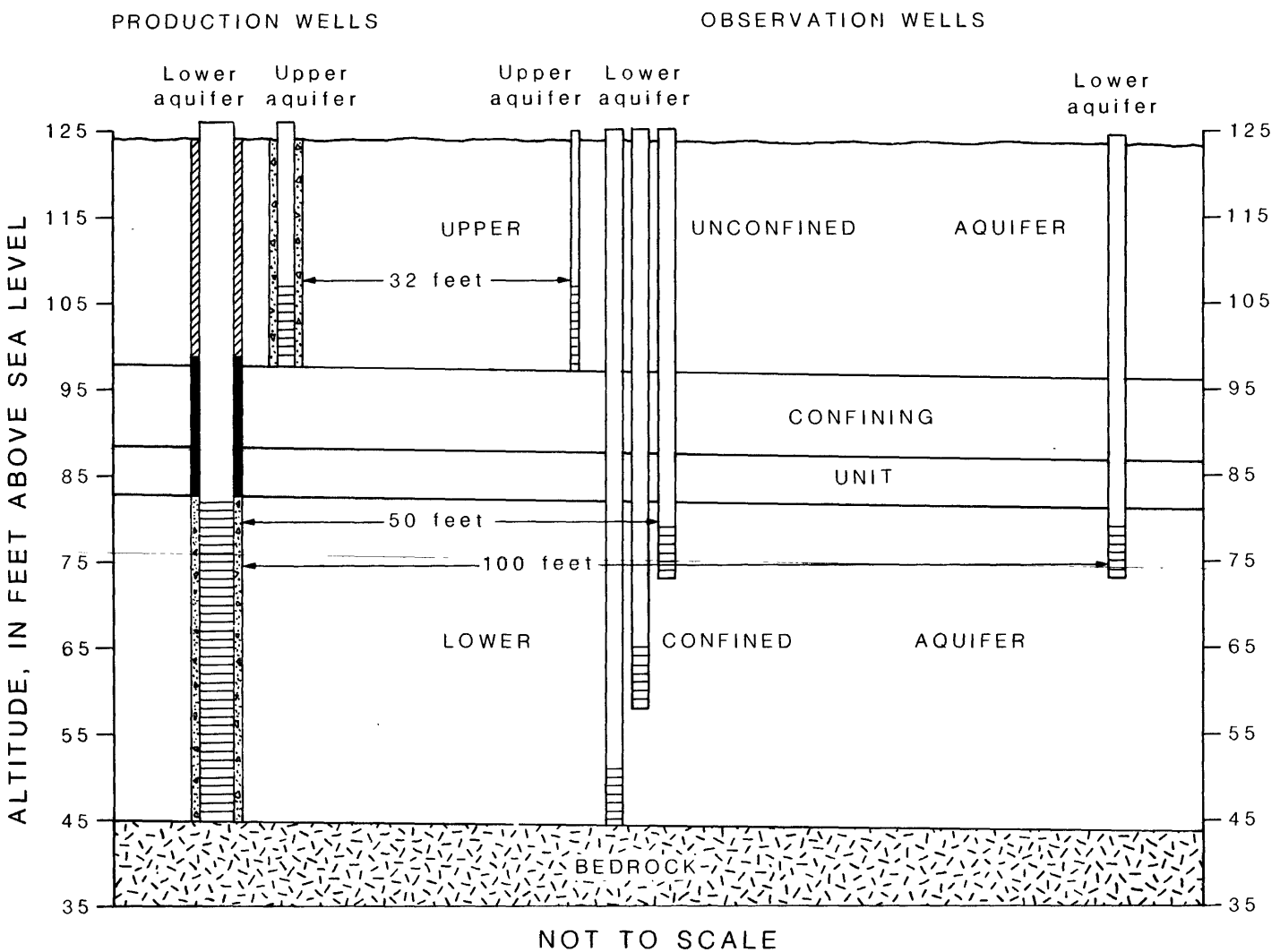


Figure 22.--Arrangement of aquifer-test wells.

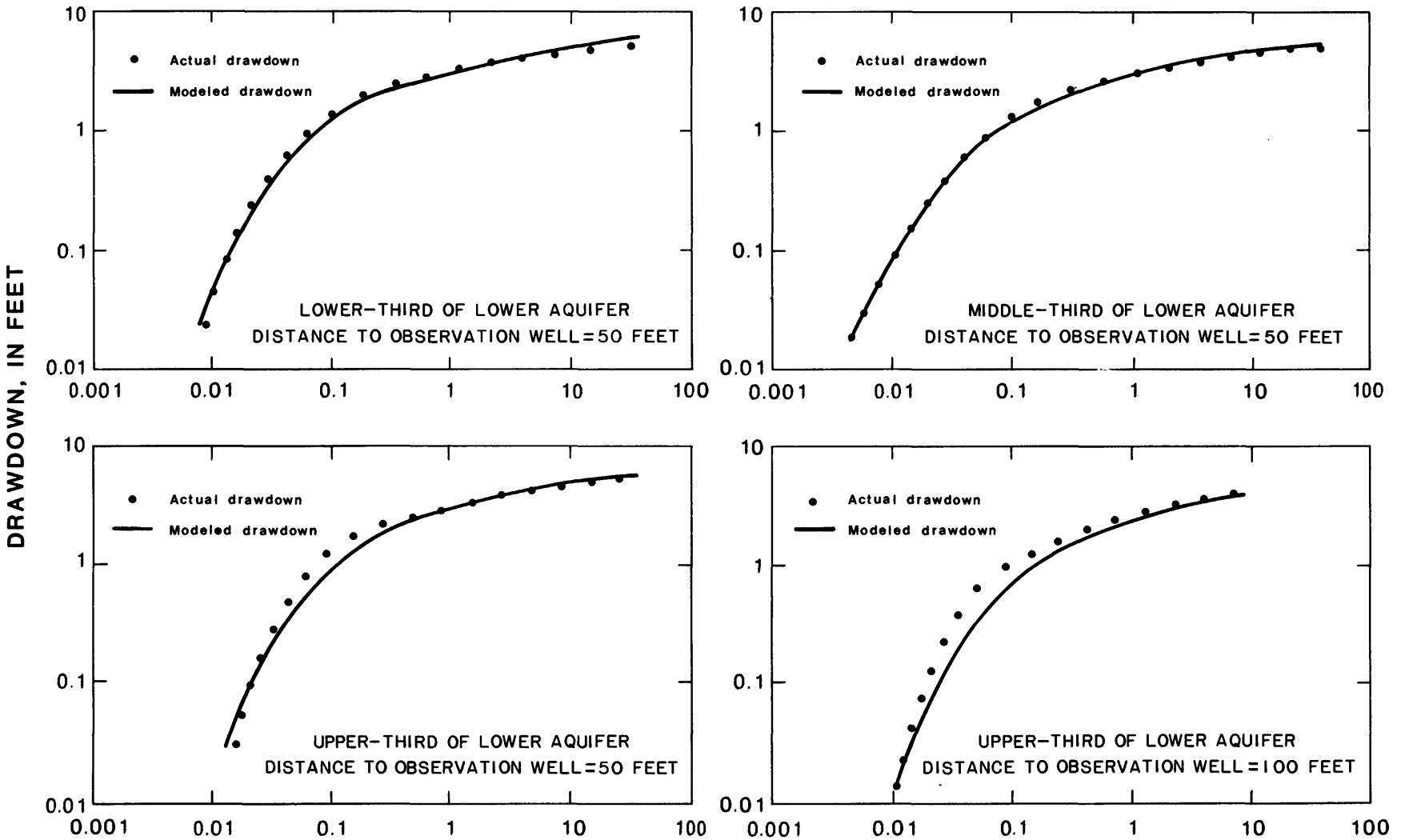


Figure 23.--Model-simulated and actual drawdown curves for lower-aquifer observation wells.

Table 3.–*Hydraulic characteristics of the upper and lower aquifers and confining unit at the Defense General Supply Center*

[T, transmissivity, in feet squared per day; K_h, horizontal hydraulic conductivity, in feet per day; K_v, vertical hydraulic conductivity in feet per day; S, storage coefficient, dimensionless; V, average linear velocity, in feet per year (porosity is equal to 0.30); PT, pumping-test analysis with type-curve matching; RM, radial-flow modeling; LP, laboratory-permeability testing; –, indicates data are not available]

Formation	Hydrogeologic unit	T	K_h	K_v	S	V	Method
Eastover	Upper unconfined aquifer	90.0	6.0	–	$1x10^{-2}$	63.0	PT
Calvert	Confining unit	–	–	$2.7x10^{-4}$	–	.07	LP
Aquia	Confining unit	$3.5x10^{-2}$	$5.0x10^{-3}$	$5.0x10^{-3}$	$2x10^{-8}$	1.3	PT; RM
Potomac	Lower confined aquifer						
	Upper part	110.0	7.3	.73	$3x10^{-5}$	89.0	PT; RM
	Middle part	275.0	18.3	1.83	$2x10^{-5}$	223.0	PT; RM
	Lower part	165.0	16.5	1.65	$2x10^{-5}$	200.0	PT; RM

The highest horizontal hydraulic conductivity in the lower aquifer, 18.3 ft/d (feet per day), is in the middle third of the aquifer. The lowest horizontal hydraulic conductivity, 7.3 ft/d in the lower aquifer, is in the upper third of the aquifer. These values indicate that ground water moves most rapidly, based on a gradient of 0.01 and estimated porosity of 30 percent, in the middle third of the lower aquifer (about 223 ft/yr) and most slowly in the upper third of the lower aquifer (about 89 ft/yr). These conditions are consistent with the hydrogeologic sections (figs. 13 and 14) that show contaminants were migrating farther downgradient in the middle third of the lower aquifer than in the upper and lower thirds of the lower aquifer.

Hydraulic characteristics of the upper aquifer were estimated using type-curve matching (Lohman, 1979). Ground-water velocity in the upper aquifer is about 63 ft/yr, based on a gradient of 0.01 and an estimated porosity of 30 percent. The actual drawdown curve and type-curve used to determine hydraulic characteristics are shown in figure 24. Because of the textural variations in the composition of the upper aquifer, an estimated velocity does not, however, have the transfer value of similar estimates in the more homogeneous lower aquifer. Horizontal ground-water movement in the upper aquifer appears to be primarily within a narrow zone of cobbles and gravel. The extensive disturbance of the upper aquifer by excavation and filling in the study area further limits the transfer value of flow velocity estimates for the upper aquifer.

Hydraulic characteristics determined from analysis of confining-unit core samples in the laboratory indicate vertical ground-water velocities of 0.07 and 1.30 ft/yr for the Calvert and Aquia Formations, respectively. Movement of water through the confining unit, however, may be much

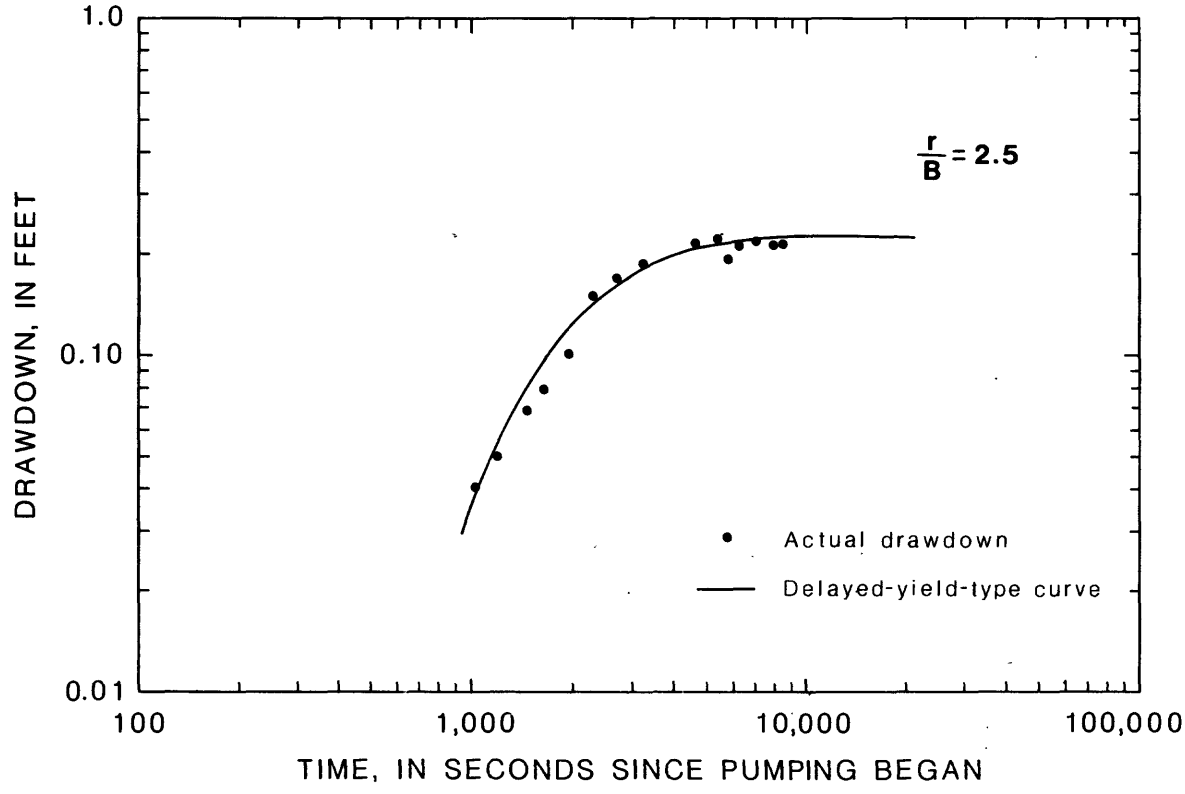


Figure 24.--Actual drawdown and delayed-yield-type curve for upper-aquifer pumping test.

more rapid locally because of erosional features and fractures. Estimated characteristics of the formations of the confining unit are provided in table 3.

Through the use of estimated characteristics, an approximation of the vertical and horizontal flow of ground water in the area of the landfill can be made. The vertical flow through an area about the size of the Area 50 landfill (1,000 by 300 ft) can be estimated using Darcy's law:

$$Q_v = K_v iA,$$

where Q_v is vertical flow, K_v is the vertical hydraulic conductivity, i is the vertical gradient (0.444 ft/ft, based on water-level measurements) across the confining unit, and A is the approximate area of the Area 50 landfill. The hydraulic conductivity value (2.97 ft/yr) is a geometric mean of laboratory analysis of core samples of the confining unit and from aquifer-test results. On the basis of the parameters, approximately 2.95 Mgal/yr (million gallon per year) pass through the confining unit to the lower aquifer in the area of the landfill.

Through the use of characteristics estimated from the aquifer test in the lower aquifer, an approximation of the horizontal flow under the Area 50 landfill can be accomplished using Darcy's law:

$$Q_h = K_h i A ,$$

where Q_h is horizontal flow, K_h is the horizontal hydraulic conductivity, i is the hydraulic gradient across the DGSC in the lower aquifer, and A is the cross-sectional area of the lower aquifer along the length of the Area 50 landfill. The hydraulic conductivity (5,018 ft/yr) is a geometric mean based on hydraulic conductivities derived from the aquifer test. The hydraulic gradient is based on water levels measured in the lower aquifer in monitoring wells located upgradient and downgradient from the DGSC. The cross-sectional area is based on a 1,000-ft length for the landfill and a 40-ft thickness for the lower aquifer. On the basis of these characteristics, approximately 15 Mgal/yr moves eastward through the lower aquifer under the landfill.

Rate of Contaminant Movement

Although aquifer tests indicate that the rate of movement of ground water in the lower aquifer is about 200 ft/yr, the contamination apparently moves at a much slower rate. Contamination in O cluster was first reported in analyses from the June 1989 sampling. When F and G clusters were first installed and sampled in March 1985, contamination was already evident in water from these wells (located approximately 200 ft upgradient from O cluster). Assuming that the contamination has migrated about 200 ft between March 1985 and June 1989, the approximate rate of contaminant migration ranges from 40 to 50 ft/yr. From these observations, an approximation for the retardation factor of volatile-organic compounds in the lower aquifer can be made by use of the general relation of Bedient and others (1984);

$$R = V_w / V_c ,$$

where R is the approximate retardation factor, V_w is the velocity of ground water, and V_c is the observed velocity of the contaminants. The retardation factor for volatile-organic contaminants in the lower aquifer at the study area is about 4.4, or the contaminants move about 80 percent slower than the ground-water flow. Biochemical degradation of the volatile-organic compounds and adsorption of contaminants on organic matter on the sediments probably are the causes for retardation of the contaminants.

SUMMARY AND CONCLUSIONS

Contaminants in the upper aquifer have moved downgradient beyond the boundaries of the DGSC in the area of well clusters A, B, and F. The principal contaminants are the volatile-organic compounds trichloroethene and 1,2-trans-dichloroethene. The compounds were apparently spilled or dumped within the Area 50 landfill or within the NGA. The upper aquifer seems to be discharging into the unnamed creek, and, thus, contaminated ground water in the upper aquifer probably does not move eastward beyond the creek.

Contaminants in the lower aquifer have moved downgradient approximately 400 ft beyond the boundaries of the DGSC. The area of greatest concentrations is in the vicinity of clusters A, B, F, and G. The principal contaminants are the volatile-organic compounds trichloroethene and 1,2-trans-dichloroethene. Other volatile-organic compounds (such as chlorobenzene, tetrachloroethene, and

toluene) are found in this area but inconsistently and in relatively small concentrations at some locations. The area of the greatest extent of contamination is in the vicinity of O cluster; this plume of contamination appears to be related to the contaminants detected in clusters A, B, F, and G. The third area of contamination where toluene is primarily detected in water from monitoring wells is in the vicinity of clusters E and I; toluene was apparently spilled or dumped east of the creek and has subsequently passed through the confining unit into the lower aquifer. The concentrations of toluene in the area of clusters E and I are generally an order of magnitude lower than concentrations of contaminants in the area of clusters A, B, F, and G.

Aquifer-test data indicate ground water flows fastest in the middle part of the lower aquifer at about 200 ft/yr. Data presented in longitudinal cross sections of the lower aquifer support this result because the migration of contaminants is farthest in the middle part of the lower aquifer.

Contamination in O cluster was first reported in analyses from the June 1989 sampling. When F and G clusters were first installed and sampled in March 1985, contamination was already evident in water from these wells (located approximately 200 ft upgradient from O cluster). Assuming that the contamination has migrated about 200 ft between March 1985 and June 1989, the approximate rate of contaminant migration ranges from 40 to 50 ft/yr. The retardation factor (The ratio of rate of ground-water movement divided by the contamination rate of movement) for migration of volatile-organic compounds at the study site is about 4.4. The contaminants move about 80 percent slower than the ground-water flow, presumably because of biochemical degradation and adsorption of contaminants onto aquifer material.

REFERENCES

Bedient, P.B., Rodgers, A.C., Bouvette, T.C., Tomson, M.B., and Wang, T.H., 1984, Ground-water quality at a creosote waste site: Ground Water, v. 22, no. 3, p. 318-329.

Hantush, M.S., and Jacob, C.E., 1955, Nonsteady radial flow in an infinite leaky aquifer: Transactions of the American Geophysical Union, v. 36, no. 1, p. 96-100.

Lohman, S.W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Ludemann, W.D., Bane, J.M., Jonas, R.L., Leibel, N.P., Muhly, R.L., Weinand, J.D., and Woods, H.K., 1981, Installation assessment of the Defense General Supply Center, Virginia, Report 190: Chemical Systems Laboratory, Aberdeen Proving Grounds, Maryland, 98 p.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate of duration of discharge of a well using ground-water storage: Transactions of the American Geophysical Union, v. 16, p. 519-524.

U.S. Army Environmental Health Agency, 1982a, Geohydrologic study no. 38-26-0164-82, Defense General Supply Center, Richmond, Virginia, 8-19 March, 1982, 50 p.

_____ 1982b, Phase II- Geohydrologic study no. 38-26-0164-83, Defense General Supply Center, Richmond, Virginia, 26 October, 1982, 44 p.

_____ 1983, Final Report, Geohydrologic study no. 38-26-0164-84, Defense General Supply Center, Richmond, Virginia, 14-19 November, 1983, 68 p.

Walton, W.C., 1970, Groundwater resource evaluation: New York, New York, McGraw-Hill, Inc., 664 p.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 529-428/20089