HYDROGEOLOGY AND WATER QUALITY IN THE GRACES QUARTERS AREA OF ABERDEEN PROVING GROUND, MARYLAND

By Frederick J. Tenbus and Joel D. Blomquist

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
acre	0.4047	hectare
gallon per minute	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
cubic foot per day per square foot [(ft ^{3}/d)/ft^2]	0.3048	cubic meter per day per square meter
pound, avoirdupois (lb)	0.4536	kilogram

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by use of the following equation:

$$^{\circ}C = 5/9 \times (^{\circ}F - 32)$$

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

Chemical concentrations and water temperature are given in metric units. Chemical concentration for water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as well as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

The standard unit for hydraulic conductivity is cubic foot per day per square foot [(ft^3/d)/ft^2]. This mathematical expression reduces to foot per day (ft/d).

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Acronyms and Abbreviations

ADR: Analog-to-digital recorder
AEHA: U.S. Army Environmental Hygiene Agency
APG: Aberdeen Proving Ground
BNA: Base-neutral acid extractable
BZ: An incapacitating agent (3-quinuclidinyl benzilate)
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
CN: A tear agent (chloroacetophenone)
CNB: A tear agent (10-percent CN, 45-percent benzene, 45-percent carbon tetrachloride)
CS: A tear agent (o-chlorobenzylidenemalononitrile)
CS-1: CS blended with 5-percent silica aerogel
DANC: Decontaminating agent, noncorrosive
DM: Adamsite, a vomiting agent (diphenylaminechloroarsine)
EA 3990: A nerve agent (no common or chemical name available)
EM: Electromagnetic induction
FEMA: Federal Emergency Management Agency
FWA: Freshwater acute
FWC: Freshwater chronic
GB: Sarin, a nerve agent (isopropylmethylphosphonofluoridate)
GC/MS: Gas chromatography/mass spectroscopy
GD: Soman, a nerve agent (pinacolyl methylphosphonofluoridate)
HD: Distilled mustard, a blister agent [bis(2-chloroethyl) sulfide]
HGA: Hydrogeologic assessment
MCL: Maximum Contaminant Level
MCLG: Maximum Contaminant Level Goal
PVC: Polyvinyl chloride
RCRA: Resource Conservation and Recovery Act
RFI: RCRA Facility Investigation
SWA: Saltwater acute
SWC: Saltwater chronic
SMCL: Secondary Maximum Contaminant Level
SWMU: Solid waste management unit
TOH: Total organic halogens
USATHAMA: U.S. Army Toxic and Hazardous Materials Agency
USEPA: U.S. Environmental Protection Agency
USGS: U.S. Geological Survey
VX: A nerve agent (β-diisopropylaminoethyl-mercapto-O-ethyl methylphosphonothioate)
WP: White phosphorus, an incendiary or smoke munition

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By Frederick J. Tenbus *and* Joel D. Blomquist

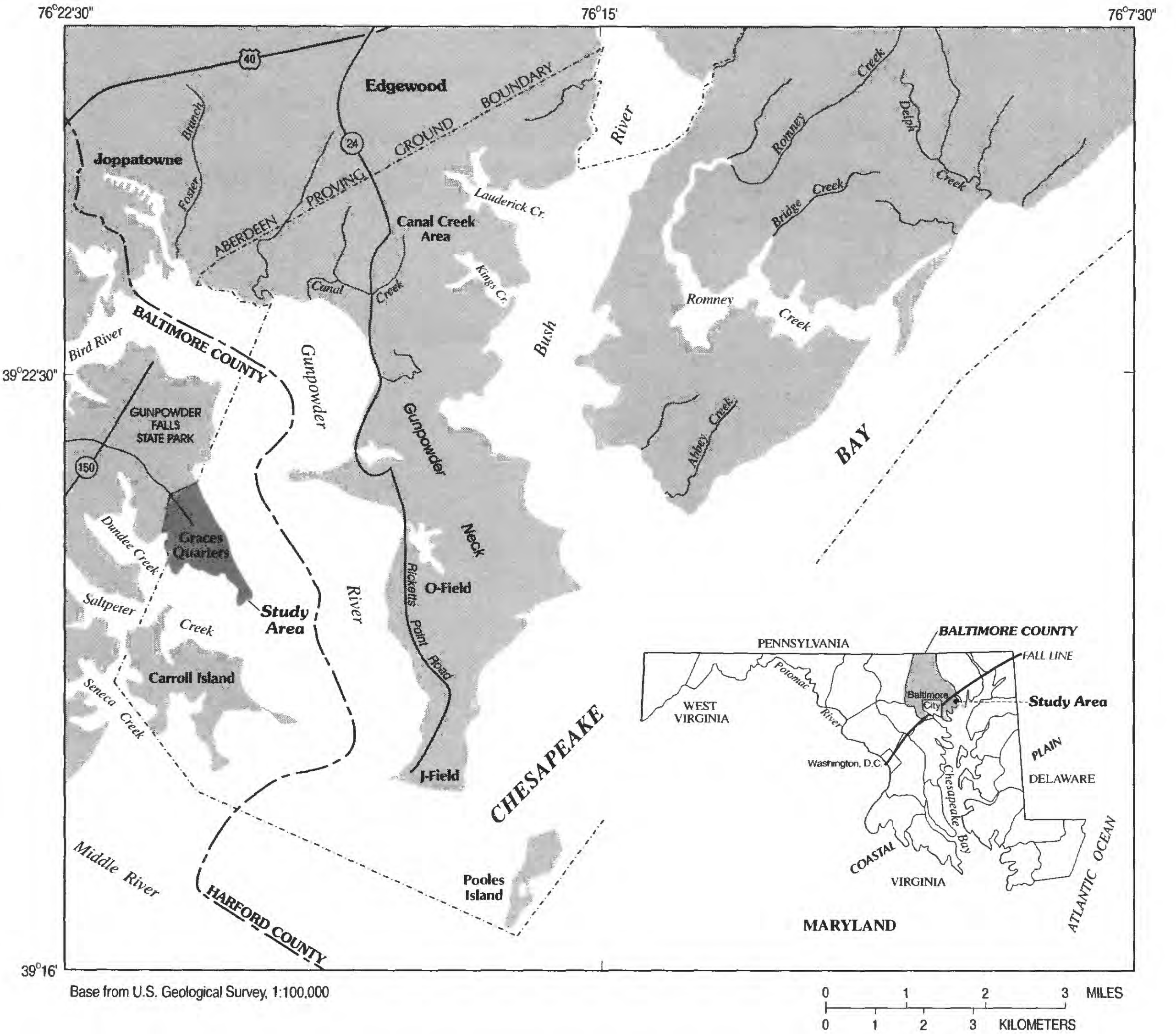
ABSTRACT

Graces Quarters was used for open-air testing of chemical-warfare agents from the late 1940's until 1971. Testing and disposal activities have resulted in the contamination of ground water and surface water. The hydrogeology and water quality were examined at three test areas, four disposal sites, a bunker, and a service area on Graces Quarters. Methods of investigation included surface and borehole geophysics, water-quality sampling, water-level measurement, and hydraulic testing. The hydrogeologic framework is complex and consists of a discontinuous surficial aquifer, one or more upper confining units, and a confined aquifer system. Directions of groundwater flow vary spatially and temporally, and results of site investigations show that groundwater flow is controlled by the geology of the area. The ground water and surface water at Graces Quarters generally are unmineralized; the ground water is mildly acidic (median pH is 5.38) and poorly buffered. Inorganic constituents in excess of certain Federal drinking-water regulations and ambient water-quality criteria were detected at some sites but they probably were present naturally. Volatile and semivolatile organic compounds were detected in the ground water and surface water at seven of the nine potentially contaminated sites that were investigated. Concentrations of organic compounds at two of the nine sites exceeded Federal drinking-water regulations. Volatile compounds in concentrations as high as 6,000 μg/L (micrograms per liter) were detected in the ground water at the site known as the primary test area. Concentrations of volatile compounds detected in the other areas ranged from 0.57 to 17 μg/L.

INTRODUCTION

The Edgewood Area of Aberdeen Proving Ground (APG), Maryland, has been used to develop, manufacture, and test military-related chemicals and munitions since World War I. Some of the munitions and chemical agents include smoke munitions (WP), nerve agents (GB, VX), blister agents (HD, lewisite), vomiting agents (DM), tear agents (CN, CS), and incapacitating agents (BZ). An environmental survey of the Edgewood Area was conducted by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) during 1977 and 1978 to determine the effects of past manufacturing and testing operations on the environment (Nemeth and others, 1983). The report from this environmental survey identified several areas that were contaminated, including Canal Creek, O-Field, J-Field, Carroll Island, and Graces Quarters (fig. 1).

In 1986, the U.S. Environmental Protection Agency (USEPA) issued a Resource Conservation and Recovery Act (RCRA) permit (MD3-21-002-1355) to address solid waste management units (SWMU's) in the Edgewood Area of APG. Solid waste management units are those sites that contain



Base from U.S. Geological Survey, 1:100,000

Figure 1. Location of Graces Quarters study area on Aberdeen Proving Ground near Baltimore, Md.

hazardous materials and thus have a potential to affect the environment. The RCRA permit required that a hydrogeologic assessment (HGA) be conducted at each of the sites that contained SWMU's. Graces Quarters was identified as one of the Edgewood Area sites that contained SWMU's.

In October 1986, at the request of the Environmental Management Office of APG (U.S. Department of Defense) the U.S. Geological Survey (USGS) began an HGA of Graces Quarters.

The purpose of the HGA was to collect hydrologic data in the vicinity of SWMU's to provide a framework for characterizing any release and movement of contaminants. The HGA also would provide information about chemical-agent test sites, including the types of chemical agent tested at each site and the period during which testing took place.

In 1988, when the RCRA permit was renewed, the requirements for RCRA had changed, and the HGA became the RFI, or RCRA Facility Investigation. The RFI required more and different data collection than the HGA, but much of the required data were the same. The RFI required that an observation-well network be established to determine the directions and rates of ground-water movement, the concentrations and spatial distributions of selected chemical constituents, and the spatial distributions of selected compounds that may be considered indicators of ground-water contamination. These data were necessary for the development of predictive tools, such as ground-water and solute-transport models, to aid in the planning of any remediation efforts that might be needed. The RFI also required that a surface-water sampling network be established to provide information on the concentrations and spatial distributions of chemical constituents in this medium.

In February 1990, the Edgewood Area of APG was placed on the USEPA National Priority List of hazardous-waste sites. Since that time, the Edgewood Area studies have been subject to CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) guidelines. The data and reports from this study will be used to fulfill some of the CERCLA requirements for the remedial investigation at Graces Quarters.

Purpose and Scope

This report (1) describes the hydrogeologic system of Graces Quarters, including the surface water, soils, aquifers, confining units, and flow paths; (2) describes the inorganic and organic constituents of the ground water and surface water in the Graces Quarters area; and (3) makes preliminary inferences regarding the source of the chemical constituents in the water.

The HGA focused on the area of Graces Quarters where military activities such as chemical testing and solid-waste disposal were known to have taken place. Within this area, three test areas, four disposal sites, a bunker, and a service area were identified as potential sources of environmental contamination (fig. 2). The purpose of the HGA was to detect chemical releases from these potential sources and to describe and evaluate potential pathways of chemical transport.

The presence of surface water in ponds, ditches, and marshes on Graces Quarters was noted during onsite visits to determine whether the surface water potentially could be affected by contamination. Soils were examined by comparing data from the county soil survey (Reybold and Matthews, 1976) with onsite observations and borehole logs. The lithology and hydrogeology of the aquifers and confining units were examined through the use of test holes and observation wells. Five test holes (140-180 ft deep) were drilled on Graces Quarters for lithologic correlations; these test holes were completed later as observation wells. Twenty-six observation wells (fig. 3) were installed at 22 locations and used with the 5 observation wells from a previous study for lithologic correlations, aquifer tests, water-level measurements, and ground-water sampling. Lithologic correlations were interpreted from split-spoon samples collected at discrete intervals in the test holes, from continuous cores collected during the drilling of the observation wells, and from geophysical logs collected during the drilling of both types of boreholes. Aquifer properties in the vicinity of 15 of the observation wells in the surficial and confined aquifers were determined with slug tests. Water levels in all of the wells were measured monthly from March 1988 through March 1989, and again during June and August 1989. Automatic water-level recorders were installed on 11 wells to record water levels continuously at 15-minute intervals for various lengths of time during the study period, October 1987 through September 1989.

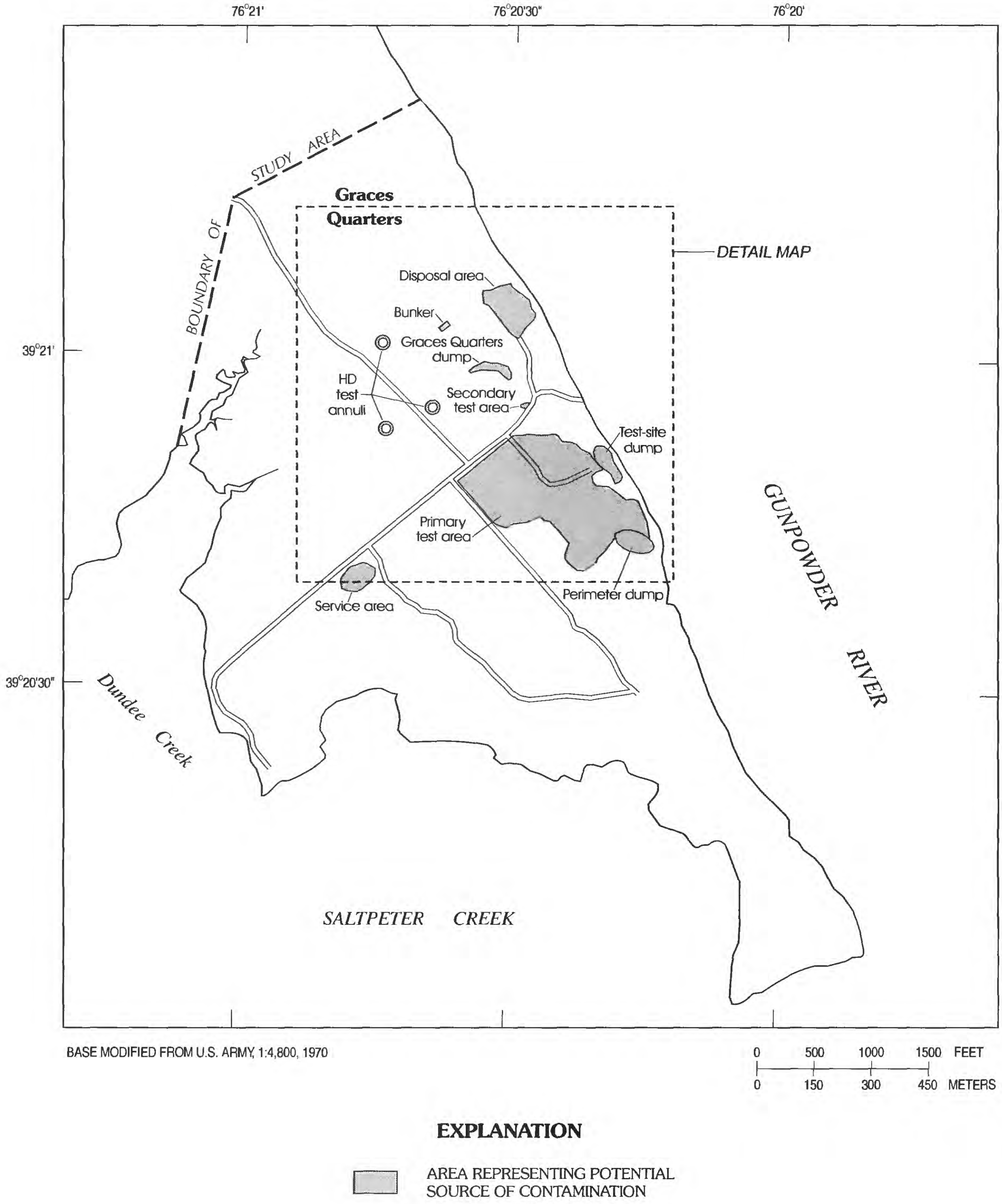
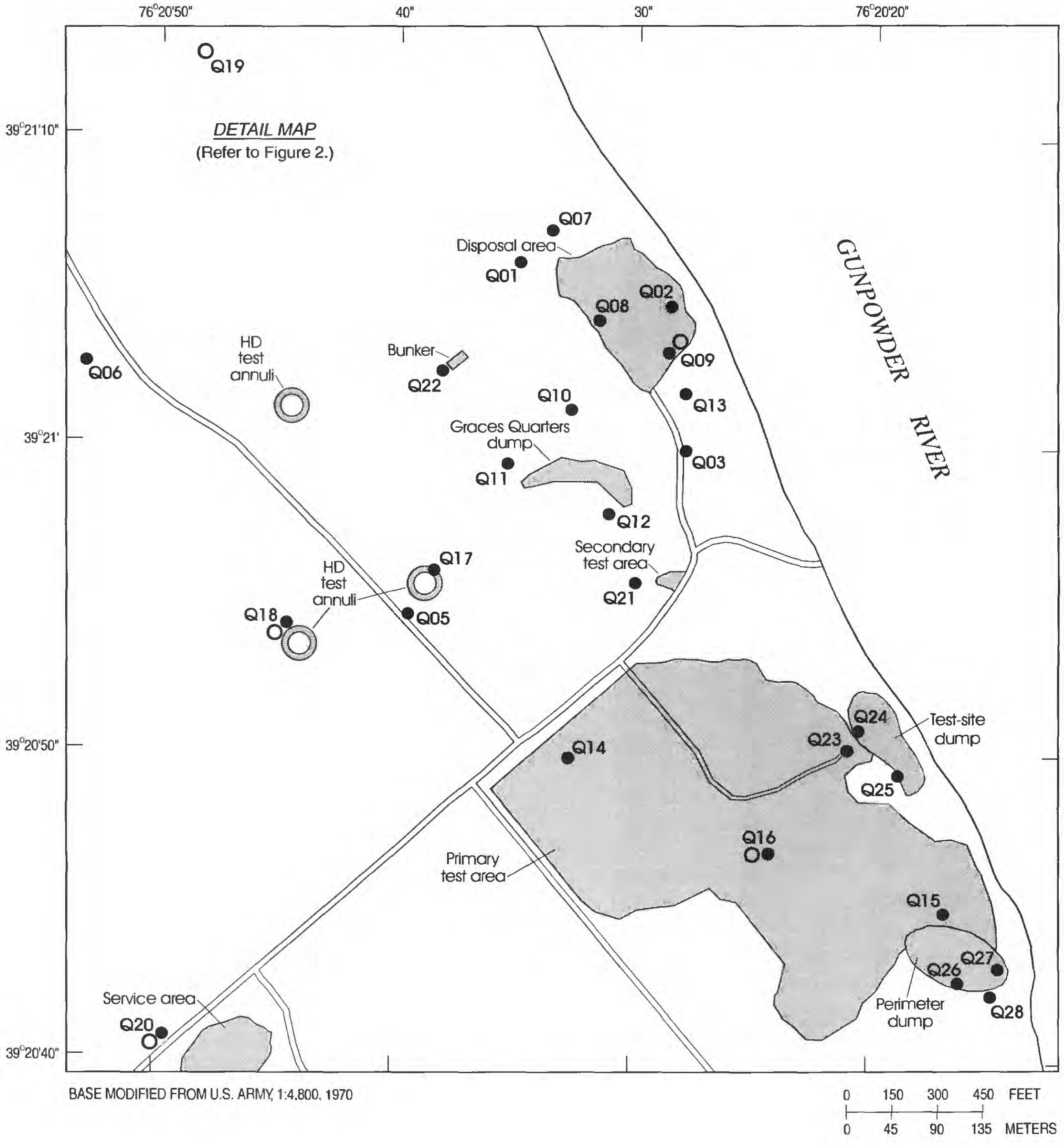


Figure 2. Location of potential sources of environmental contamination on Graces Quarters, Aberdeen Proving Ground, Md.



EXPLANATION

▨ AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION

OBSERVATION WELLS AND WELL NUMBERS:

Q14 ● Well screened in surficial aquifer
Q19 ○ Well screened in confined aquifer
Q20 ○● Well cluster

Figure 3. Location of observation wells, Graces Quarters, Aberdeen Proving Ground, Md.

The observation-well network was designed to detect releases of contaminants from the SWMU's and test areas. Observation wells were installed near the test areas and disposal sites at locations presumed to be downgradient to determine whether chemicals from these sites were being released into the ground water. Electromagnetic-induction (EM) data were collected to assist in well placement. Two groups of ground-water and surface-water samples were collected to compare the wet season (spring) with the dry season (summer and fall). Ground-water samples were collected for chemical analysis from all of the new and pre-existing wells. Surface-water samples (fig. 4) were collected at seven sites in and around the test areas and disposal sites, three sites in the Gunpowder River, and one site in Dundee Creek.

Previous Investigations

In 1977-78, USATHAMA conducted an environmental survey of the Edgewood Area of Aberdeen Proving Ground (Nemeth and others, 1983). The report concluded that the contaminants that were found posed no significant threat to the environment and that further ground-water monitoring was not necessary (Nemeth and others, 1983, p. 4-3). In 1986, however, the USEPA issued a RCRA permit for the Edgewood Area of APG, which required that hydrogeologic and chemical information be collected from each area that contained SWMU's, including Graces Quarters. At that time, the U.S. Army Environmental Hygiene Agency (AEHA) began work on the RCRA Facility Assessment of the Edgewood Area. The report from that study (Nemeth, 1989) includes descriptions of the SWMU's and test areas on Graces Quarters, along with all the known information on the testing and disposal practices and the types of materials used at Graces Quarters.

Also in 1986, the USGS began an HGA of Graces Quarters. This report is one of the results of that study. Previous reports from the HGA include Ham and others (1991), which presents the hydrogeologic data collected during the study, and Tenbus and Phillips (1991), which describes the methodology and sampling rationale for the HGA.

Description of Study Area

Aberdeen Proving Ground is located on the western shore of the Chesapeake Bay in Harford and Baltimore Counties, Maryland. The land area of APG covers about 30,000 acres (Nemeth, 1989, p. 1), and consists primarily of peninsulas and islands along the upper Chesapeake Bay. Graces Quarters is a 476-acre peninsula located in the southern part of the Edgewood Area of APG (fig. 1). The peninsula is surrounded on three sides by estuaries and is not connected by land to the Edgewood Area. The estuaries surrounding Graces Quarters include the Gunpowder River, Saltpeter Creek, and Dundee Creek. There are no perennial streams or rivers on Graces Quarters itself.

Physiographic Setting

Graces Quarters is located within the Atlantic Coastal Plain Physiographic Province, which extends from Long Island, New York, to Texas (Fenneman, 1938). The Coastal Plain consists of unconsolidated deposits of sand, silt, and clay underlain by crystalline rock. This sediment begins at the Fall Line, which is the boundary between the Coastal Plain and the Piedmont Plateau, and thickens to the east in a wedge shape toward the Atlantic Ocean. The depth to bedrock in the Graces Quarters area is more than 300 ft (Bennett and Meyer, 1952, pl. 5).

The climate in this part of Maryland is temperate and moderately humid, with milder winters than areas farther inland because of the proximity to the Chesapeake Bay (Nemeth, 1989, p. 5). The mean annual precipitation is 45 in. and is distributed fairly uniformly throughout the year. The mean annual temperature is about 54 ^{o}F.

The altitude of the land surface at Graces Quarters ranges from sea level to about 45 ft. Land cover on Graces Quarters includes wooded areas, open fields, low brush, and marshes. The land slopes from the higher altitudes at the northern end toward the lower lying marsh areas at the southern end. A cliff about 30 ft high is found in one part of the eastern shore of the peninsula.

The surficial manifestations of contamination on Graces Quarters include concrete pads, mounded areas, empty drums and other containers, miscellaneous testing debris, surface depressions, and some areas of stressed vegetation. Springs and seeps are visible onsite, but none of them is visibly contaminated.

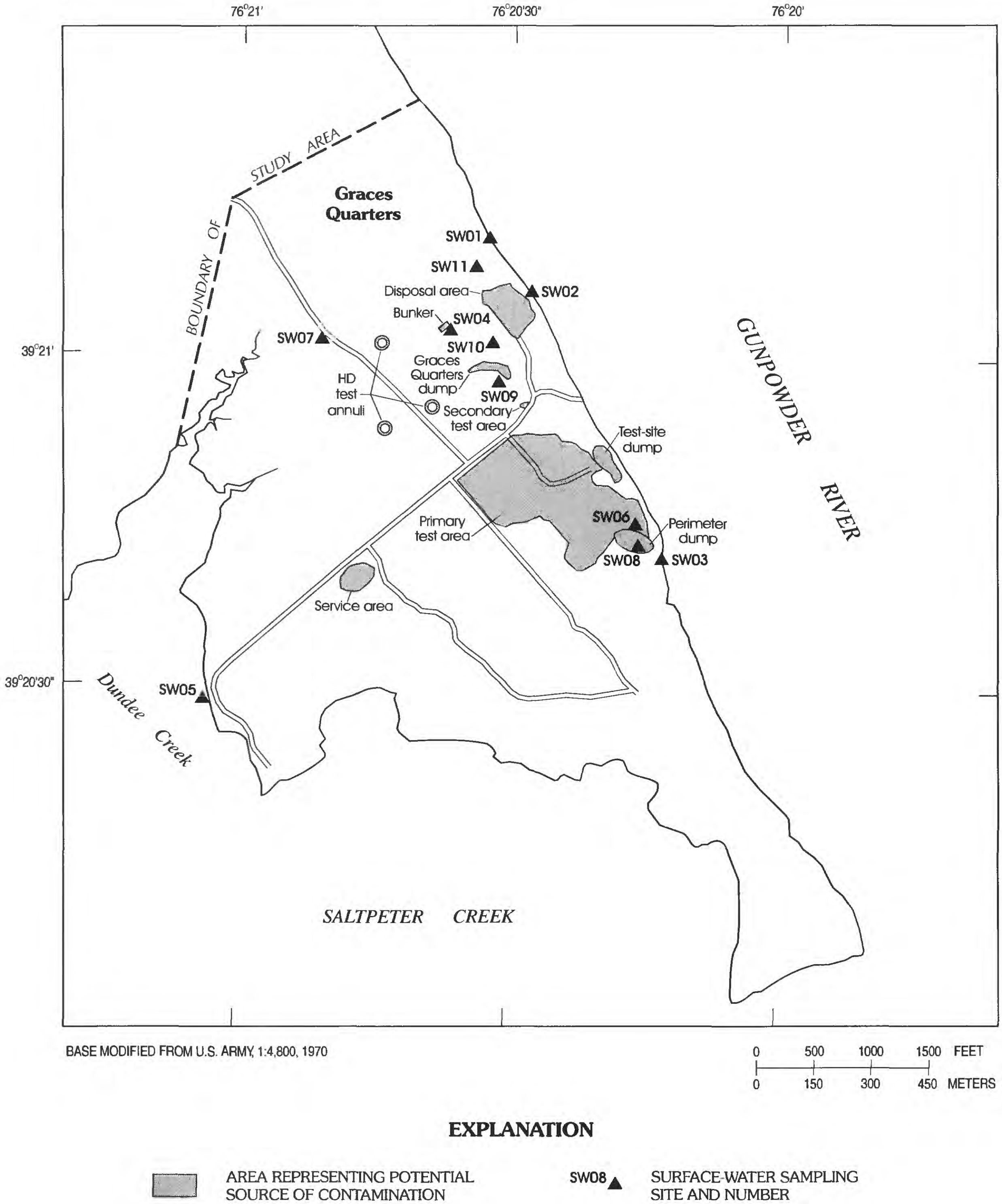


Figure 4. Location of surface-water sampling sites, Graces Quarters, Aberdeen Proving Ground, Md.

Graces Quarters has no current military activity. The area was leased by the U.S. Federal Emergency Management Agency (FEMA) from 1970 to 1988 as a site for an emergency radio transmitter. This lease was terminated, and the area then was leased by the U.S. Air Force for use as a radio receiving station. Initial surveys and test drilling were done for construction of this station on the peninsula, but plans for construction at this site have been suspended indefinitely.

The estuaries surrounding Graces Quarters are used for recreational purposes such as fishing and boating. A State park adjacent to Graces Quarters is used for activities such as picnicking, swimming, and target shooting with longbows.

Regional Hydrogeologic Setting

Graces Quarters is located on unconsolidated sediment that is mainly Cretaceous in age (Crowley and others, 1976) and classified as part of the Potomac Group (Otton and Mandle, 1984, p. 10). Potomac Group sediment is of continental origin and most likely was deposited on the flood plains of rivers and in lakes and swamps (Vokes, 1957, p. 47). The aquifers of the Potomac Group are important sources of ground water for the State of Maryland. Ground-water withdrawals from Potomac Group aquifers in Maryland totaled 56 Mgal/d in 1986 (Wheeler, 1990).

The Potomac Group consists of the Patuxent, Arundel, and Patapsco Formations (Vokes, 1957, p. 47-48). Delineation of the three formations can be difficult because sediment within each of the formations can be similar in appearance. Definition of the three formations at Graces Quarters is beyond the scope of this study; however, a general description of each is provided in the following paragraphs.

The Patuxent Formation consists mainly of sand and gravel, and is the basal formation of the Potomac Group. The Patuxent Formation crops out in an area several miles west of Graces Quarters (Bennett and Meyer, 1952, pl. 2; Crowley and others, 1976) and is an important water-bearing formation in the Baltimore area (Bennett and Meyer, 1952, p. 42). The Patuxent Formation also is an important source of sand and has been quarried extensively for building materials (Vokes, 1957, p. 47). The top of the Patuxent Formation at Graces Quarters is more than 200 ft below sea level (Chapelle, 1985, p. 7).

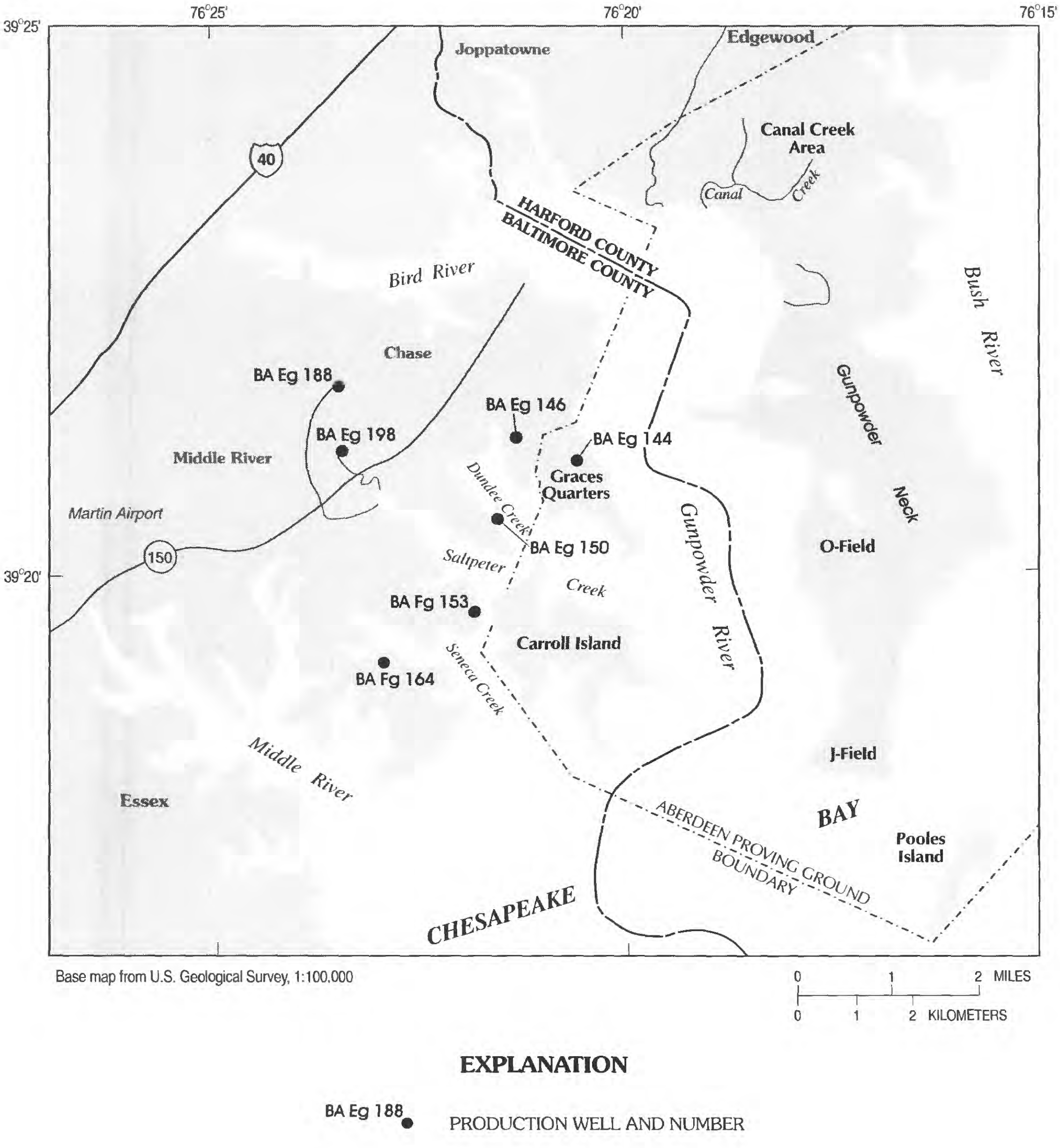
The Arundel Formation overlies the Patuxent Formation and acts as a confining unit. The Arundel Formation is composed mainly of red and brown clay, but it also includes some layers and concretionary masses of sandstone cemented with iron oxide or iron carbonate (Vokes, 1957, p. 47). The Arundel Formation is not considered to be a water-bearing formation (Bennett and Meyer, 1952, p. 59), but it has been used as a source material for brick, terra cotta, and pottery (Vokes, 1957, p. 47).

The Patapsco Formation unconformably overlies the Arundel Formation (Bennett and Meyer, 1952, p. 59) and crops out on Graces Quarters (Bennett and Meyer, 1952, pl. 2; Crowley and others, 1976). The Patapsco Formation consists of a sand facies and a clay facies; the clay facies crops out on Graces Quarters (Crowley and others, 1976). The Patapsco Formation is a water-bearing formation in the Baltimore area (Bennett and Meyer, 1952, p. 64).

Ground-water pumpage in the area around Graces Quarters is not believed to be extensive. Most domestic water in the area is provided by a municipal water system, which is supplied largely by reservoirs. Seven production wells are located within a 3-mi radius of Graces Quarters (fig. 5), and each is screened in one of the confined aquifers in the area. None appropriates more than 36,000 gal/d (table 1), and most of the pumpage is seasonal. Location and construction information on the known active and abandoned wells in the Graces Quarters area can be found in Laughlin (1966), Chapelle (1985), and Ham and others (1991).

Location and Historical Use of Solid Waste Management Units and Chemical-Agent Test Areas

Graces Quarters was acquired by the U.S. Army in 1918 (Nemeth, 1989, p. 470). The early history of Army activity in the area is not well-documented, but it is likely that Graces Quarters was leased as farmland until the 1940's (Nemeth, 1989, p. 470). In 1944, improvements were initiated to prepare Graces Quarters for use as a chemical-agent test site (Nemeth, 1989, p. 470). The improvements included construction of roads and docks, removal of trees and brush, and renovation of existing buildings. In the late 1940's, land in the southeastern part of Graces Quarters was designated as a munition impact area (Nemeth, 1989, p. 471).



Base map from U.S. Geological Survey, 1:100,000

Figure 5. Location of production wells on or near Graces Quarters, Aberdeen Proving Ground, Md.

Table 1. *Pumpage from production wells on or near Graces Quarters, Aberdeen Proving Ground, Maryland, 1988*

[GAP no., Ground-Water Appropriation Permit number. Screened interval is depth below land surface. Use of water: AG, agriculture (farming); AQ, aquaculture; CO, commercial; IN, industrial; IR, irrigation. ft, feet below land surface; gal/d, gallons per day; --, no data. Source: Ham and others, 1991, table 9]

U.S. Geological Survey well no. (fig. 5)	State permit no.	GAP no.	Owner	Screened interval (ft)	Use of water	Aquifer	Status	Pumpage reported (gal/d)	Pumpage appro-priated (gal/d)
BA Eg 144	BA-72-0354	BA72G007	U.S. Army	166-186	IN	Patapsco	Inactive	--	5,300
BA Eg 146	BA-73-7660	BA79G001	Gunpowder State Park	200-210	CO	Patapsco	Active	800 (Apr.-Oct.)	5,000
BA Eg 150	BA-73-1990	BA75G012	Marshy Pt. Nursery	245-255	IR	Patapsco	Active	11,000 (Apr.-Oct.)	25,000
BA Eg 188	BA-81-2838	BA84G026	T&A Excavation	90-100	CO	Patapsco	Active	--	150
BA Eg 198	BA-81-7396	BA87G064	Moore Pre-cast Concrete	213-220	CO	Patuxent	Active	--	200
BA Fg 153	--	BA87G014	Baltimore Gas & Electric	70-105	AQ	Patapsco	Active	67,225 (Aug.)	36,000
BA Fg 164	BA-81-6866	--	C. Ritter	237-250	AG	Patuxent?	Active	--	--

During the early 1950's, most of the testing of lethal chemical agents at APG was moved from other areas of the Proving Ground to Carroll Island and Graces Quarters (Nemeth, 1989, p. 141). Known test areas on Graces Quarters included the primary test area, the HD test annuli, and the secondary test area (fig. 2).

Most of the testing at Graces Quarters was done in one field, known as the primary test area (fig. 2). The primary test area is located on the eastern side of Graces Quarters, southeast of the road that crosses the peninsula (fig. 2). Aerial photos (Nemeth, 1989, p. 252-271) indicate that test activities in the primary test area took place in various locations throughout most of the area. Therefore, definition of likely point sources of contamination was difficult, if not impossible.

Less testing was done at sites known as the HD test annuli and the secondary test area (fig. 2). The HD test annuli were three concrete rings, each about 120 ft in diameter, located in the central part of Graces Quarters (fig. 2). The annuli probably were constructed in the early 1950's (Tenbus and Phillips, 1991, p. 33). The northernmost annulus was removed in 1971 for the construction of the FEMA radio tower; the other two annuli still exist (as of 1992). The secondary test area is located north of the primary test area and east of the HD test annuli (fig. 2). The area is not believed to have been used extensively for testing (Tenbus and Phillips, 1991, p. 32) but is, nevertheless, a potential source of environmental contamination.

The testing activity on Graces Quarters is poorly documented for the period between the late 1940's, when testing began, and July 1964. From July 1964 through December 1971, testing was documented in the form of handwritten notes kept by test engineers (Nemeth, 1989, p. 146). A summary of this documentation (from Nemeth, 1989, p. 150) is presented in table 2.

Table 2. *Known quantities of chemicals released on Graces Quarters, Aberdeen Proving Ground, Maryland, from July 1964 through December 1971*

[Modified from Nemeth (1989, p. 150)]

Material released	Type	Chemical name		Pounds released
VX	Anticholinesterase	β-Diisopropylaminoethyl-mercapto-O-ethyl methylphosphonothioate		199.5
Telvar	Herbicide			50.0
GB [1]	Anticholinesterase	Isopropylmethylphosphono-fluoridate		9.2
GD	Anticholinesterase	Pinacolyl methylphosphono-fluoridate		1.2
EA 3990	Anticholinesterase	No chemical name available		.5
CS-1	Irritant	o-Chlorobenzylidene-malononitrile (blended with 5-percent silica aerogel)		.3
			Total pounds	**260.7**

[1] Includes 6.6 pounds destroyed in a caustic bath

Table 2 probably does not represent all of the chemical-agent testing on Graces Quarters. Earlier testing probably was conducted with chemicals other than those listed. For instance, Nemeth (1989, p. 150) reports that distilled mustard (HD) was tested on Graces Quarters before 1964, and that the HD test annuli (fig. 2) were used in decontamination studies of HD, VX, and fuming nitric acid (Nemeth, 1989, p. 495).

Materials were disposed of in four main areas on Graces Quarters. These areas are designated as the disposal area, the Graces Quarters dump, and the test-site dump and perimeter dump within the primary test area (fig. 2). The largest of these four areas is the disposal area, which consists of a series of small disposal pits located near the shore on the eastern part of the peninsula. The Graces Quarters dump is located south of the disposal area and consists of a mounded area and some empty bleach cans at the surface and partially buried. The test-site dump and perimeter dump are two small areas on the eastern and southeastern edges of the primary test area where materials were disposed of during testing activities.

The materials designated for disposal at these sites were those generated during testing at Graces Quarters. These materials probably included munitions fragments and remains, unusable sampling equipment, empty containers, and other similar solid wastes (Nemeth, 1989, p. 492). Some of the same types of materials also were disposed of in the secondary test area and in random locations within the primary test area. The remains of empty containers, old testing equipment, and other debris can be found in several places within the test areas.

Two other areas were considered as possible sources of environmental contamination. The service area (fig. 2) is presumed to have been a vehicle and equipment maintenance area. Maintenance activities may have resulted in small-scale spills or disposal of oil, grease, or solvents. The bunker (fig. 2) is a small, rectangular, water-filled depression about 30 by 75 ft in size. It was used as a timber-and-sandbags bunker during the late 1940's or early 1950's when Graces Quarters was an impact area (Nemeth, 1989, p. 495-497). The bunker was not a designated disposal site (Nemeth, 1989, p. 495-497) but was investigated during the present study to determine whether or not it was used for disposal.

Sampling-Network Numbering System

The observation-well network (fig. 3) on Graces Quarters consists of 26 wells screened in the surficial or uppermost aquifer and 5 wells screened in confined aquifers. The network was designed to provide information on the hydrogeologic framework of Graces Quarters and to determine whether or not ground water from the SWMU's and test areas is contaminated.

Five of the wells in the surficial aquifer were installed during an earlier study (Nemeth and others, 1983) that encompassed the entire Edgewood Area of APG. The wells drilled on Graces Quarters during that study were designated with the letter "Q" and are located at sites Q01, Q02, Q03, Q05, and Q06 (fig. 3).

A similar well-numbering system was used for the wells installed during the present study. Each of the well sites was assigned a unique identifier that consists of the letter "Q" followed by a two-digit number. At some sites, more than two wells were installed to allow the investigation of different aquifers. In these cases, an "A" or "B" designation was added to each individual well number at the site, depending on which well was drilled first. The "A" or "B" designation does not indicate which well is shallow and which well is deep.

The surface-water sampling network (fig. 4) consisted of three sites in the Gunpowder River, one site in Dundee Creek, and seven sites in ponds, marshes, and ditches on the Graces Quarters peninsula. The numbering system used for the surface-water samples includes the designation "GQ" (for Graces Quarters), "SW" (for surface water), and a two-digit sample identifier. If a shorter identifier is desired (such as in fig. 4 and the tables in this report), the "GQ" designation is dropped. Therefore, a surface-water sampling site on Graces Quarters could be identified as GQSW04 or simply SW04.

Acknowledgments

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METHODS

The methods used to determine the hydrogeology and water quality at Graces Quarters during the first phase of the study are presented in the following sections. The methods include surface and borehole geophysics, well and test-hole drilling, water-quality sampling, and hydraulic testing. Additional details about the methods used in this study are available in Tenbus and Phillips (1991).

Surface Geophysics

Surface geophysical techniques were used during this study to locate potential contaminant plumes, delineate disposal pits, and locate buried objects for drilling safety. Electromagnetic induction (EM) and magnetometry were used on Graces Quarters for these purposes.

Electromagnetic induction is a method that detects changes in ground conductivity and can be used to locate conductive contaminant plumes. Ground-conductivity data are collected with the

EM instrument and mapped to determine the locations of anomalously high readings. These data can be compared with known information on geologic differences or other sources of interference to determine whether or not a conductivity anomaly is likely to have been caused by contaminated ground water.

The EM survey was done with an instrument known as the Geonics EM34-3[1]. Information on the instrument and its use is available in McNeill (1980a; 1980b). Data were collected in areas that included the disposal area, the bunker, Graces Quarters dump, and the primary and secondary test areas (fig. 6). The first area was surveyed in April 1987. This area included all the units just mentioned, except the primary test area. The area was divided into a grid with 100-ft spacing and surveyed by using the instrument's 10-m (meter) coil configuration with vertical and horizontal dipoles. At selected areas, grid spacing was reduced to 50 ft; at other selected areas, a 20-m coil spacing was used to see whether conductivity varied with depth.

The primary test area was divided into three transects separated by distances of 175 and 200 ft. Station spacing in these transects was 50 ft. The coil orientation for this part of the survey was 10-m spacing with a horizontal dipole. This part of the survey was conducted in fall 1987.

Data from this survey were plotted on a map and used to assist in locating optimum well sites. However, determination of the sources of various anomalies was difficult as a result of complicated geology and the presence of many interferences resulting from human activities on Graces Quarters. Therefore, the location of only one well (well Q07) was based on the results of the EM survey.

Magnetometry was the other surface geophysical technique used on Graces Quarters. This method was used to delineate the extent of buried metal in the SWMU's and for safety purposes at drill sites.

Magnetometers were used in two ways to delineate the extent of buried metal within SWMU's. At sites where no mounding of disposal pits was present on the land surface, magnetometers were swept over the area in a regular grid pattern. If mounding or surficial debris was present, the magnetometers were swept mainly over the mounds and the adjacent areas. Information about the location and extent of buried metal detected with the magnetometers was recorded and used to generate maps of the SWMU's.

At drill sites, magnetometers were used to prevent the drill bits from encountering buried metal. When a drill site was chosen and staked, an area with a radius of about 10 ft around the chosen site was surveyed with the magnetometer. Buried metal discovered within this radius often made it necessary to move the drill site slightly to decrease the risk of encountering buried objects during drilling.

Drilling

Boreholes were drilled on Graces Quarters during the HGA to determine the geologic framework and to install observation wells for ground-water sampling, water-level measurements, and the determination of hydraulic properties. All drilling and well-installation activities were done by the U.S. Army Corps of Engineers.

Drilling procedures were designed to minimize the risk of injury or toxic-chemical exposure to personnel and to minimize cross contamination between aquifers and between drill sites. For safety purposes, the first 15 ft of each borehole was drilled by using remote-control drilling with hollow-stem augers. The boreholes then were completed by using nonremote mud-rotary drilling or hollow-stem augering. Hollow-stem augers were used for the shallow wells; mud-rotary drilling was used whenever a borehole was drilled deeper than the maximum depth for the auger rig, which was about 100 ft.

The mud-rotary method was used to drill five test holes on Graces Quarters for determining the geologic framework. The test holes were located at sites Q09, Q16, Q18, Q19, and Q20 (fig. 3), and were 140 to 180 ft deep. The first two test holes (at sites Q09 and Q19) were drilled with a 10-in. bit so that an observation well could be installed within the borehole after the geologic information was obtained. This proved to be a very slow process

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

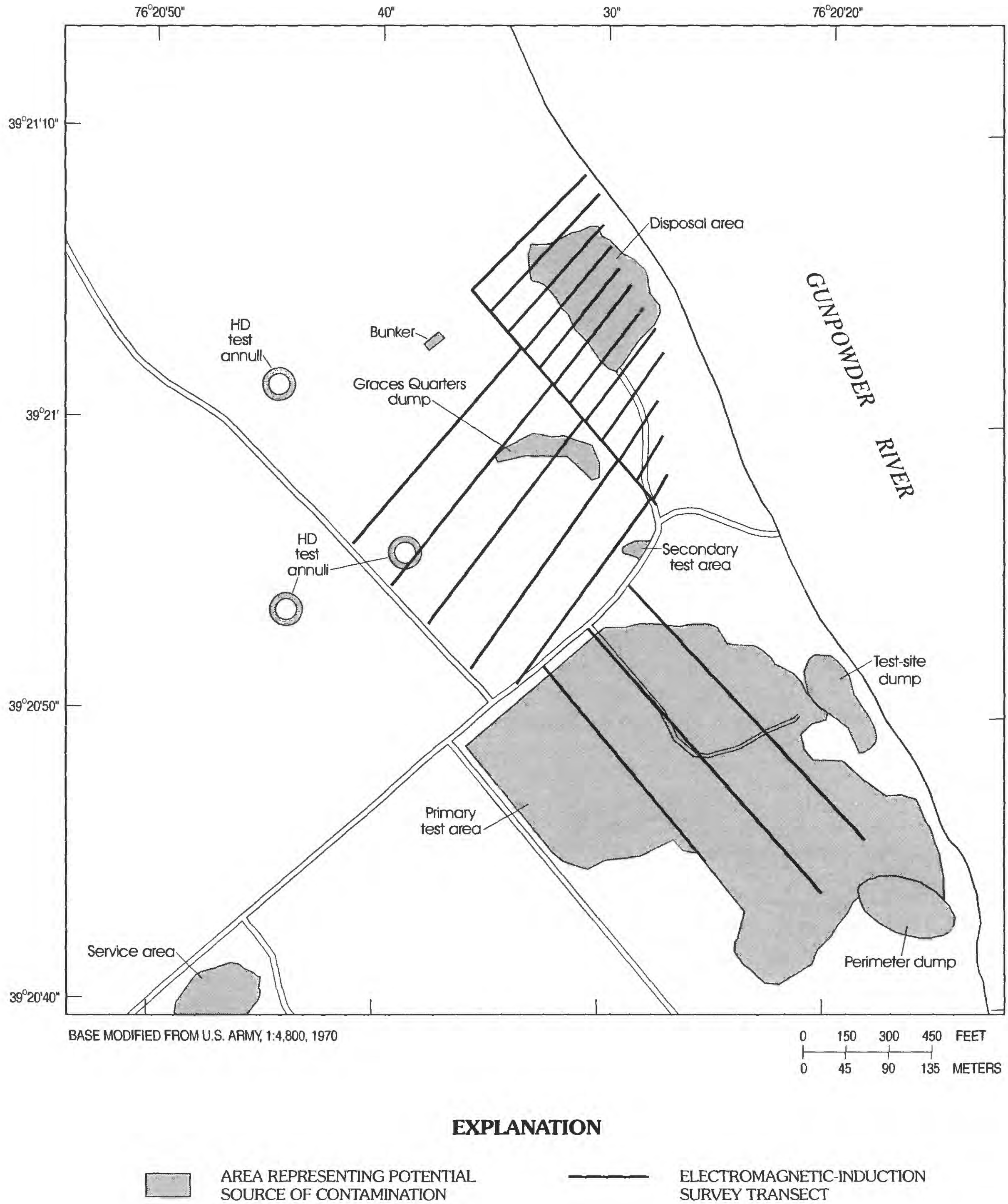


Figure 6. Location of electromagnetic-induction survey transects, Graces Quarters, Aberdeen Proving Ground, Md.

because thick layers of resistant clay were encountered in the first two boreholes. Therefore, the last three test holes were drilled with a 4-in. bit and were reamed out later for well installation. To do this without cross contamination, the 4-in. test holes were first filled with a thick bentonite slurry. The holes then were widened by using 10-in. diameter continuous-flight hollow-stem augers to the desired depth for well installation. The test-hole portion of the boring was sealed off, and an observation well was installed.

During test-hole drilling, an attempt was made to obtain a split-spoon sample of lithologic material at 10-ft intervals. This was not accomplished in every hole because of time constraints. However, geophysical logs were collected at each of the test holes. Gamma logs were made on all of the test holes drilled during the study. In addition, electric logs (resistance and spontaneous potential) were made in four of the five test holes (sites Q09, Q18, Q19, and Q20). Geologic and geophysical logs from the test holes can be found in Ham and others (1991).

The observation wells that were not installed in test holes were drilled with hollow-stem augers for the entire borehole. The auger used was continuous-flight hollow-stem auger with a 10-in. outside diameter and an 8-in. inside diameter (id). Lithologic samples were obtained during drilling with a 5-ft-long core-barrel sampler equipped with a bottom basket. Drilling was done by advancing a 5-ft-long auger flight, removing the sample from the core barrel, attaching another auger flight, and repeating the process. When the desired depth was attained, a gamma log was made, the screened interval was chosen by a USGS hydrologist, and the observation well was installed. Auger flights were scrubbed clean between holes with water and brushes to minimize contamination.

Observation wells were constructed of 4-in.-id threaded PVC pipe and screen. Twenty-six observation wells were installed at 22 sites (Q07-Q28) on Graces Quarters (fig. 3). Information on well construction and installation for each of the wells on Graces Quarters is available in Ham and others (1991) and Tenbus and Phillips (1991).

Water-Quality Sampling

Water-quality samples were collected at Graces Quarters to characterize the ground-water and surface-water chemistry of the area and to determine whether the quality of the water has been affected adversely by the presence of SWMU's and by the historical testing activity. Many chemical compounds were used on Graces Quarters during the historical testing period. The compounds included chemical-warfare agents, organic solvents, inorganic decontaminating agents, and various other chemicals. The sampling and analysis strategy was designed to detect releases of chemicals from the SWMU's and test areas and to analyze for compounds that would most likely be present as a result of activities at the site. Ground water and surface water were sampled twice, once during a dry month (August 1988) and once during a wet month (May 1989). This sampling strategy was used to detect any contaminants whose concentrations might have varied with the physical conditions. A complete list of laboratory analyses is available in Tenbus and Phillips (1991, tables 8-12).

Ground-water samples were collected from 31 wells at the 27 well locations shown in figure 3. Twenty-six of the wells were screened in the surficial aquifer, and five (wells Q09B, Q16A, Q18B, Q19A, and Q20A) were screened in confined aquifers. Of the 26 surficial wells, 5 were 2-in. diameter wells installed during a previous study (Nemeth and others, 1983). These five wells are located at sites Q01, Q02, Q03, Q05, and Q06 (fig. 3).

Stagnant water was purged from the wells with a bailer, a bladder pump, or an air-lift pump. The water was withdrawn from the top of the column to induce flow through the screen. A bottom-filling bailer was used for the shallow wells (less than 30 ft of standing water). A bladder pump or submersible air-lift pump was used for the wells with more than 30 ft of standing water in the well bore. For some wells, a packer was used with the bladder pump to isolate the well screen and to reduce the amount of water that had to be purged.

Specific conductance, pH, temperature, and dissolved oxygen were measured and recorded before purging. One to five well volumes of water were purged from each well. The number of volumes removed depended on the stability of specific conductance, temperature, and pH, which were measured after each well volume was purged. When successive measurements were within 5 percent, the well was sampled. If the measurements did not stabilize after five well volumes were removed, purging was stopped, and the well was sampled. If a well went dry during purging, it was sampled after the water level recovered.

After purging, a bailer or bladder pump was lowered to the well screen to collect the sample. The first sample water collected was used to rinse the sample bottles, beakers, and collection containers. Samples then were collected for analysis for constituents in order of decreasing volatility, starting with volatile organic compounds, continuing with total organic halogens, total organic carbon, total phenols, dissolved metals, and anions, and ending with physical properties such as specific conductance, pH, and alkalinity.

The samples collected for analysis for volatile organic compounds, semivolatile organic compounds, and total organic halogens were emptied from the bottom-discharge device on the bailer, or from the discharge line on the bladder pump, into appropriate containers. Both of the discharge methods produced a slow, steady stream of water into the sample vial with a minimum of aeration. A 40-mL (milliliter) glass vial was used for volatile organic compounds, a 1-L (liter) bottle was used for semivolatile compounds, and a 250-mL glass bottle was used for total organic halogens. All of the bottles were amber-colored and had caps lined with Teflon. The 40-mL vials were filled so no air space or bubbles were present. Sodium sulfite was added to the total organic halogen bottle as a preservative. Samples for total organic carbon and total phenols were collected in 500-mL amber-glass bottles and preserved with sulfuric acid. All samples were chilled to a temperature of 4 °C.

Samples collected for inorganic analysis were collected in an acid-washed, field-rinsed container and transferred to the onsite sample station. The sample station was set up with specific conductance and pH meters, filter equipment, and preservatives. Samples for inorganic analysis and alkalinity were filtered through a 0.45-micrometer membrane filter attached to a peristaltic pump. The dissolved-metals samples were filtered into a field-rinsed 500-mL polyethylene bottle and preserved with nitric acid. The samples for total nitrogen and anions were filtered into 500-mL polyethylene bottles and chilled to 4 °C. Alkalinity then was calculated by titration of a 100-mL filtered sample with sulfuric acid.

All equipment was decontaminated between sampling sites. Bailers and well pumps were rinsed with distilled water, cleaned with laboratory wipes, and rinsed again with distilled water. Filter equipment was cleaned with distilled water, and new filters were installed. Equipment wash blanks were collected to test the effectiveness of the decontamination.

Within 24 hours of collection, all samples were recorded on chain-of-custody sheets and sealed with filament and evidence tape in coolers filled with ice and packing material. The sealed coolers were then shipped by overnight freight to the analytical laboratory for analysis.

Surface-water sampling sites (fig. 4) were located in areas that would most likely be receptors for runoff and seepage from the SWMU's and test areas. Seven samples were collected from inland sites, including ponds (sites SW04, SW06), puddles (sites SW09, SW08), and ditches (sites SW07, SW10, SW11) on Graces Quarters. Four samples (sites SW01, SW02, SW03, SW05) were collected from the estuaries surrounding the peninsula.

Techniques for collection of surface-water samples differed from those for collection of ground-water samples. In general, surface-water samples were collected by lowering the collection bottles into the surface-water body and filling the bottles with water. In some areas, however, access was difficult or water was found only in very shallow puddles. In these cases, a peristaltic pump was used to draw the sample from the water body into the collection container.

The samples were collected in the same order of decreasing volatility of constituents as the ground-water samples. Care was taken to prevent any aeration of the samples to be analyzed for volatile organic compounds. The sample bottles, preservatives, and physical-property measurements described for the ground-water samples also were used for the surface-water samples. None of the surface-water samples were filtered because the water-quality criteria for surface water apply to unfiltered samples. Therefore, the analyses included constituents that had sorbed onto the suspended sediment in the samples.

Ground-water and surface-water samples from the August 1988 and May 1989 sample collections were analyzed by two different laboratories under contract to USATHAMA. The analysis protocols and quality-assurance/quality-control procedures of the laboratories were monitored by USATHAMA and were required to conform to USATHAMA standards (U.S. Army Toxic and Hazardous Materials Agency, 1987). However, the legitimacy of the laboratory analyses of the August 1988 samples was questioned by USATHAMA, and the data were invalidated. For this reason, the August 1988 data are not presented in this report and are not used for any of the interpretations that appear in later sections of the report.

Water-Level Measurements

Digital water-level recorders were installed on 11 wells on Graces Quarters for various lengths of time during the study period. The wells that were fitted with water-level recorders included wells Q01 and Q05 from the previous study (Nemeth and others, 1983); the deep well at site Q09 (well Q09B); well Q13; wells Q16A and B; wells Q18A and B; well Q19A (which is deep); and wells Q20A and B. Water levels were recorded at 15-minute intervals at each of these wells. Hydrographs of water levels in these wells are available in Ham and others (1991, p. 62-67).

Synoptic measurements of water levels in all wells were made on a monthly basis from March 1988 through March 1989 and again in June and August 1989. Water levels were measured with steel tapes to an accuracy of 0.01 ft during synoptic surveys. Data from the synoptic surveys were used to produce maps of hydraulic head for determining ground-water flow directions within the aquifers in the study area. Water-level data from the synoptic surveys are available in Ham and others (1991, table 8).

Hydraulic Testing

Hydraulic testing was conducted on Graces Quarters to determine aquifer properties at the site. Pumping tests were impractical because of potential contamination problems, so the aquifer properties were determined with slug tests.

A slug test consists of an instantaneous change in the water level in a well and the measurement of the response of the water level through time as the aquifer adjusts to the change. The water-level response is a function of well hydraulics and the properties of the aquifer in the area near the well. The aquifer properties that can be determined from a slug test are transmissivity and horizontal hydraulic conductivity.

Several methods can be used to analyze data from slug tests. Commonly used methods (Chirlin, 1989, p. 131) include those of Hvorslev (1951), Cooper and others (1967), and Bouwer and Rice (1976). Each of these methods is best applied to a particular well geometry and hydrogeologic setting. Well geometry refers to the dimensions of the casing and screen; hydrogeologic setting refers to the aquifer type, the relation of the well screen to the aquifer, and the stratigraphic features near the well. Because little overlap exists among the well geometries and hydrogeologic settings to which each method is best applied, the particular method used for data analysis often is chosen on the basis of well geometry and setting (Chirlin, 1989, p. 131).

The Hvorslev (1951) method represents a simple interpretation of slug-test data (Freeze and Cherry, 1979, p. 340) that is applicable over a wide variety of well geometries and hydrogeologic settings. The method assumes a homogeneous, isotropic, infinite medium in which the aquifer and water are incompressible (Freeze and Cherry, 1979, p. 340). Use of the Hvorslev (1951) method for analyzing slug tests in well geometries that are similar to those in the surficial aquifer at Graces Quarters is described by Freeze and Cherry (1979, p. 340-341).

The Bouwer and Rice (1976) method of analyzing slug-test data was designed for use in homogeneous and isotropic unconfined aquifers with completely or partially penetrating wells. The method is similar to that of Hvorslev (1951) in that it ignores the effects of compressive storage within the aquifer (Chirlin, 1989, p. 131). Bouwer and Rice (1976) used an electrical analog model to evaluate the effective radius over which the hydraulic-head differences between the well and the equilibrium water table are dissipated, and developed an empirical equation to determine this effective radius, which is an important factor in the Hvorslev (1951) calculation of hydraulic conductivity.

The method of Cooper and others (1967) was designed to calculate transmissivity in homogeneous and isotropic confined aquifers of uniform thickness in which the well fully penetrates the aquifer. The method is a curve-matching procedure that is different from the Hvorslev (1951) and Bouwer and Rice (1976) methods because it accounts for both well-bore storage and aquifer storage (Chirlin, 1989, p. 131). Hydraulic conductivity can be determined with this method by dividing the transmissivity by the aquifer thickness. Reed (1980) provides type curves for the calculation of aquifer properties by the method of Cooper and others (1967).

Each of the methods for determining aquifer properties can be adapted to hydrogeologic settings that do not match their respective ideal settings. Because homogeneous, isotropic aquifers of infinite extent do not exist in the real world, none of the methods can produce an exact solution to the problem of determining hydraulic conductivity in real aquifers. Each method has advantages and disadvantages in real-world situations, and if the methods are used carefully, each can provide useful information about aquifer properties.

Although the ideal hydrogeologic setting for the Cooper and others (1967) method of analysis is a fully penetrating well in a confined aquifer (Cooper and others, 1967, p. 263), the test can be valid for use in other hydrogeologic settings. In many stratified aquifers, the vertical permeabilities are only a small fraction of the horizontal permeabilities, and flow during a slug test is likely to be two-dimensional (Cooper and others, 1967, p. 268). This means that the calculated transmissivity for a partially penetrating well would approximate the transmissivity of that part of the aquifer in which the well is screened. For a well in an unconfined aquifer, hydraulic conductivity can be estimated with the method of Cooper and others (1967) if the hydrogeologic setting closely approximates that of a confined aquifer. If the screened length of the well is far below the water table and the perturbation in the water level is small relative to the active length of the well bore, the screened area acts as if it were confined (Kenneth Belitz, U.S. Geological Survey, oral commun., 1988). Therefore, if conditions are right, hydraulic conductivity can be approximated by determining the transmissivity of the screened part of the aquifer with the Cooper and others (1967) method and dividing that value by the screen length.

The slug tests on Graces Quarters were analyzed by the methods of Cooper and others (1967) and Hvorslev (1951). The Cooper and others (1967) method was used to analyze the slug-test data from each of the wells in the confined aquifer system and from selected wells in the surficial aquifer where the well geometry and hydrogeologic setting were similar to those in a confined aquifer. Generally, the Cooper and others (1967) method was applied to all of the wells in the surficial aquifer that contained 8 ft of water or more in the well casing above the screen. The validity of each of the analyses then was determined from the results by a comparison of fit between the actual data and the type curves presented in Reed (1980). The Hvorslev (1951) method was used to analyze all of the slug-test data from the wells that were screened within the surficial aquifer. The Bouwer and Rice (1976) method was not used for the Graces Quarters slug tests because the calculations are relatively difficult, and the results were not expected to be appreciably different from, or more accurate than, results from the other methods.

Fifteen slug tests were conducted on Graces Quarters during this study. Ten of the slug tests were conducted in wells screened in the surficial aquifer, and five were conducted in wells screened in the confined aquifer system. The slug tests were conducted with a Teflon-coated cylindrical slug, a pressure transducer, and a digital data logger. The slug was introduced into the well, and the water level was allowed to equilibrate. The slug then was removed rapidly, and the response was recorded by the pressure transducer and data logger. Each test was conducted for approximately 16 minutes. Water levels were recorded at intervals that varied from 0.2 seconds at the beginning of the test to 100 seconds at the end.

HYDROGEOLOGY

The components of the hydrogeologic system at Graces Quarters include the surface water, soils, aquifers, and confining units. Each of these components potentially plays a part in the transport of chemical materials from the areas in which they were originally applied or disposed of to areas that otherwise may have been unaffected.

Surface Water

The surface-water component includes the estuaries that surround Graces Quarters (Dundee Creek, Saltpeter Creek, and the Gunpowder River) along with the perennial and intermittent ponds, the marshes, and the intermittent runoff that occurs during and after storms. Water flow and water chemistry in the estuaries can be affected by tides, storms, and a multitude of factors present in their extensive watersheds. Water flow and chemical transport within the estuaries were not investigated during this study and are beyond the scope of this report. For the purposes of this report, the estuaries are considered to be potential receptors for water and chemicals transported from Graces Quarters.

The ponds, marshes, and stormwater runoff on Graces Quarters also are affected by several different factors. Ponds and marshes also can be considered receptors of runoff and ground-water flow, and they are affected by storms, evapotranspiration, and various biological and chemical factors. The runoff on Graces Quarters occurs during and after storms or during the spring thaw and is affected by hillslope, infiltration capacity of soils, and amount of available water.

Topographic relief at Graces Quarters is more than 40 ft (Tenbus and Phillips, 1991, p. 25). This feature, combined with the low permeability of soils on the topographic highs and slopes of the peninsula, causes overland flow during storms and snowmelt. The overland flow generally originates on the uplands of the eastern part of Graces Quarters and moves either toward the Gunpowder River to the east or toward the lowlands to the west and south. A topographic map of the area of concentrated investigation on Graces Quarters is shown in figure 7.

Soils

The soil component of the hydrogeologic system includes all of the soil horizons and the unsaturated part of the soil parent material above the surficial aquifer. Soils are an important part of the hydrogeologic system of an area because they affect water flow and the transport of contaminants. The information on soils presented in this section was obtained from various sections of Reybold and Matthews (1976) and from comparison of soil data obtained during this investigation to their descriptions.

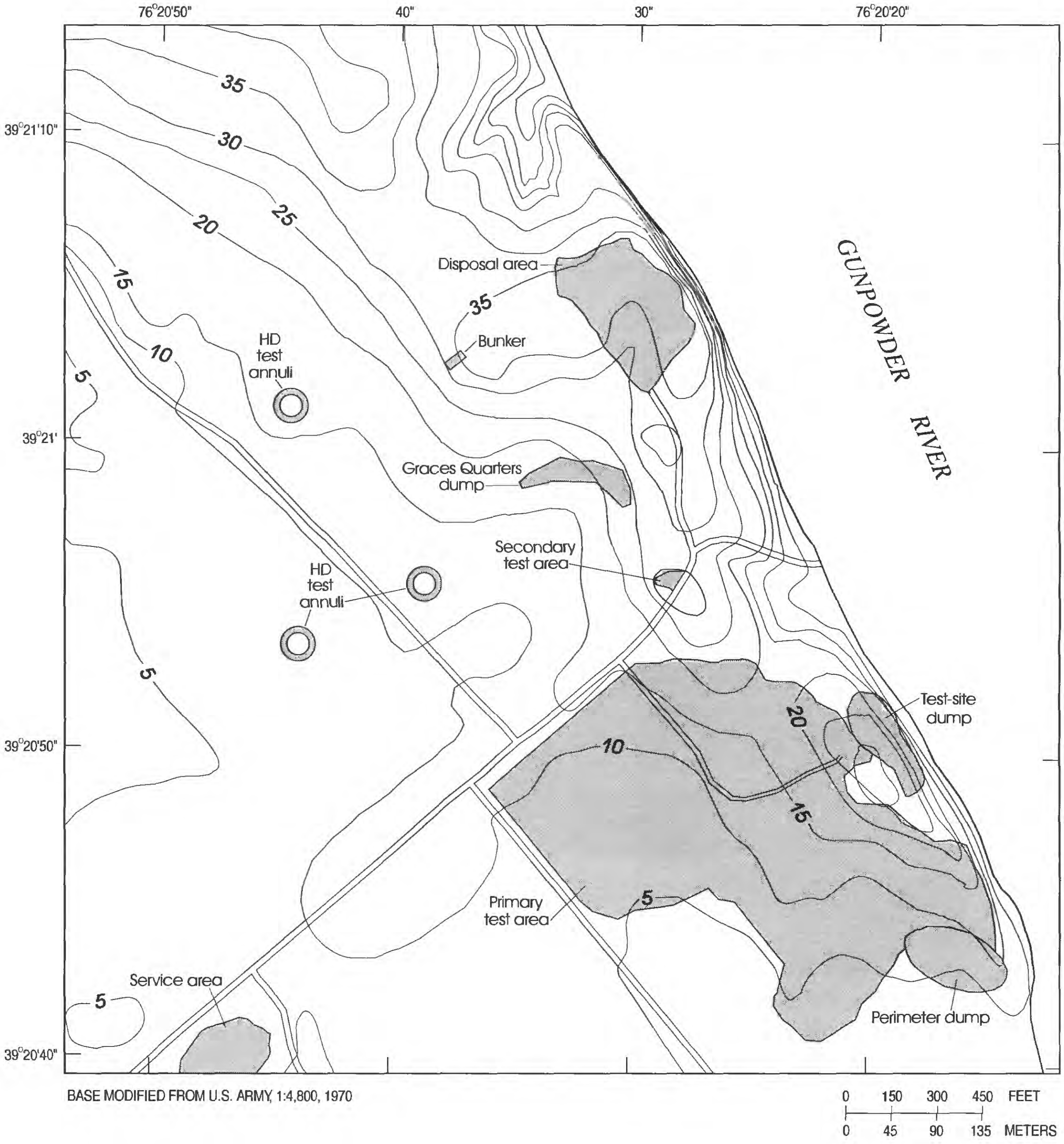
The basic soil units described include the soil series, the soil phase, and the soil association. The soil series describes soils that have major horizons that are similar in thickness, arrangement, and other important characteristics (Reybold and Matthews, 1976, p. 2). Soil phases characterize the differences within a soil series that affect the use of the soil by humans, such as slope, texture of the surface soil, or stoniness (Reybold and Matthews, 1976, p. 2). Soil associations are generalized landscapes made up of distinctive proportional patterns of soil series (Reybold and Matthews, 1976, p. 2).

Important characteristics of soils that are available from county-wide soil surveys, such as Reybold and Matthews (1976), include drainage class, reactivity, and soil permeability. These characteristics are reported as ranges or typical conditions for the soils in the county but can be useful either as a general guide where other data are not available or as a tool for comparison with soil data obtained onsite.

Drainage class refers to the conditions of frequency and duration of periods of saturation or partial saturation that existed during the development of a soil (Reybold and Matthews, 1976, p. 148). Drainage class can be determined from characteristics such as soil texture and the presence or absence of mottling in the various soil horizons. Of the seven drainage classes recognized by soil scientists, four were represented in Graces Quarters soils--well drained, moderately well drained, somewhat poorly drained, or poorly drained. Distinguishing characteristics of each drainage class are given in Reybold and Matthews (1976, p. 148).

Well-drained soils are described as nearly free from mottling and commonly of intermediate texture. Moderately well-drained soils commonly have a slowly permeable layer in or immediately beneath the A and B horizons. They have uniform color in the A and upper B horizons, and have mottling in the lower B and C horizons. Somewhat poorly drained soils are wet for substantial periods but not all the time. Some of these soils have mottling at a depth below 6 to 16 in. Poorly drained soils are wet for long periods. These soils are generally light gray and mottled from the surface downward. In some poorly drained soils, mottling may be absent or nearly absent.

Reactivity in soils refers to the degree of acidity or alkalinity of a soil expressed in pH values (Reybold and Matthews, 1976, p. 148). The soils on Graces Quarters were acidic and were



BASE MODIFIED FROM U.S. ARMY, 1:4,800, 1970

EXPLANATION

▨	AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION
——10——	TOPOGRAPHIC CONTOUR – Shows elevation of land surface. Contour interval 5 feet. Datum is sea level.

Figure 7. Topography of the area of concentrated investigation on Graces Quarters, Aberdeen Proving Ground, Md.

categorized as being strongly acidic (pH 5.1 to 5.5), very strongly acidic (pH 4.5 to 5.0), or extremely acidic (pH less than 4.5).

Permeability values for various soil types can be obtained from county-wide soil surveys, but these values are very general. Permeability can vary greatly within a given area, and within a given soil type. Reybold and Matthews (1976, p 94-101) provide numerical permeability ranges (derived from soil structure) for different layers in each of the soil series found in Baltimore County.

Certain data that were obtained during the study were useful for qualitative comparison with the soil-survey information. Drainage class of a soil was inferred from the mottling and texture of soils in the lithologic logs of the wells (Ham and others, 1991). Current drainage conditions, slope, and erosion conditions were noted during site visits. These data are described in the sections of the report that follow.

Type and Distribution

Two general soil associations are present on Graces Quarters--the Mattapex-Barclay-Othello association and the Sassafras-Woodstown-Fallsington association. The Mattapex-Barclay-Othello association contains moderately well drained, somewhat poorly drained, and poorly drained soils that have a subsoil of silt loam or silty clay loam (Reybold and Matthews, 1976, p. 7). The association contains about 50 percent Mattapex soils, about 10 percent Barclay soils, about 5 percent Othello soils, and about 35 percent minor soils, including Elkton, Fallsington, Lenoir, Matapeake, Sassafras, and Woodstown soils (Reybold and Matthews, 1976, p. 7).

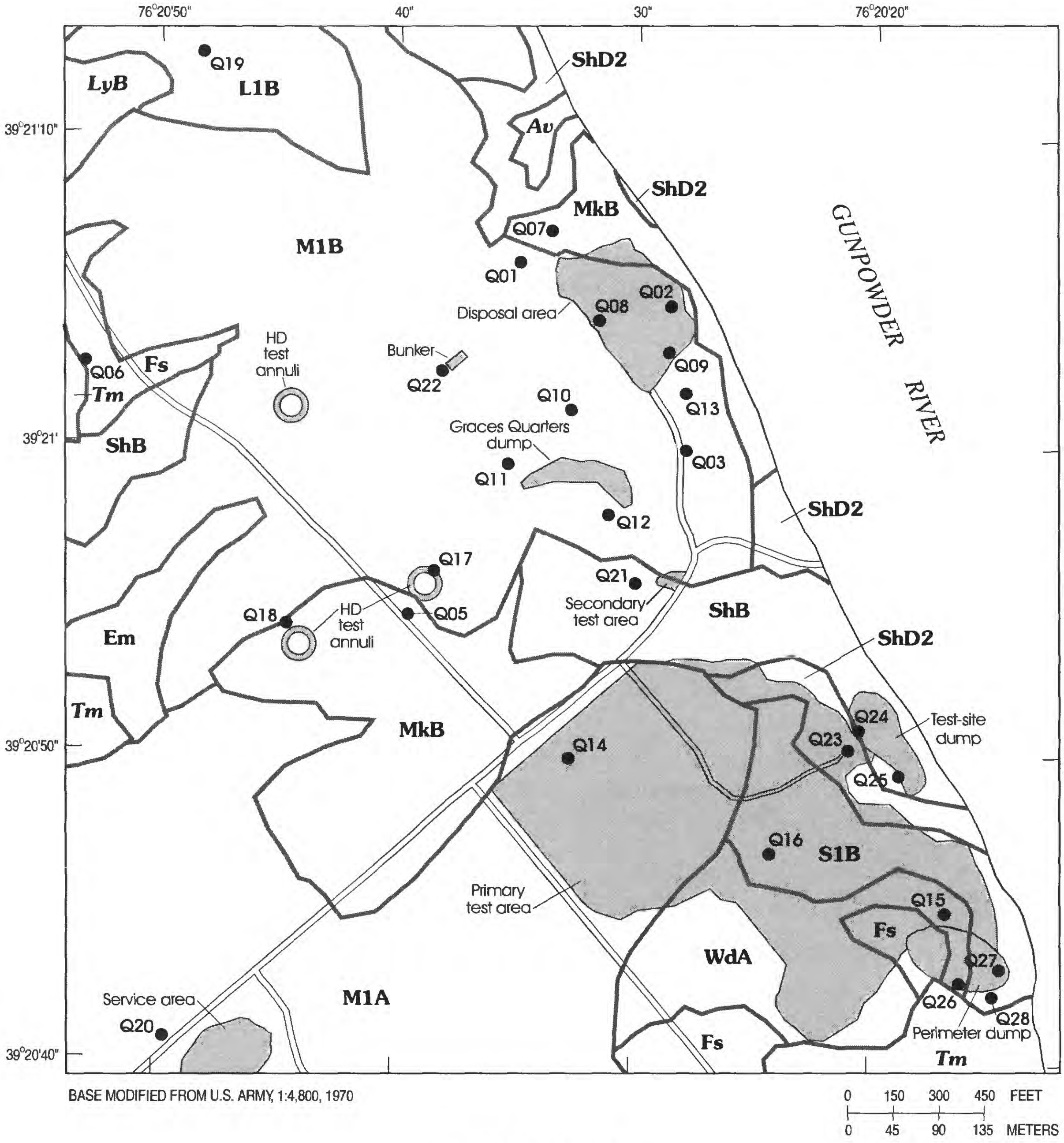
The Sassafras-Woodstown-Fallsington association is characterized by well drained, moderately well drained, and poorly drained soils that have a subsoil of sandy clay loam (Reybold and Matthews, 1976, p. 6). This association consists of about 50 percent Sassafras soils, 22 percent Woodstown soils, 7 percent Fallsington soils, and 21 percent minor soils (Reybold and Matthews, 1976, p. 6). Minor soils include Fort Mott, Galestown, and Matapeake soils, along with alluvial land and tidal marsh land types.

The soil series, phases, and land types within the area of concentrated investigation on Graces Quarters are identified in figure 8. The soil series and land types that were mapped in this area include Elkton, Fallsington, Lenoir, Matapeake, Mattapex, Sassafras, and Woodstown soils, as well as alluvial land, loamy and clayey land, and tidal marsh land types. The soil series that are present within and around the SWMU's and test areas are described in the following paragraphs.

Soils of the Mattapex series cover a large part of Graces Quarters (fig. 8). Mattapex soils are deep, moderately well drained, nearly level to gently sloping, and strongly acidic to very strongly acidic (Reybold and Matthews, 1976, p. 48). The soils are formed in old deposits of silty material underlain by older, coarser textured sediment (Reybold and Matthews, 1976, p. 48). The Mattapex series is represented on Graces Quarters in two phases--Mattapex silt loam, 0- to 2-percent slopes, and Mattapex silt loam, 2- to 5-percent slopes. Parts of the disposal area, the primary and secondary test areas, and the HD test annuli are located within the Mattapex silt loam mapping units. The bunker, Graces Quarters dump, and the service area also are on Mattapex silt loam.

The Sassafras series is another major soil group on Graces Quarters. The Sassafras series consists of deep, well-drained, nearly level to steep soils that are strongly acidic to very strongly acidic (Reybold and Matthews, 1976, p. 56). Sassafras soils are formed in unconsolidated deposits of very old, dominantly sandy sediment (Reybold and Matthews, 1976, p. 56). The Sassafras series is represented by several phases on Graces Quarters (fig. 8). An area north of the disposal area is mapped as Sassafras sandy loam, with 10- to 15-percent slopes and moderate erosion. The primary test area includes areas of Sassafras loam, with 2- to 5-percent slopes; Sassafras sandy loam, with 2- to 5-percent slopes; and Sassafras sandy loam, with 10- to 15-percent slopes and moderate erosion. The test-site dump in the primary test area is located on Sassafras soils, and the perimeter dump and the secondary test area are located partially on Sassafras soils.

One of the minor soils in the Mattapex-Barclay-Othello association is the Matapeake series.



BASE MODIFIED FROM U.S. ARMY, 1:4,800, 1970

EXPLANATION

▨	AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION	Q14 ●	OBSERVATION WELL AND WELL NUMBER

SOIL TYPE AND PHASE

Em	ELKTON LOAM	**M1B**	MATTAPEX SILT LOAM *(2-5% slopes)*
Fs	FALLSINGTON LOAM	**ShB**	SASSAFRAS SANDY LOAM *(2-5% slopes)*
L1B	LENOIR LOAM *(0-5% slopes)*	**ShD2**	SASSAFRAS SANDY LOAM *(Moderately eroded 10-15% slopes)*
MkB	MATAPEAKE SILT LOAM *(2-5% slopes)*	**S1B**	SASSAFRAS LOAM *(2-5% slopes)*
M1A	MATTAPEX SILT LOAM *(0-2% slopes)*	**WdA**	WOODSTOWN SANDY LOAM *(0-2% slopes)*

LAND TYPE

Av	ALLUVIAL LAND	***LyB***	LOAMY AND CLAYEY LAND *(0-5% slopes)*	***Tm***	TIDAL MARSH

Figure 8. Soil and land types in the area of concentrated investigation on Graces Quarters, Aberdeen Proving Ground, Md. (From Reybold and Matthews, 1976, sheet number 42).

This series is present on Graces Quarters as the Matapeake silt loam, with 2- to 5-percent slopes. Matapeake silt loam consists of deep, well-drained, nearly level to moderately sloping soils that are very strongly acidic to extremely acidic (Reybold and Matthews, 1976, p. 47-48). Part of the disposal area is on Matapeake silt loam, and the southwestern HD test annulus is mapped on this soil (fig. 8).

Woodstown sandy loam and Fallsington loam are present within the primary test area on Graces Quarters. These soils are formed on essentially the same kind of sediment as the Sassafras soils (Reybold and Matthews, 1976, p. 56). Woodstown sandy loam is moderately well drained (Reybold and Matthews, 1976, p. 59), and Fallsington loam is poorly drained (Reybold and Matthews, 1976, p. 29) Both soils are very strongly acidic to extremely acidic.

Hydraulic Properties

A detailed determination of the hydraulic properties of the soils was not part of the scope of this investigation. However, general information about the vertical permeability and the drainage properties of the soils was inferred from the published soil-survey information and from onsite observations.

The soils at the Graces Quarters disposal area (fig. 8) include Mattapex silt loam, with 2- to 5-percent slopes, and the Matapeake silt loam, with 2- to 5-percent slopes. Geologic logs were recorded at five well sites in and near the disposal area. Four of these (wells Q08, Q09, Q10, and Q13) were within the areas mapped as Mattapex silt loam; one site (well Q07) was within the Matapeake silt loam.

Mattapex silt loam is described in Reybold and Matthews (1976, p. 48-49) as moderately well drained with moderately slow permeability. Shrink-swell potential for this soil is low (Reybold and Matthews, 1976, p. 101).

Onsite observations in that part of the disposal area mapped as Mattapex silt loam (fig. 8) were similar to the Reybold and Matthews (1976, p. 48-49) description of the soil. Each of the four wells in the Mattapex silt loam had mottling and a hard clay layer in the subsoil, indicating moderately well-drained soil. The surface layer at wells Q10 and Q13 appeared to be sandy loam rather than silt loam, and some of the soil around well Q10 was eroded. The borehole data from all four wells (Ham and others, 1991, p. 20-23) showed soils that were formed in silty and clayey material underlain by coarser sediment--a description that corresponds with that of Mattapex silt loam.

Well Q07 was located in the Matapeake silt loam (fig. 8). This soil was described in Reybold and Matthews (1976, p. 47-48) as well drained with moderate permeability. The Matapeake silt loam has low shrink-swell potential (Reybold and Matthews, 1976, p. 98-99). The borehole log at well Q07 (Ham and others, 1991, p. 20) agrees partially with the description of the Matapeake silt loam. The surface layer was silt loam, but mottling and fine-grained material was present in the subsoil, indicating a soil that was moderately well drained rather than well drained. The area around the borehole showed indications of erosion consistent with the description of the soil in Reybold and Matthews (1976, p. 48).

Soils in the primary test area include Mattapex silt loam, with 0- to 2-percent slopes; Sassafras loam, with 2- to 5-percent slopes; Sassafras sandy loam, with 2- to 5-percent slopes; Sassafras sandy loam, with 10- to 15-percent slopes and moderate erosion; Woodstown sandy loam, with 0- to 2-percent slopes; and Fallsington loam, with 0- to 2-percent slopes (fig. 8). Geologic logs were recorded at well Q14 in the Mattapex silt loam, at well Q16 in the Sassafras loam, and at well Q15 in the Woodstown sandy loam (Ham and others, 1991, p. 24-25).

The permeability and drainage characteristics of Mattapex soils were described previously. The borehole data from well Q14 show a sandy loam in the surface layer underlain by a thin silt layer and then coarse-textured sediment. The soil from the borehole is sandier and more well drained than the Mattapex silt loam described in Reybold and Matthews (1976, p. 48-49).

Sassafras soils are well drained and moderately permeable (Reybold and Matthews, 1976, p. 56). Shrink-swell potential of Sassafras soils is low (Reybold and Matthews, 1976, p. 100-101). The soil in the boreholes at wells Q16A and B was sandy but was well drained and otherwise similar to the description of Sassafras loam in Reybold and Matthews (1976, p. 56-57).

Woodstown sandy loam is moderately well drained and moderately permeable (Reybold and Matthews, 1976, p. 59). Shrink-swell potential of Woodstown soils is listed as low (Reybold and Matthews, 1976, p. 101). Borehole data from well Q15 show a silt loam surface layer gradually grading to sandier material. The soil in the borehole was nearly free from mottling, indicating that it was well drained.

Fallsington loam is the other soil mapped in the primary test area. This soil is described as poorly drained and moderately permeable (Reybold and Matthews, 1976, p. 29). Shrink-swell potential of Fallsington soils is low (Reybold and Matthews, 1976, p. 97).

On the perimeter of the primary test area are two small dump sites known as the test-site dump and the perimeter dump. The test-site dump is mapped on Sassafras sandy loam, with 2- to 5-percent slopes, adjacent to an area of Sassafras sandy loam, with 10- to 15-percent slopes and moderate erosion (fig. 8). The permeability and drainage characteristics of Sassafras soils were described previously. Three boreholes (wells Q23, Q24, and Q25) were drilled in the test-site dump area. Geologic logs for these boreholes are available in Ham and others (1991, p. 29-30). Soils in the boreholes contained much more silt than is typical for Sassafras sandy loam, and mottling in the soils from wells Q23 and Q24 indicates that they are only moderately well drained rather than well drained like the Sassafras soils.

The perimeter dump was mapped on Sassafras loam, with 2- to 5-percent slopes; Woodstown sandy loam, with 0- to 2-percent slopes; and Fallsington loam (fig. 8). Sassafras loam differs from Sassafras sandy loam in that it contains more silt in the surface layer (Reybold and Matthews, 1976, p. 57). Three boreholes (wells Q26, Q27, and Q28) were drilled in the perimeter dump area; the logs are available in Ham and others (1991, p. 31). Well Q26 is mapped in Woodstown sandy loam, which is described in Reybold and Matthews (1976, p. 59-60). The soil in the borehole at well Q26 has silt loam in the surface layer, where a sandy loam would be expected from the soil-survey description. Directly beneath the surface layer at well Q26 is 1.5 ft of mottled clayey silt. This conforms to the description of Woodstown sandy loam, which is described as moderately well drained. The other two boreholes in the perimeter dump area (well Q27 and Q28) are mapped in Sassafras loam. Soils in these boreholes appear to be less well drained than is typical for Sassafras soils. Well Q27 has mottled silt in the B and C horizons, and well Q28 has mottled sandy silt in the lower horizons. The mottling and fine materials in the subsoil at these well sites indicate that the soils probably are moderately well drained or somewhat poorly drained.

North of the primary test area is the Graces Quarters dump, which is mapped on Mattapex silt loam, with 2- to 5-percent slopes (fig. 8). The permeability and drainage characteristics of Mattapex silt loam were described in previous paragraphs. Two boreholes (wells Q11 and Q12) were drilled near this site (fig. 8). The soil from the borehole at well Q11 (Ham and others, 1991, p. 22) has a sandy surface layer, but it is moderately well drained and contains some coarse sediment below the subsoil, which is typical for Mattapex silt loam. The soil from the borehole at well Q12 (Ham and others, 1991, p. 22-23) is also sandy loam at the surface, is moderately well drained, and contains coarse material below the subsoil.

Southeast of the Graces Quarters dump is a small secondary test area, mapped on Mattapex silt loam and Sassafras sandy loam, both of which have 2- to 5-percent slopes (fig. 8). The permeability and drainage characteristics of these soils were described in previous paragraphs. One borehole (well Q21) was drilled near this area in the Sassafras sandy loam (fig. 8). The soil in this borehole is a well-drained sandy loam underlain by coarser material (Ham and others, 1991, p. 28)--a description that closely matches that of Sassafras sandy loam in Reybold and Matthews (1976, p. 56).

The soils at the HD test annuli (fig. 8) include Mattapex and Matapeake silt loams, both with 2- to 5-percent slopes. The permeability and drainage characteristics of these soils were described in previous paragraphs. Geologic logs were recorded at two well sites (wells Q17 and Q18) in this area (Ham and others, 1991, p. 25-27). Well Q17 is mapped in Mattapex silt loam (fig. 8). The soil in this borehole is sandier than is typical for Mattapex silt loam. It is well drained and underlain by coarse material. Well Q18 is mapped in Matapeake silt loam. The soil at this location is sandier than is typical for Matapeake silt loam. However, it is well drained and underlain by coarse material, which is typical for Matapeake soils (Reybold and Matthews, 1976, p. 48).

Two other areas that were investigated on Graces Quarters are the bunker and the service area. The bunker is on Mattapex silt loam, with 2- to 5-percent slopes; the service area is on the same soil with 0- to 2-percent slopes (fig. 8). Boreholes were drilled at one site near the bunker (well Q22) and at one site near the service area (well Q20). Geologic logs from these boreholes are available in Ham and others (1991, p. 28-29).

The soil in the borehole at the bunker was typical of Mattapex silt loam. The soil was formed in a silty matrix and was underlain by coarser textured sediment. Mottling in the subsoil indicates that the soil was moderately well drained.

The soil in the boreholes at the service area (wells Q20A and B) was silty sand (Ham and others, 1991, p. 28), which does not match the description of Mattapex silt loam (Reybold and Matthews, 1976, p. 48-49). Also, there was no mottling in this soil, which indicates that the soil probably was well drained rather than moderately well drained.

Aquifers and Confining Units

The aquifers and confining units underlying Graces Quarters include a surficial aquifer, an upper confining unit, and one or more confined aquifers. In this study, the confined aquifers are considered to be a system. Complete delineation of the number of confined aquifers and confining units on Graces Quarters was not possible as a result of the following factors: (1) correlation of the units was difficult because the aquifer system is geologically complex, (2) the deeper units were encountered infrequently because most of the wells were installed in the surficial aquifer, and (3) none of the test borings extended more than about 180 ft below land surface.

The geologic units within the Potomac Group that comprise the aquifers and confining units underlying Graces Quarters have not been determined definitively. Bennett and Meyer (1952, pl. 2) show that the Arundel Formation crops out in the northeastern section of Graces Quarters. Crowley and others (1976) indicate that all of the solid ground on the Graces Quarters peninsula (including all of the area of military activity) is in the clay facies of the Patapsco Formation, and the marsh areas are Quaternary alluvium. Because Crowley and others (1976) is the more recent of the two reports, it is assumed that their interpretation represents the most accurate knowledge of the geology in the area. Therefore, in this report. the interpretation of Crowley and others (1976) is used as the basis for the geological classification of units and all of the hydrogeologic units encountered during drilling on Graces Quarters are assumed to be within the clay facies of the Patapsco Formation.

The hydrogeologic framework of Graces Quarters is illustrated in figures 9-12. A location map of three hydrogeologic sections that show the aquifers and confining units beneath Graces Quarters is provided in figure 9. The hydrogeologic sections depict the relation between the clay and sand in the Patapsco Formation (figs. 10-12); the relative positions of the clay and sand in this formation are important for determining the characteristics of ground-water flow at Graces Quarters.

Section A-A' (fig. 10) shows the hydrogeology between wells Q19 and Q16. The northern part of the section between wells Q19 and Q22 is topographically high and is dominated by a thick layer of clay, which is the upper confining unit in this area; the surficial aquifer is absent or nearly absent. A confined aquifer underlies more than 100 ft of clay at well Q19. In the central part of the section, between wells Q22 and Q11, a hydrogeologic boundary exists where the thick clay layer no longer predominates near the surface. Between this hydrogeologic boundary and the area near well Q14 is a complex area where the characteristics of the surficial aquifer and upper confining unit seem to vary over short distances. The aquifers and confining units are not well defined in this area, partly because of the lack of deep boreholes in the area and partly because of the complex nature of the geology. Data from a deep borehole in the southern part of the section (at well Q16) indicate the presence of a surficial aquifer, an upper confining unit, and a confined aquifer system.

Hydrogeologic sections B-B' (fig. 11) and A-A' are nearly perpendicular to each other, but they show several similarities. A topographically high area is present near the Gunpowder River at well Q09 in which the sediment again is dominated by a thick clay layer. The bottom of the surficial aquifer is above sea level in this area, and the upper confining unit is about 100 ft thick. Between wells Q09 and Q10, the top of the confining unit dips below sea level. At well Q11 (the intersection with section

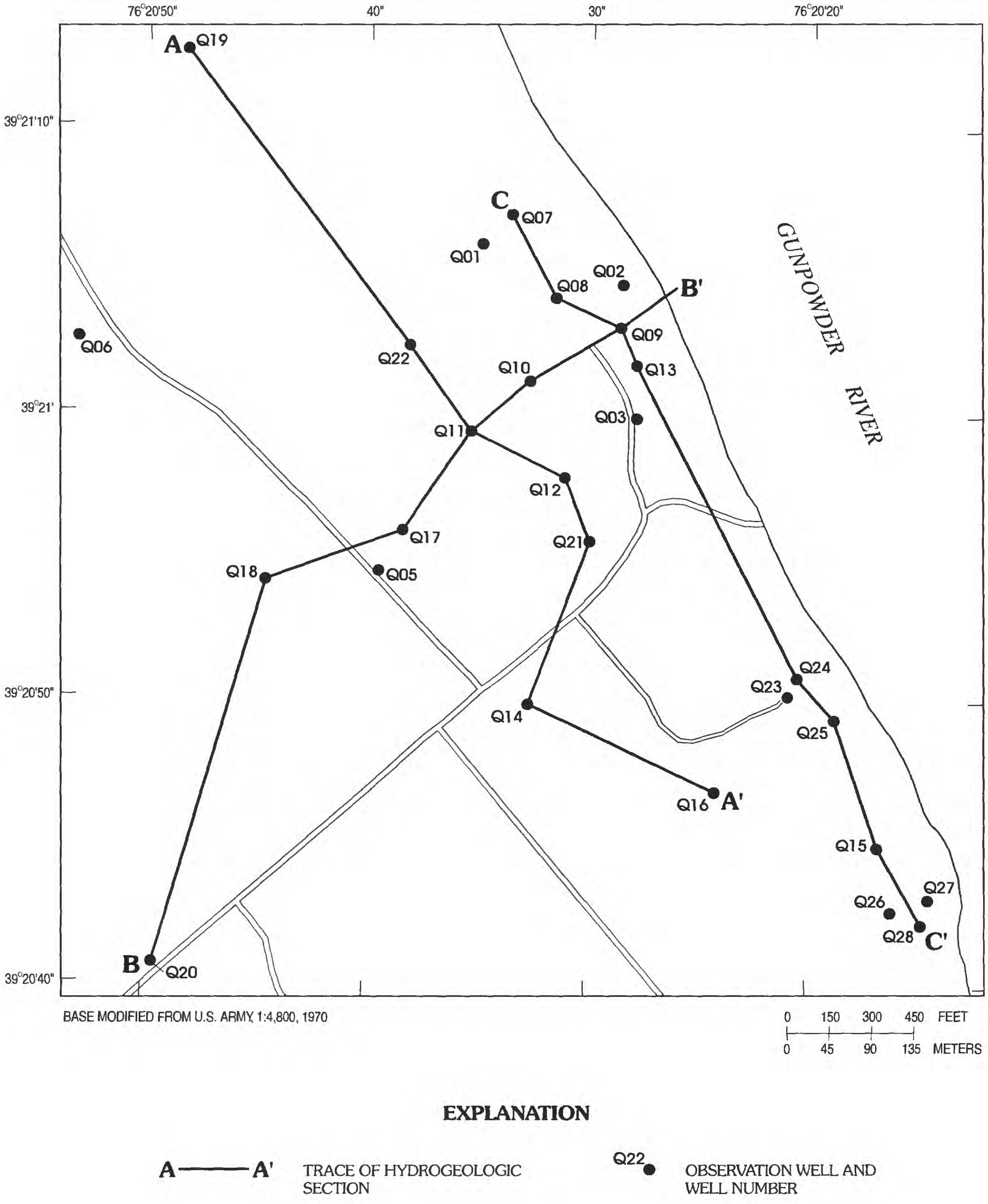


Figure 9. Traces of hydrogeologic sections through Graces Quarters, Aberdeen Proving Ground, Md. (Sections shown in figs. 10-12.)

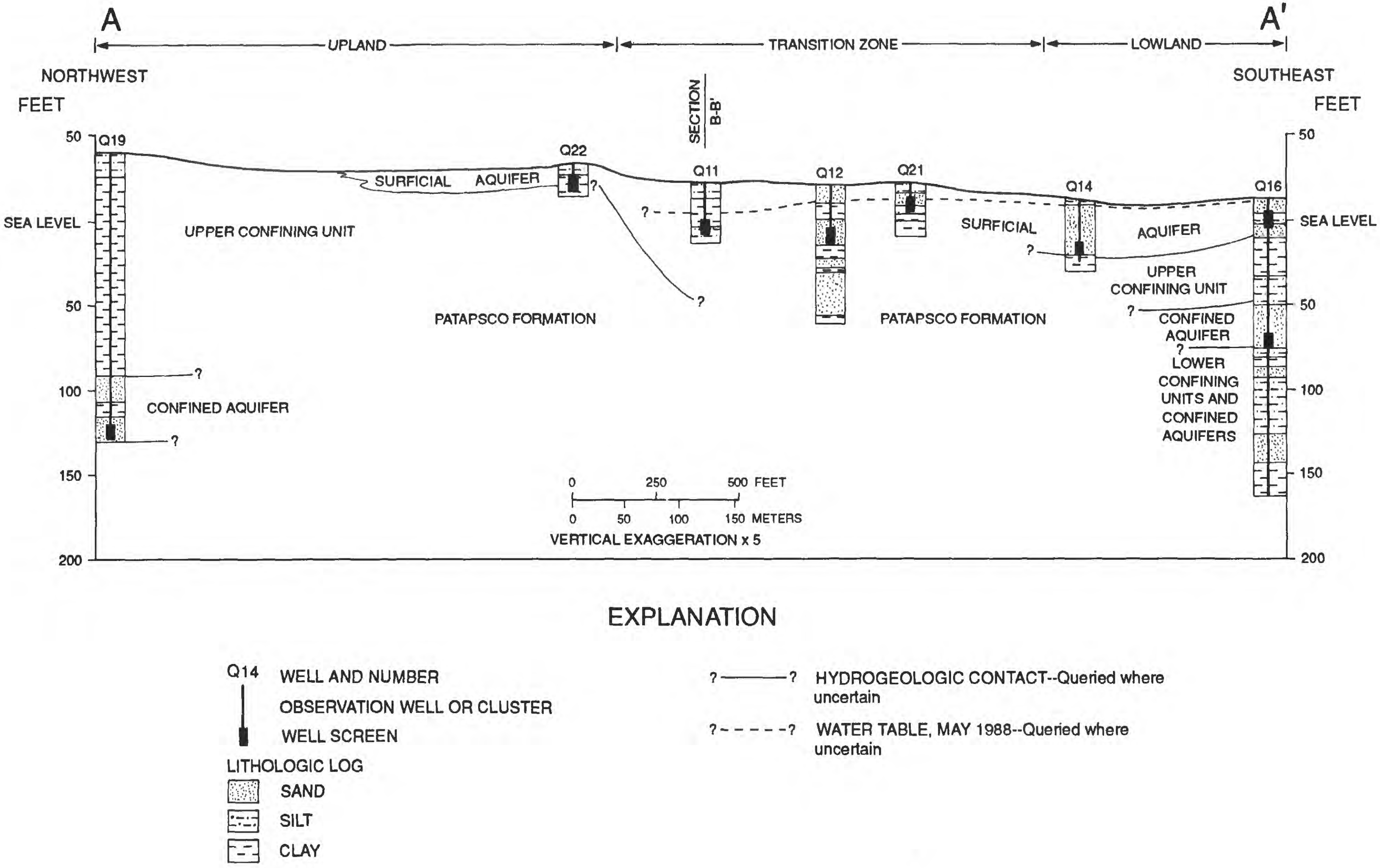


Figure 10. Hydrogeologic section A-A' through Graces Quarters, Aberdeen Proving Ground, Md. (Trace of section shown in fig. 9.)

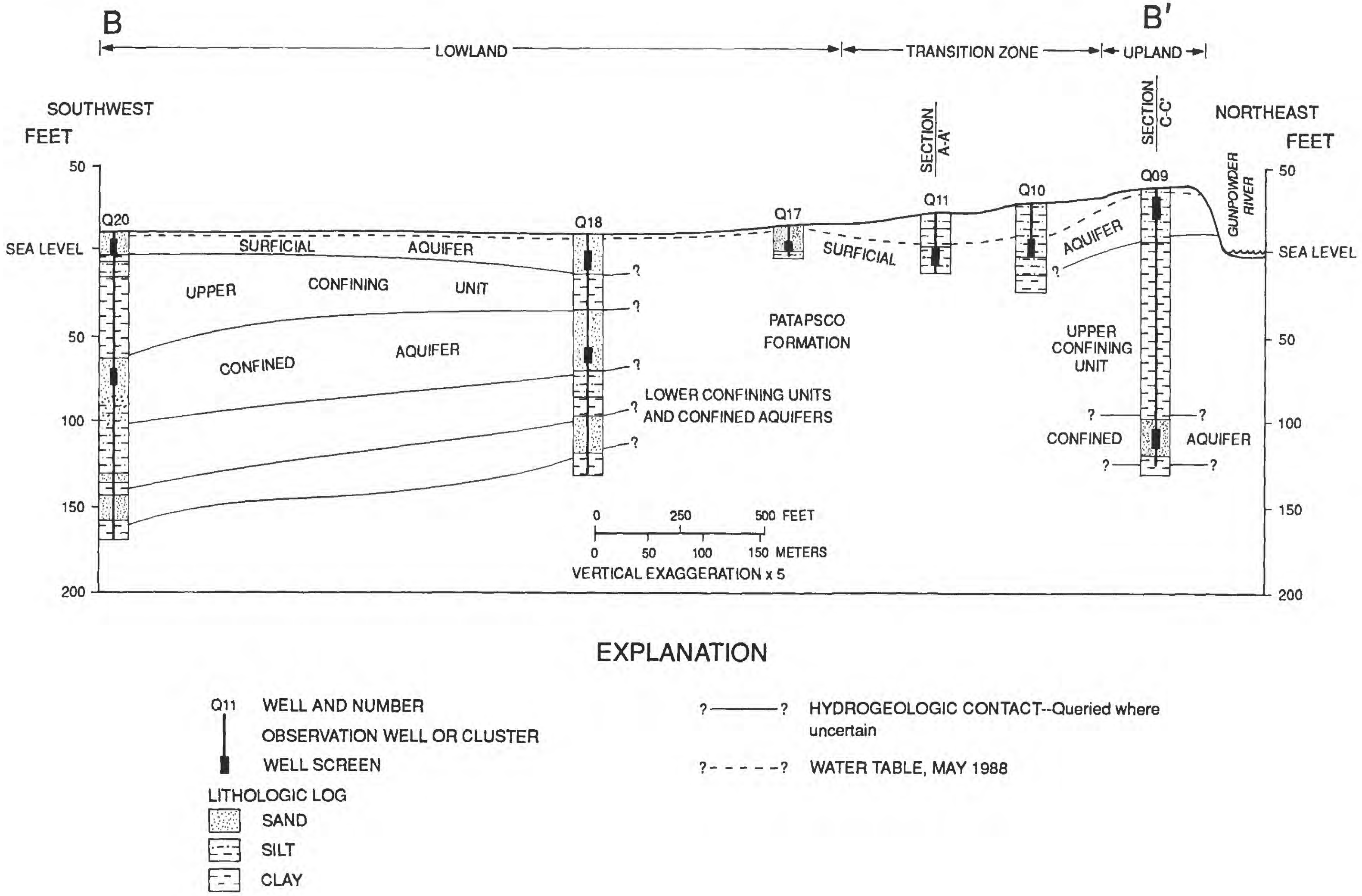


Figure 11. Hydrogeologic section B-B' through Graces Quarters, Aberdeen Proving Ground, Md. (Trace of section shown in fig. 9.)

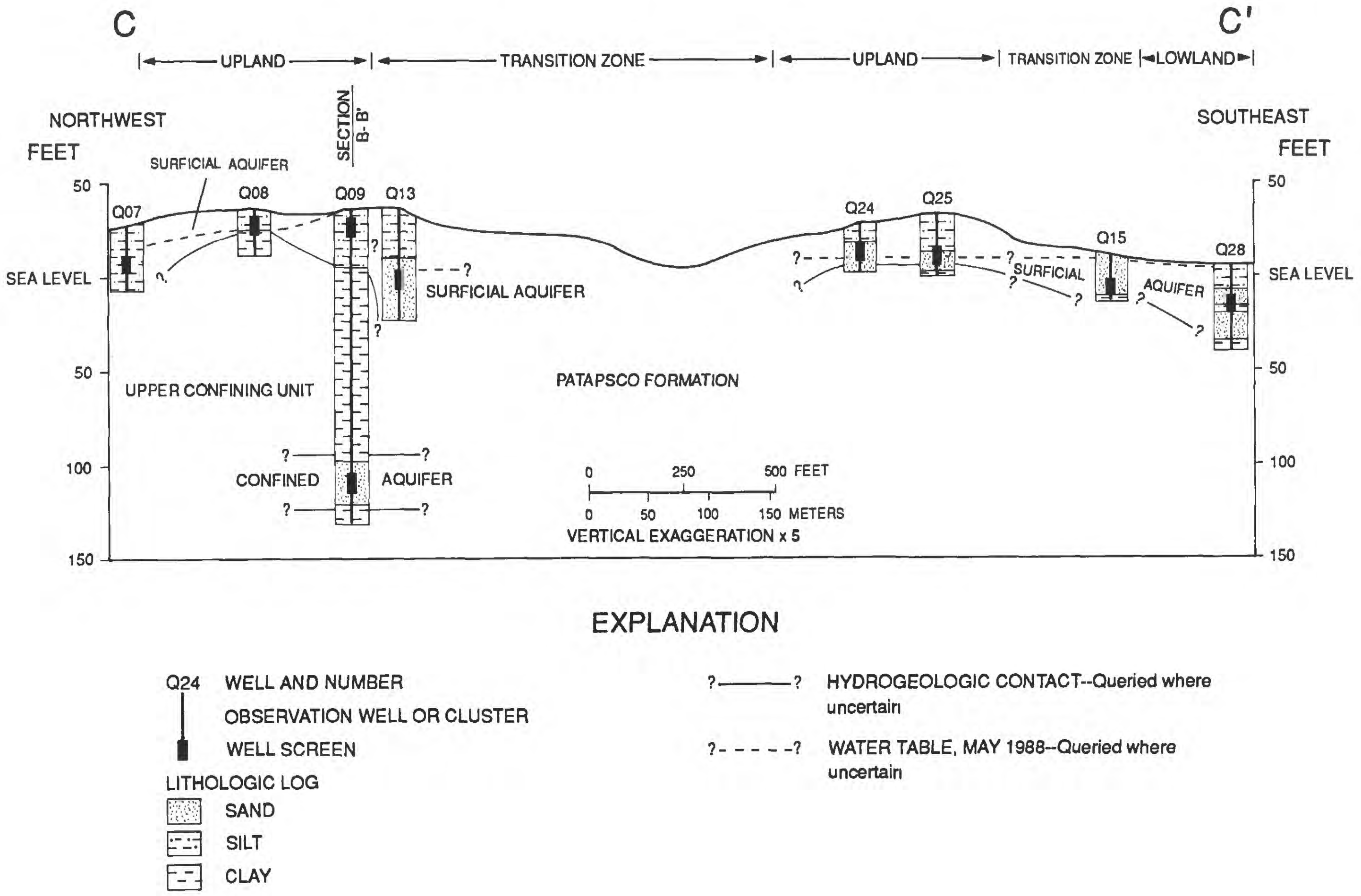


Figure 12. Hydrogeologic section C-C' through Graces Quarters, Aberdeen Proving Ground, Md. (Trace of section shown in fig. 9.)

A-A') and at well Q17, a definite confining unit was not encountered within the shallow boreholes. At wells Q18 and Q20, the surficial aquifer, the upper confining unit, and the confined aquifer system are fairly well defined and probably are continuous between the sites.

Hydrogeologic section C-C' (fig. 12) runs parallel to the shore along the eastern part of Graces Quarters from well Q07 to well Q28. In this section, two areas are present in which clay was encountered above sea level--at wells Q08 and Q09 (where section C-C' intersects section B-B') and at wells Q24 and Q25. Again, these areas are topographically higher than the surrounding areas. The abrupt change in the lithology between wells Q09 and Q13 is similar to the change between wells Q22 and Q11 in section A-A'. Data are insufficient to correlate the aquifers and confining units in the area between wells Q13 and Q24 in the central part of the section. In parts of this area, the formations that are above the waterline are visible in a cliff along the shore. The formations in this area exhibit no easily discernable pattern. A dense clay appears to be present in some locations along the cliff between wells Q13 and Q24, but there is no continuous contact above ground. It is unknown whether the clay undulates at relatively shallow depths in this area, or whether significant breaches exist in the clay that prevent it from confining the deeper aquifers.

Each of the hydrogeologic sections (figs. 10-12) shows areas that are topographically high and have a dense clay layer near the surface at an altitude that is above sea level. Adjacent to the topographic highs are areas where lithology changes abruptly or the confining unit dips steeply. In these transition zones, characteristics of the aquifers and confining units are difficult to define. Additionally, in some areas the aquifers and confining units appear to be well defined but different from the units in the topographically high areas.

Three distinct zones were defined to account for the spatial variability of aquifer and confining-unit properties within the study area at Graces Quarters (fig. 13). Within each zone, hydrogeologic properties are similar; between zones, the properties generally are different. For simplicity, the different hydrogeologic zones were given topographic names. The areas in which a thick clay layer predominates at or near the land surface were designated as the "uplands." The uplands include the disposal area, the test-site dump in the primary test area, the bunker, and the far northern part of Graces Quarters. The areas adjacent to the uplands were designated as the "transition zone." The transition zone includes the Graces Quarters dump, the secondary test area, the northernmost HD test annulus, and parts of the primary test area and perimeter dump. The remaining area was designated as the "lowlands." The lowlands of Graces Quarters include two of the three HD test annuli, the service area, the southern and western parts of the primary test area, and most of the perimeter dump.

Surficial Aquifer

The surficial aquifer on Graces Quarters is defined as the uppermost layers of permeable material in which ground water was encountered. The aquifer is generally unconfined, although it may be confined in places as a result of the presence of silt or clay layers within the aquifer. Recharge to the surficial aquifer comes from precipitation. Discharge points and areas include seeps and springs, tidal marshes, and the estuaries that surround Graces Quarters. Some water from the surficial aquifer also leaks downward through the underlying confining unit, and in some areas the upper confining unit probably is either very thin or nonexistent as a result of erosion or nondeposition of the confining-unit material. In areas such as these, the surficial aquifer directly recharges the confined aquifer system.

Saturated Thickness and Lithology

The surficial aquifer on Graces Quarters is complex and lenticular in nature. Delineation of the surficial aquifer was difficult because of the lenticular nature and heterogeneity of the sediment. In several areas of Graces Quarters, the wells were too far apart to adequately define the thickness or horizontal extent of the aquifer. Also, it was difficult in some boreholes to determine whether a clay bed that was encountered was of sufficient thickness and extent to be considered part of the upper confining unit, which defines the bottom of the surficial aquifer.

The approximate maximum saturated thickness of the surficial aquifer at Graces Quarters, defined as the depth to the confining unit minus the depth to the highest water level measured during the study period (March 1988 through March 1989) in the well penetrating the surficial aquifer at that point, is shown in figure 14. The highest water level measured in each well was not necessarily

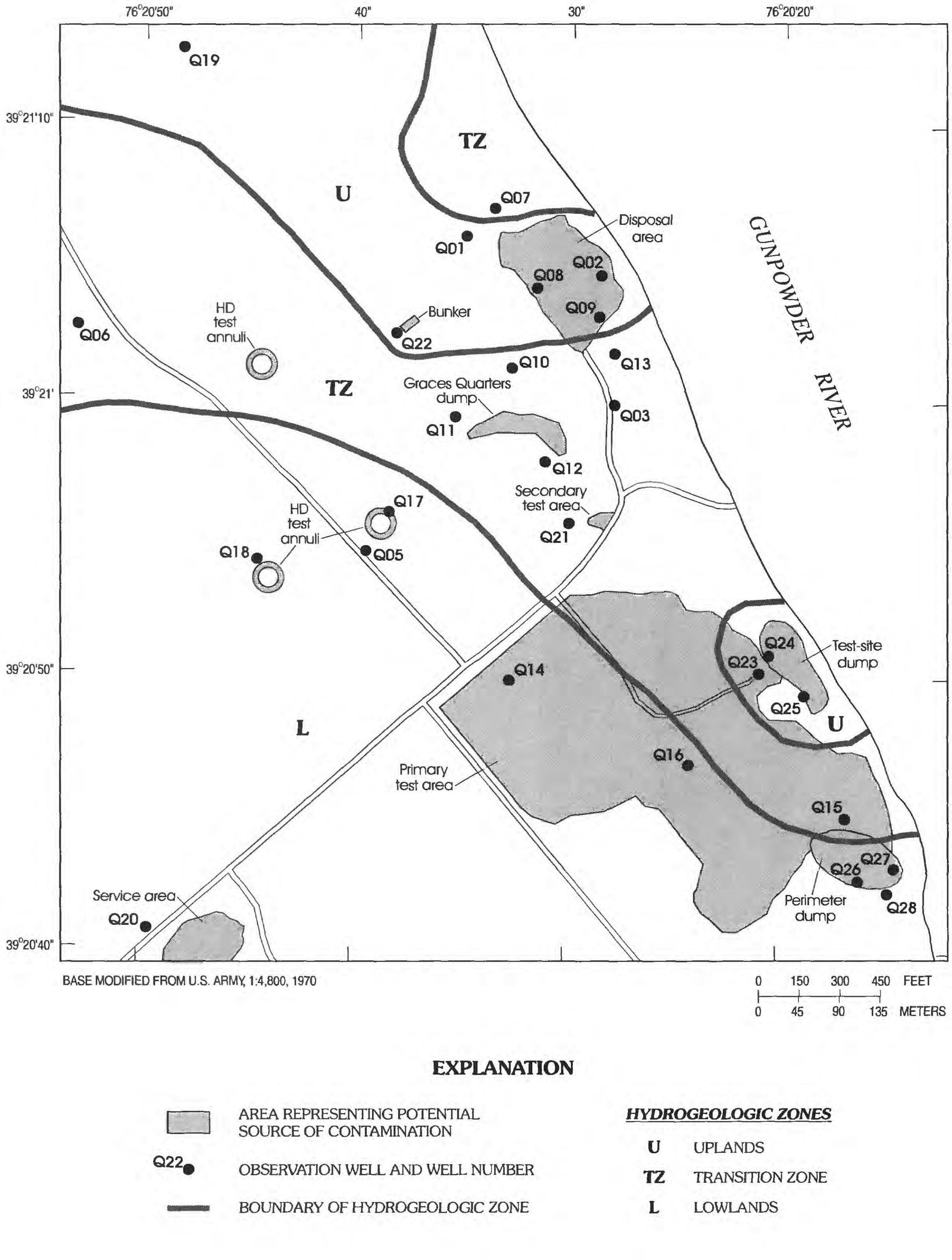
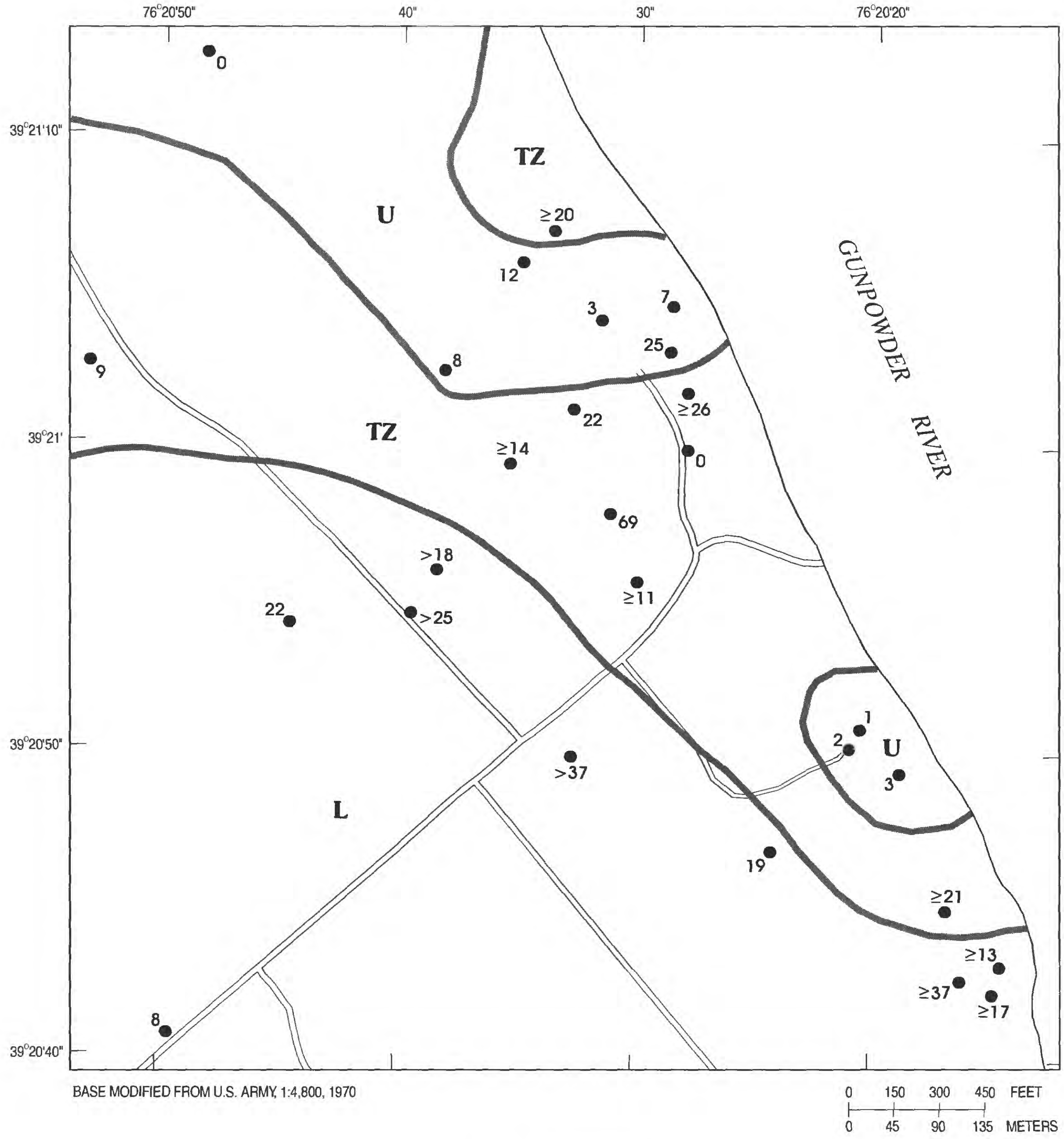


Figure 13. Approximate location of hydrogeologic zones with similar aquifer and confining-unit properties, Graces Quarters, Aberdeen Proving Ground, Md.



BASE MODIFIED FROM U.S. ARMY, 1:4,800, 1970

EXPLANATION

HYDROGEOLOGIC ZONES

U	UPLANDS
TZ	TRANSITION ZONE
L	LOWLANDS
▬	BOUNDARY OF HYDROGEOLOGIC ZONE

● ≥11 OBSERVATION WELL-- Number is approximate maximum saturated thickness of surficial aquifer measured during study period, in feet.

>, greater than

≥, greater than or equal to

Figure 14. Approximate maximum saturated thickness of surficial aquifer measured in observation wells on Graces Quarters, Aberdeen Proving Ground, Md., during the study period (October 1987 to March 1989).

measured on the same date; hence, the maximum saturated thickness given here is arbitrary and does not represent the saturated thickness of the aquifer on any particular date. In figure 14, numbers with a "greater than" (>) sign indicate that no significant clay layer was encountered, and the saturated thickness of the surficial aquifer is greater than the value shown on the map. Numbers with a "greater than or equal to" (≥) sign indicate uncertainty about the significance of the clay layer encountered at the bottom of the borehole. At these sites, the clay layer at the bottom of the borehole was barely penetrated by the drill bit, so the thickness of the clay is unknown. It is uncertain whether the clay in these holes is the bottom of the surficial aquifer or a relatively thin clay lens within the aquifer. Therefore, the clay layer at the bottom of the borehole may or may not represent the bottom of the surficial aquifer at that point. All saturated-thickness values in figure 14 are reported to the nearest foot.

The saturated thickness of the surficial aquifer varies greatly--from 0 ft to 69 ft or more. The variation in aquifer thickness indicates that the surficial aquifer at Graces Quarters is discontinuous. In the uplands, the aquifer consists of 0 to 25 ft of sandy silt underlain by dense clay. In the lowlands and transition zone, the aquifer generally is thicker and sandier, and the confining unit beneath it is less well defined than the confining unit in the upland area.

The surficial aquifer in the uplands is relatively thin. It is composed mostly of silt that is mixed or layered with sand and clay. The color of the aquifer material is mostly tan, light brown, orange, and light gray. The sand is quartzose, poorly sorted to well sorted, and commonly subrounded. The bottom of the surficial aquifer is easily defined in the uplands by the presence of a thick, dense clay, which is characteristically red and gray and is more than 100 ft thick in places (figs. 10-12). The top of this clay layer is above sea level in the uplands.

In the transition zone, the thickness of the surficial aquifer varies but generally seems to be greater than in the uplands. The aquifer thickness in the transition zone is difficult to quantify because the clay layer at the base of the aquifer is not well defined. At one well site, the maximum saturated thickness of the surficial aquifer is greater than or equal to 69 ft (fig. 14).

The aquifer in the transition zone consists of layers of sandy silt, silty clay, and silty sand. The sand-sized material is primarily quartz. Colors in the aquifer materials range from light to dark and are similar to those in the upland parts of the surficial aquifer. Most of the sand is well-sorted, fine-grained, and subrounded.

The clay layers encountered in the parts of the surficial aquifer located in the transition zone are different from the clay layer that defined the base of the aquifer in the uplands. The transition-zone clay is varicolored and less hard and dense than the uplands. The clay generally is thinner (less than 10 ft in some of the boreholes), and it is difficult to determine whether the clay layers can act as a confining unit. Therefore, determination of the actual thickness of the surficial aquifer also is difficult.

The thickness and composition of the surficial aquifer in the Graces Quarters lowlands are variable. The maximum saturated thickness ranges from about 10 ft near the service area to 37 ft or more in parts of the primary test area. The aquifer material is primarily quartz, but grain sizes vary discontinuously from gravelly sand in some areas to silt and silty sand in others. Near the service area, the aquifer consists of about 10 ft of poorly sorted sand and silty sand. At the HD test annuli, the aquifer is thicker and consists of coarser material, such as gravelly sand and well-sorted medium-grained sand. Gravelly sand also is present in the northern and central parts of the primary test area, but the aquifer material near the perimeter dump is mostly silt and silty sand.

Hydraulic-Head Distribution and Direction of Flow

Water levels measured in observation wells completed in the surficial aquifer during a time when water levels were high (May 1988) and when they were low (October 1988) are shown in figures 15 and 16, respectively. These months were selected to illustrate the variations in the hydraulic head within the surficial aquifer during the study period. The hydraulic-head values depicted in figures 15 and 16 were measured in 1988, whereas the water-quality samples described later in the report were collected in 1989.

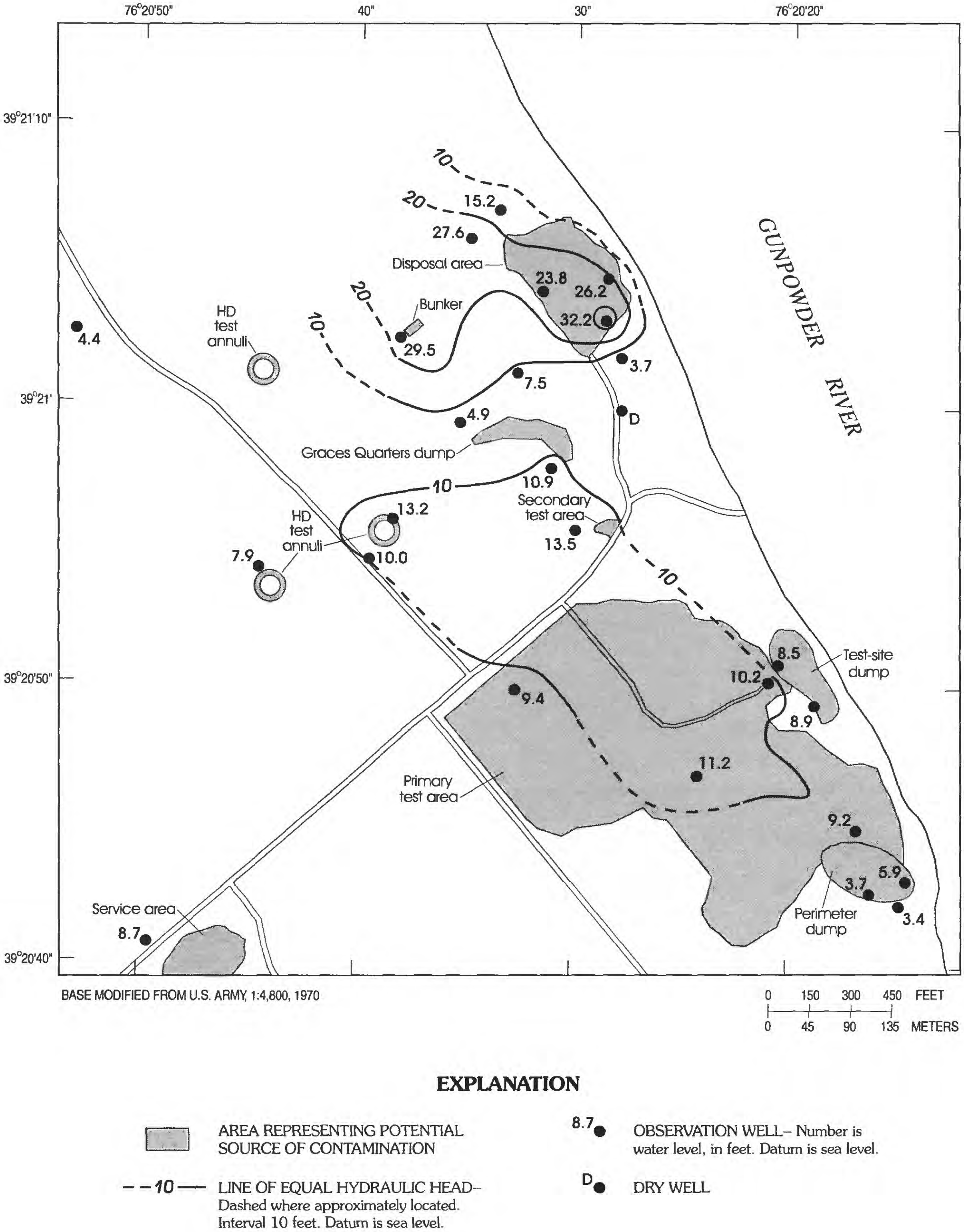


Figure 15. Hydraulic head in the surficial aquifer, Graces Quarters, Aberdeen Proving Ground, Md., May 1988.

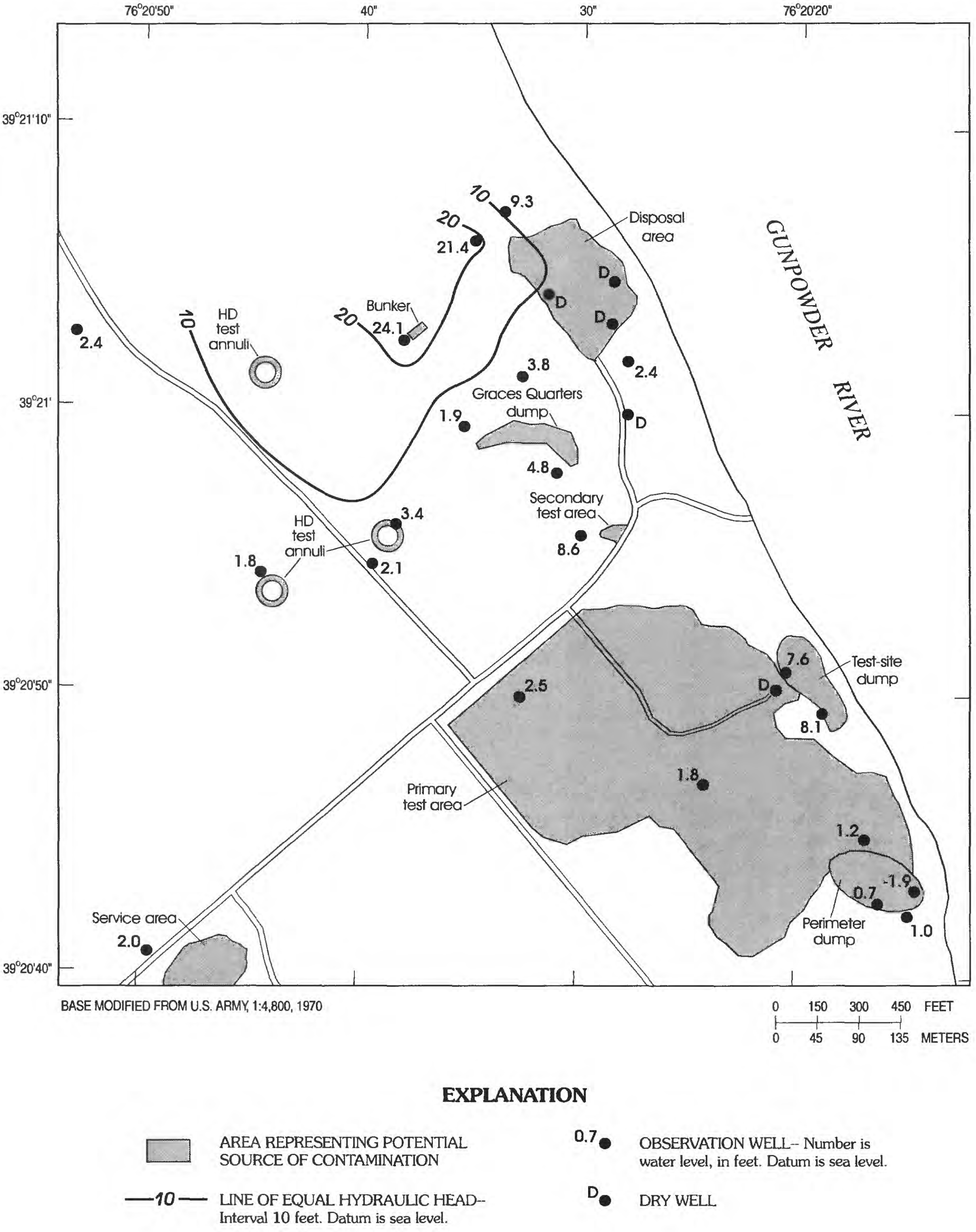


Figure 16. Hydraulic head in the surficial aquifer, Graces Quarters, Aberdeen Proving Ground, Md., October 1988.

The water levels measured in May 1988 (fig. 15) were highest in the northern uplands, which include the disposal area and the bunker. The upland water levels were about 5 to 10 ft higher than those in the adjoining transition zone and in all of the other areas of Graces Quarters.

The steep gradients between the uplands and the adjoining transition zone probably reflect the strong effect of geology on hydraulic head in the surficial aquifer at Graces Quarters. Ground water moves from areas of high head to areas of low head. If the aquifer material is very transmissive, the hydraulic-head gradient that develops to move the water can be relatively flat. However, if aquifer material has a low transmissivity, steep gradients tend to develop because more energy is required to move the ground water. In the uplands, the surficial aquifer consists mostly of fine-grained material, such as silt and silty sand, and the bottom of the aquifer is defined by a clay layer that is above sea level. Assuming equal recharge rates on all areas of Graces Quarters, the higher hydraulic head in the uplands could be explained by the low transmissivity between the uplands and the surrounding areas.

The hydraulic-head values measured in October 1988 (fig. 16) were lower than those measured in May, reflecting decreased recharge and increased evapotranspiration during the drier season. The greatest change in the hydraulic-head distribution was in the uplands at the disposal area where three wells in the surficial aquifer were dry at the time of measurement. Two of the wells labeled "D" (for dry) in figure 16 contained water but at a level below the top of the upper confining unit. These wells were drilled for an earlier study (Nemeth and others, 1983) and were partially screened in the upper confining unit.

The direction of ground-water flow generally is perpendicular to the lines of equal hydraulic head if the aquifer is homogeneous and isotropic. On Graces Quarters, the aquifer generally is not homogeneous, so flow direction may not be exactly perpendicular to the lines of equal head. However, these maps can be used to gain an understanding of the potential movement of ground water from one area to another.

At the disposal area in the northeastern part of Graces Quarters, the hydraulic head is high during times of substantial recharge (fig. 15), and the hydraulic gradient slopes away from the area in all directions except west-northwest. Flow directions following the hydraulic gradient are likely in this area. Intermittent seeps and springs have been observed on the cliff face to the east of the disposal area and at the head of a gully to the north. South of the disposal area in the transition zone the hydraulic head is much lower. The steep gradient in this direction may indicate that some ground-water flow is occurring, but a good hydraulic connection is unlikely. A geologic barrier probably exists between the disposal area and the area to the south.

During drier months (fig. 16), the saturated thickness of the surficial aquifer at the disposal area approaches zero. In the wells screened above the upper confining unit, water levels decline below the screen depth. In wells screened partially in the upper confining unit, water levels decline below the bottom of the surficial aquifer. Discharge from the springs and seeps in the area stops, and any water remaining in the aquifer would have only flat gradients along the top of the confining unit and movement would be slow.

The bunker is also in the uplands where hydraulic head is higher than in the rest of Graces Quarters. The difference between the bunker site and the disposal area is that hydraulic head remains high at the bunker during dry months (figs. 15 and 16). The bunker itself contained ponded water throughout the study period. Steep gradients away from this area exist toward the west, east, and south during both wet and dry months. However, these steep gradients indicate that ground-water flow from the bunker may be impeded by the hydraulic properties of the subsurface material, which is only slightly permeable in this area. This subsurface material may trap shallow ground water and prevent flow away from the area, causing ponding and high ground-water levels.

Flow directions in the transition zone south of the disposal area and bunker are difficult to determine. In an area just west of the Graces Quarters dump, the water level in one well (Q11) is consistently lower than in any of the surrounding wells (figs. 15 and 16). There are no known pumping effects on the surficial aquifer, so the anomalous water levels indicate that the geologic framework probably affects ground-water flow. The upper confining unit may be thin or nonexistent in the area around this well, making the area a recharge zone for one of the confined aquifers. Alternatively, the surficial aquifer at the bunker may not be connected to the surficial aquifer in the transition zone; in this case, hydraulic head at the bunker would not affect flow direction in the transition zone. Instead, the likely flow direction in the transition zone at the Graces Quarters dump would be to the west. The installation of deeper wells near well Q11 might help to resolve some of these questions.

The other upland area on Graces Quarters is in the primary test area at the test-site dump. The hydraulic head in this area is lower than that in the disposal area and bunker. The saturated part of the aquifer in this area is only about 1 to 3 ft thick (fig. 14), and the wells in the area are occasionally dry. Ground water from this upland also may flow in several directions, including east of the site toward the cliff face.

At the perimeter dump site, flow direction appears to vary between wet and dry seasons. This area is low and is near a tidal marsh and the Gunpowder River. In May 1988 (fig. 15) and other months during the wet season, the water level in one of the wells (well Q26) in the surficial aquifer was higher than the land surface (fig. 7). However, the land surface surrounding the well was dry, indicating that the hydraulic head at depth was higher than the hydraulic head at the surface. This situation can occur in parts of an unconfined aquifer where there is an upward component to flow, such as in discharge areas (Fetter, 1980, p. 154), or where fine-grained material at the surface produces confining pressures within the aquifer. During drier times, evapotranspiration appears to affect ground-water levels. In October 1988 (fig. 16) and several other months during the dry season, the water level in one of the wells at this site (well Q27) was as much as 1.9 ft below sea level.

Hydraulic-Head Fluctuations

Six wells in the surficial aquifer were fitted with analog-to-digital water-level recorders (ADR's), which recorded the water levels at 15-minute intervals during the study period. The ADR's were located on wells in the surficial aquifer near the disposal area (wells Q01 and Q13), at the HD test annuli (wells Q05 and Q18A), near the service area (well Q20B), and within the primary test area (well Q16B).

The greatest hydraulic-head variation for all the wells in the surficial aquifer resulted from seasonal changes in rainfall and evapotranspiration. Hydraulic head exhibited a seasonal variation of 6 to 8 ft in most of the surficial wells equipped with ADR's. Hydraulic-head fluctuations in well Q05 near the HD test annuli are related to rainfall (the rain gage was located at nearby Carroll Island, about 2 mi from this area). The seasonal change in water levels from May to October 1988 in well Q05 (fig. 17) is similar to that measured in many of the other wells on Graces Quarters (figs. 15 and 16). Water levels decreased from May to October 1988, even though rainfall recorded from July through September was significant (fig. 17). This indicates that evapotranspiration is an important factor affecting recharge rates into the surficial aquifer at Graces Quarters.

Hydraulic Properties

Ten wells in the surficial aquifer were tested in summer 1988 by slug injections and analyzed by the methods of Cooper and others (1967) and Hvorslev (1951). Results that could be analyzed by at least one of the methods were obtained from nine of the wells. The values for horizontal hydraulic conductivity derived from the slug tests are shown in table 3. Original data from the slug tests are available in Ham and others (1991, table 10). Unless otherwise noted, all hydraulic conductivities are horizontal hydraulic conductivities.

The value of hydraulic conductivity that is obtained from a slug test is affected by the aquifer properties near the well screen and by several factors that include the method of analysis, the well hydraulics, and the changes that occur in the aquifer near the well as a result of drilling, well installation, and well development. With so many different factors affecting the calculated value of hydraulic conductivity, care must be taken to interpret successfully the significance of the magnitude of the values and the variation between wells. The magnitude and the variation of the hydraulic conductivity calculated from slug tests in the surficial aquifer at Graces Quarters are discussed in the following paragraphs.

The method of Cooper and others (1967) was used to analyze data from six of the nine wells in the surficial aquifer that were tested successfully (table 3). Each of these six wells contained 8 ft or more of water in the well casing above the screen at the time of testing. Three of the wells (Q07, Q10, and Q13) did not contain enough water in the casing above the well screen for the hydrogeologic setting to be similar to that of a confined aquifer, which is the setting for which the method of Cooper and

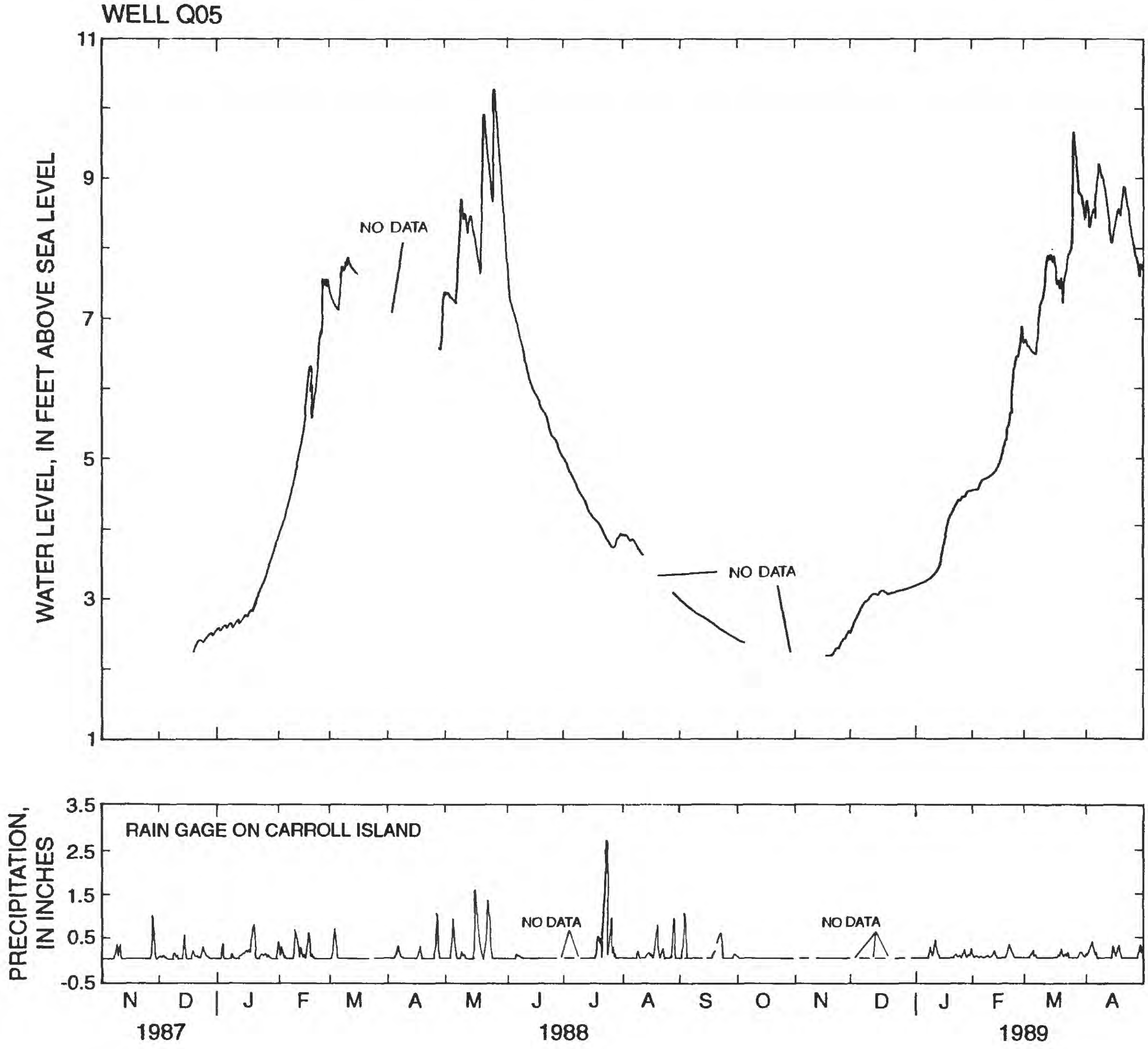


Figure 17. Water levels in well Q05 in the surficial aquifer related to precipitation during study period, November 1987-April 1989, Graces Quarters, Aberdeen Proving Ground, Md.

others (1967) was intended.

Hydraulic conductivity calculated with the method of Cooper and others (1967) ranged from less than 0.01 ft/d in well Q12 to 24 ft/d in well Q18A (table 3). The range of four orders of magnitude indicates that the surficial aquifer is heterogeneous with respect to hydraulic conductivity. Hydraulic conductivity was lowest in three wells (Q12, Q26, and Q28) that were screened in generally fine-grained material (table 3). The wells with higher hydraulic-conductivity values (wells Q14, Q15, and Q18A) were screened in coarser-grained material (table 3).

Hydraulic conductivities calculated by the Hvorslev (1951) method ranged over three orders of magnitude (table 3). The range of hydraulic conductivity is smaller than that calculated by the method of Cooper and others (1967) primarily because of the degree of precision to which the numbers could be calculated. Of the nine slug tests analyzed with the Hvorslev (1951) method, four had hydraulic-conductivity values less than 0.1 ft/d (table 3). The rest of the hydraulic-conductivity values ranged from 0.5 to 13 ft/d (table 3).

Table 3 shows that hydraulic-conductivity values varied with sediment texture. However, the magnitude of the difference between hydraulic conductivity in each well calculated by the two different methods also varied from well to well. Therefore, it is useful to do a well-by-well comparison of the hydraulic conductivity calculated by each method to examine the differences and similarities between the calculated values in table 3.

Wells Q07, Q10, and Q13 did not contain enough water above the well screen at the time of slug testing for the Cooper and others (1967) method to be used. In these wells, the hydraulic conductivity calculated with the Hvorslev (1951) method included the highest and lowest values calculated by this method (table 3). The low hydraulic

Table 3. *Summary of slug-test results for the surficial aquifer, June through September 1988, Graces Quarters, Aberdeen Proving Ground, Md.*

[N/A denotes that the assumptions for the Cooper and others (1967) method were not met and, therefore, a value is not applicable. <, less than]

Well no. (fig. 3)	Horizonal hydraulic conductivity (cubic feet per day per square foot)		Material screened[3]
	Cooper method[1]	Hvorslev method[2]	
Q07	N/A	<0.1	Beds of silt, clay, sand, and gravel.
Q10	N/A	.5	Sandy silt, some silty sand.
Q12	<0.01	<.1	Sandy silt, silty sand, interbedded with some clayey silt.
Q13	N/A	13	Silty sand, sand.
Q14	22	7	Runny sand (no sample was recovered).
Q15	6	7	Coarse, poorly sorted sand.
Q18A	24	8	Coarse, poorly sorted sand.
Q26	<.02	<.1	Clay, sand, silty sand.
Q28	<.02	<.1	Fine sand, silty sand.

[1] Cooper and others (1967).

[2] Hvorslev (1951).

[3] From Ham and others (1991, table 6).

conductivity in well Q07 may be the true value for the aquifer material in which the well was screened, or it may have resulted from smearing of the interbedded layers in the screened zone during the drilling and well installation. The hydraulic conductivity calculated for wells Q10 and Q13 (table 3) is within the range that would be expected for those materials.

Hydraulic conductivities in three wells other than Q07 were very low (table 3). Well Q12 was screened in sandy silt and silty sand interbedded with some clayey silt (table 3) within the screened depth of 20 to 30 ft (Ham and others, 1991, p. 17). Wells Q26 and Q28 were screened in mostly fine-grained materials, such as clay, sand, fine-grained sand, and silty sand (table 3). As with well Q07, smearing may have affected the hydraulic-conductivity measurements at these wells. However, the hydraulic conductivities calculated for these wells are still within the range commonly measured in aquifer materials of similar texture.

Wells Q14, Q15, and Q18A were screened in sandy aquifer materials. The hydraulic conductivities at these wells were essentially similar to one another if calculated by the Hvorslev (1951) method (table 3). However, the Cooper and others (1967) method yielded hydraulic conductivities that were somewhat higher at wells Q14 and Q18A than those calculated by the Hvorslev (1951) method for the same wells (table 3). The differences likely are caused by the effects of compressive storage within the aquifer, which is accounted for by the Cooper and others (1967) method but not by the Hvorslev (1951) method (Chirlin, 1989, p. 130-131). An explanation of these effects is provided in the following paragraphs.

Storage coefficient is a dimensionless aquifer property defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head (Fetter, 1980, p. 479). A storage coefficient that results from compressive storage alone (as in a confined aquifer) is typically on the order of 0.005 or less (Fetter, 1980, p. 96). Where the storage coefficient results primarily from dewatering or refilling of pore spaces, the value is commonly about 0.02 to 0.30 (Fetter, 1980, p. 96-97).

The storage coefficient of an aquifer in the area near the well screen can be approximated from slug tests if the data are analyzed by the Cooper and others (1967) method. The shape of the curve that results from plotting the data is related to the aquifer storage coefficient (Cooper and others, 1967, p. 267). The storage coefficients that resulted from plotting the data for wells Q14 and Q18A were about 10^{-10}; for well Q15, the storage coefficient was about 10^{-2}.

Chirlin (1989, p. 134-136) contends that the accuracy of the Hvorslev (1951) method in the hydrogeologic setting for which the Cooper and others (1967) method is appropriate depends on the degree to which the well response can be attributed to compressive storage. Because compressive storage is not addressed by the Hvorslev (1951) method, the method will underestimate hydraulic conductivity in hydrogeologic settings where compressive storage is important. The magnitude of the storage coefficient in wells Q14 and Q18A indicates that compressive storage was an important factor in the response of the water level during the slug test, which means that the Cooper and others (1967) method is more appropriate than the Hvorslev (1951) method. In well Q15, the magnitude of the storage coefficient indicates that the effects of compressive storage were negligible. In this well, the Hvorslev (1951) and the Cooper and others (1967) methods produced equivalent hydraulic-conductivity values (table 3).

From the preceding discussion, it follows that the results from the Hvorslev (1951) method are probably fairly accurate for the slug tests in wells Q07, Q10, and Q13, where the Cooper and others (1967) method was not applicable (table 3). Because the water level in these wells was not far above the screen, it is likely that the effect of compressive storage during the slug tests in these wells was unimportant, and the Hvorslev (1951) method provided an accurate representation of the aquifer response to the slug perturbation.

Although differences in the effects of compressive storage on slug-test response can explain the different results from the Cooper and others (1967) and Hvorslev (1951) methods for wells Q14, Q15, and Q18A (table 3), there is still some question as to why hydraulic conductivity is higher at wells Q14 and Q18A than it is at well Q15 if all three wells are screened in similar material (table 3). This is a question that cannot be answered definitively with existing data. Many of the factors that affect slug-test response cannot be measured easily. Well hydraulics may have had an effect because wells Q14 and Q18A had 10-ft-long screens, whereas well Q15 had a 5-ft-long screen (Ham and others, 1991, p. 17). Well development may have had an effect, or the differences in hydraulic conductivity may have resulted simply from differences in aquifer material that are not apparent in a qualitative lithologic description such as is given in table 3. Again, the hydraulic conductivities determined during these slug tests are within the range common to sandy aquifer materials.

Upper Confining Unit

The upper confining unit underlies the surficial aquifer and was encountered in several of the boreholes drilled in the study area on the Graces Quarters peninsula (fig. 18). It is unlikely that the upper confining unit is continuous over the entire study area (figs. 10-12). The continuity of the upper confining unit in the transition zone between the uplands and lowlands is uncertain.

The upper confining unit beneath the uplands consists of a dense clay layer. The top of this clay layer ranges from 7 to 22 ft above sea level (fig. 18). The thickness of the upper confining unit in the uplands was more than 100 ft at two deep wells (fig. 18). Leakage between the surficial aquifer and the confined aquifer in the uplands is unlikely unless undiscovered breaches are present in the clay in these areas.

Away from the uplands, the dense, thick clay generally was absent. Some clay units were found in the transition zone, but they probably were not continuous and did not have the characteristic color or density of the upland clay. In the lowlands, a clay confining unit was encountered in each of the three deep boreholes. The lowland clay also appears to be different from the one encountered in the uplands and is 20 to 65 ft thick in the boreholes in which it is present.

The confining unit between the surficial aquifer and the deeper aquifers on Graces Quarters probably is discontinuous. The fluvial environment of deposition for these materials produced interfingering of the clay and sand that comprise the aquifers and confining units. Information from the boreholes drilled in the transition zone indicates that breaches probably exist in the upper confining unit (figs. 10-12). For example, the deepest borehole in the transition zone was well Q12, which was drilled to a depth of 80 ft. In this borehole, there was a clay layer from 9 to 18 ft below land surface, and another clay of unknown thickness that was encountered at a depth of 78 ft. It is difficult to determine whether either of these clay layers is continuous with the upper confining unit in the uplands or whether either of the clay layers acts as the upper confining unit in this part of the transition zone. Because there was no saturated material above the upper clay layer, this layer was considered to be part of the surficial aquifer. Because the thickness and extent of the lower clay layer were not determined, it cannot be said with certainty to be a continuous confining unit. Even if it is thick enough to be a confining unit, its depth correlates more closely with that of one of the lower confining units beneath the lowlands than with that of the upper confining unit. If this correlation is correct, no significant upper confining unit exists in the area around well Q12, and the transition zone is a recharge area for the confined aquifer system in the lowlands. Because available geologic data in the transition zone are sparse, however, additional information is needed to confirm this possibility.

Confined Aquifer System

One or more confined aquifers were encountered in each of the five deep boreholes drilled on Graces Quarters. Deep boreholes were located in the uplands (wells Q09 and Q19) and in the lowlands (wells Q16, Q18, and Q20). The limited number of boreholes that penetrated confined aquifers on Graces Quarters did not allow for delineation of individual confined aquifers. The lack of data also prevented the definition of the extent of this confined aquifer system.

Thickness and Lithology

The top and thickness of the confined aquifer system in each of the deep boreholes are shown in figure 19. Thicknesses in figure 19 are shown with a "greater than or equal to (≥)" sign, which indicates that the boreholes were not drilled to a depth great enough to determine whether the clay layers encountered at the bottoms of the holes represent the bottom of the confined aquifer system. However, information from the five boreholes indicates that the confined aquifer system on Graces Quarters consists of layers of sand and clay. The sand encountered ranged from well-sorted, medium-grained, rounded sand to very poorly sorted, gravelly sand mixed with clay. The clay layers generally were beige, light gray, or red.

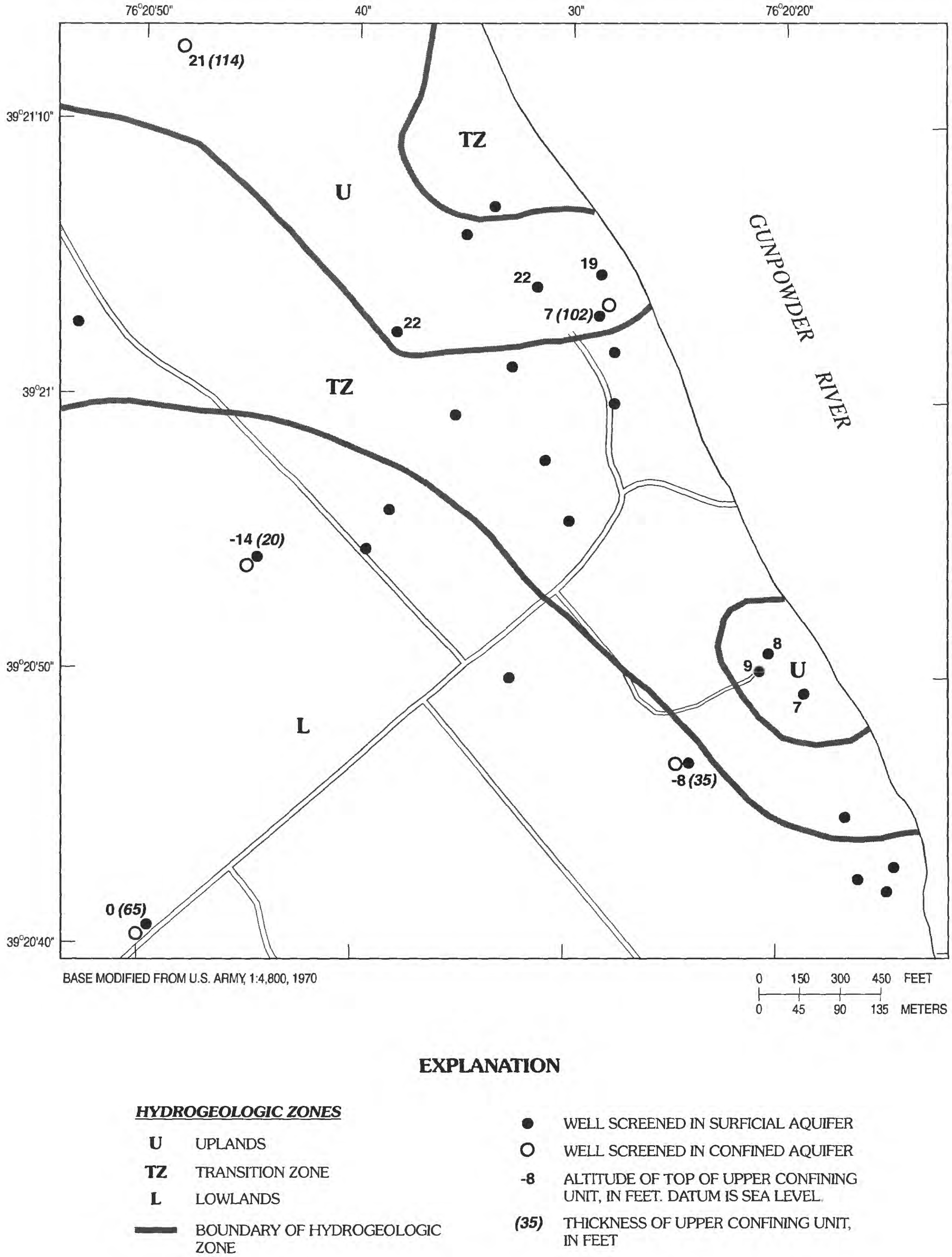


Figure 18. Altitude of top and thickness of upper confining unit, Graces Quarters, Aberdeen Proving Ground, Md.

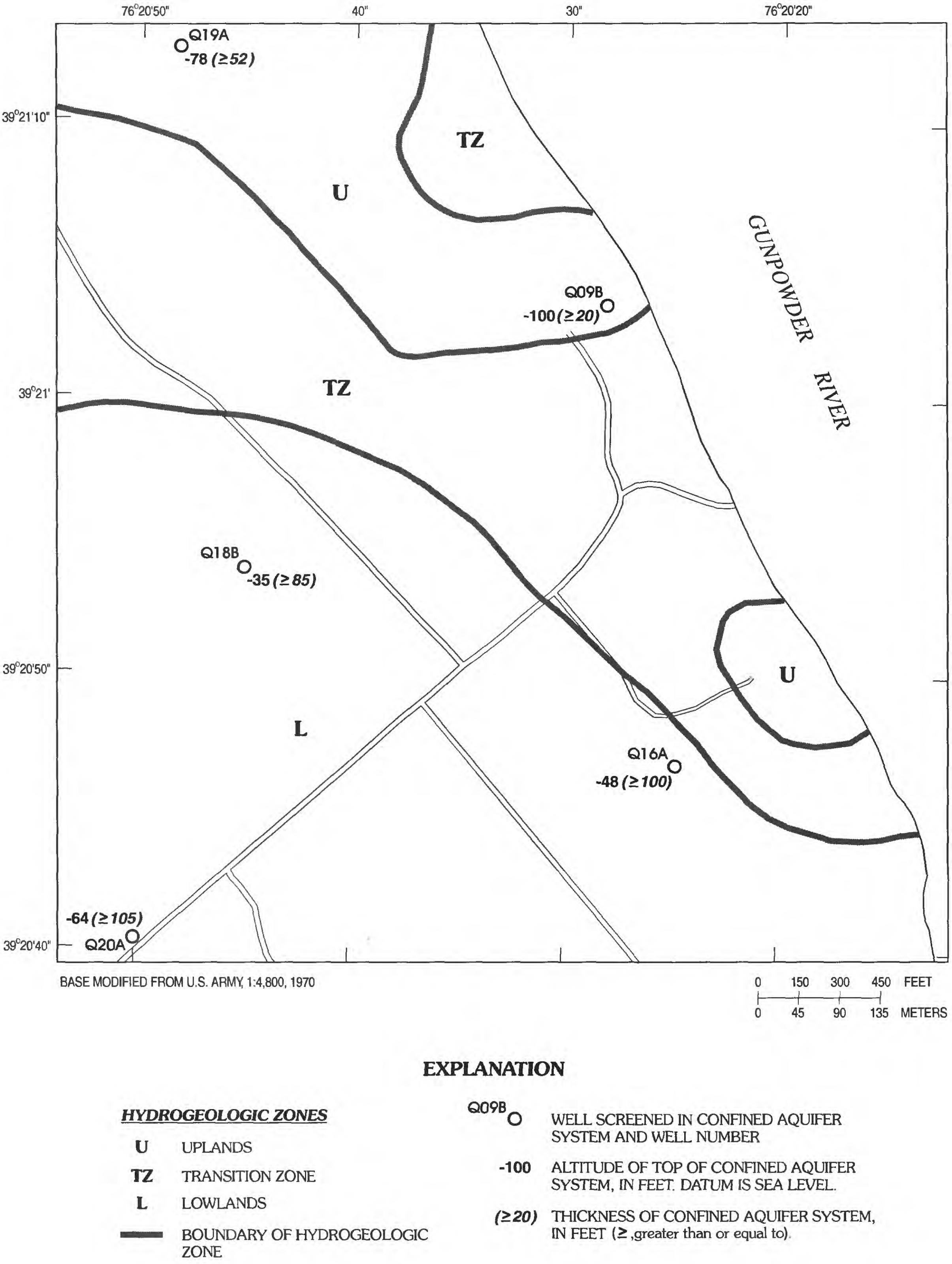


Figure 19. Altitude of top and thickness of the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md.

Geologic data from the boreholes indicate that the confined aquifer system beneath the uplands is different from the confined aquifer system beneath the lowlands. In the uplands at wells Q09B and Q19A, the top of the confined aquifer system is 120 to 150 ft below land surface, and the aquifer underlies about 100 ft of dense clay (figs. 10-12). Beneath the lowlands, the top of the confined aquifer system is approximately 50 to 70 ft below land surface, and the aquifer underlies clay layers that are 20 to 65 ft thick.

Hydraulic-Head Distribution and Direction of Flow

Hydraulic-head distributions in the confined aquifer system in February, May, and October 1988 are shown in figures 20-22. These months were chosen to illustrate the difference in conditions in the confined aquifer system during the winter, spring, and autumn of 1988. The head distributions in figures 20-22 provide additional evidence of the differences in the confined aquifer system between the uplands and lowlands.

During February 1988 (fig. 20), the hydraulic head in the confined aquifer system at Graces Quarters was above and below sea level, depending on location. In the northern (upland) part of Graces Quarters, the hydraulic head in wells Q09B and Q19A was below sea level, indicating that offsite pumping might be affecting the water levels. The hydraulic gradient generally was toward the northwest in this area, but more wells are needed to determine direction of flow accurately. In the southern (lowland) section of Graces Quarters, hydraulic head was above sea level, and flow was toward the south.

Some of the highest hydraulic heads of the year in wells screened in both the confined and surficial aquifers occurred in May 1988. The hydraulic head in the confined aquifer system during May 1988 was above sea level in all wells screened in this unit (fig. 21), possibly because of increased recharge, a return to unstressed conditions, and (or) a decrease in the pumpage that affected water levels in the two upland wells. Hydraulic head increased 7.5 ft from February to May in one of the upland wells, whereas the hydraulic head in the lowland wells increased approximately 1.5 ft. The direction of the hydraulic gradient in the lowland wells during May 1988 was south-southwest. The apparent gradient direction in the upland wells was southeast but, again, more wells would be needed to improve the definition of the gradient in this area.

Some of the lowest hydraulic heads of the year were recorded in the confined and surficial aquifers in October 1988. The hydraulic head in the confined aquifer system in the upland wells again showed the effects of pumping, whereas the lowland wells were not affected (fig. 22). The apparent hydraulic-gradient direction in the upland was again to the northwest, and the gradient direction in the lowland wells was to the southwest.

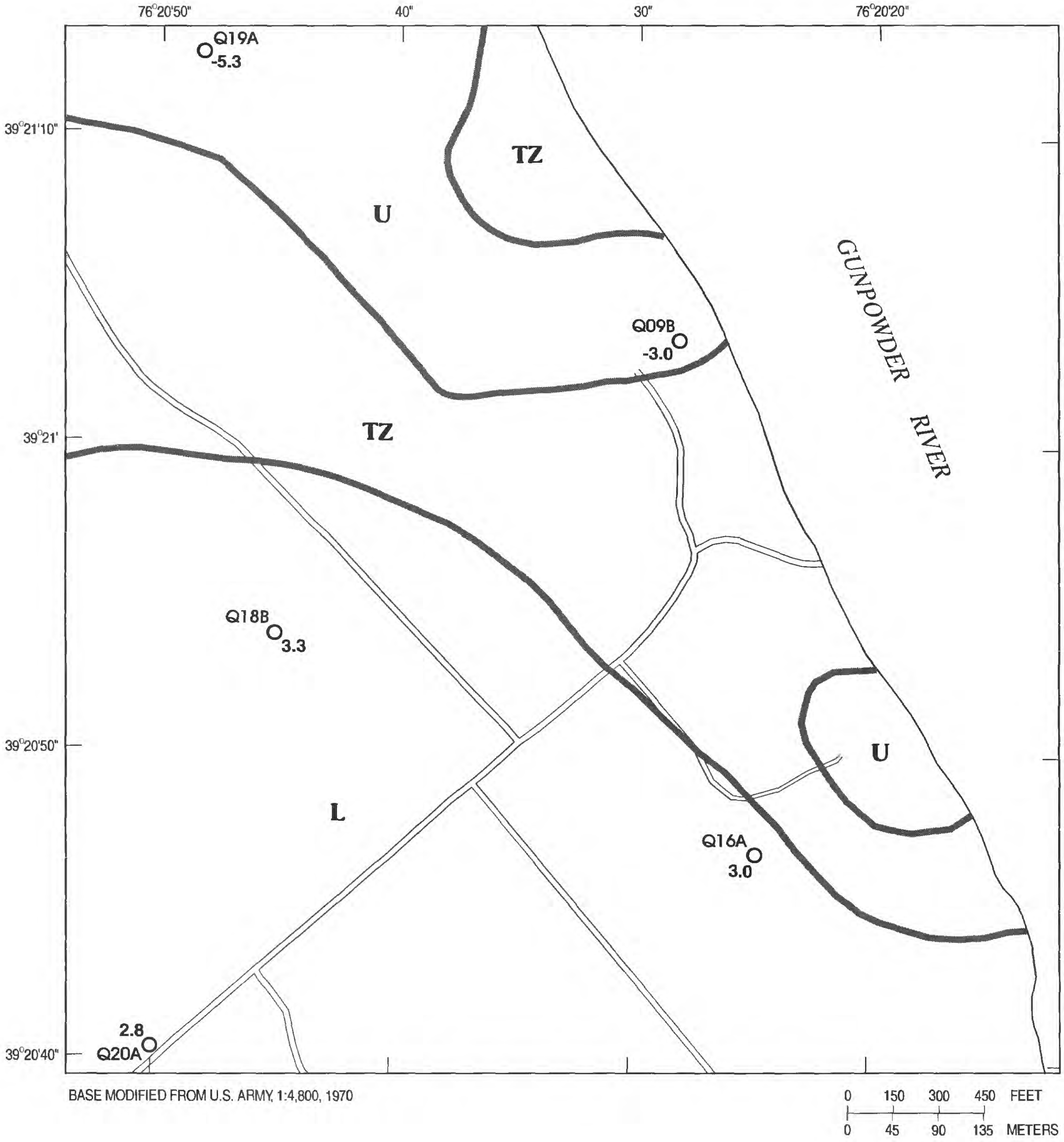
The source of the pumpage that affects hydraulic head in the upland confined aquifer system on Graces Quarters is unknown. The direction of the pumpage source from the study area is unknown because the direction of the hydraulic gradient in this part of the aquifer system could not be determined. It is likely, however, that the pumpage source is one or more of the production wells listed in table 1.

Hydraulic-Head Fluctuations

The hydraulic head in the confined aquifer system at Graces Quarters appears to be affected by three main factors--seasonal recharge variation, tidal (and possibly barometric) fluctuations, and pumpage from an unknown location. Each of the wells responded similarly to tidal fluctuations, but the response of each well to seasonal recharge variation and pumpage depended on whether the well was screened in the confined aquifer system beneath the uplands or beneath the lowlands.

The wells in the lowlands responded mainly to recharge variation and tidal fluctuation (fig. 23). The hydraulic head in the spring months of 1988-89 was approximately 3 ft higher than the hydraulic head in summer and autumn. Tidal fluctuations caused the heads to vary 0.5 to 1.5 ft on a daily basis. Barometric-pressure variations were not measured as part of this study, so any head fluctuations due to changes in barometric pressure are indistinguishable from the head fluctuations caused by tides.

The hydraulic head in the confined aquifer system beneath the uplands also responded to tides, but natural seasonal variation was not apparent. Instead, the hydraulic head appeared to be affected by pumpage (fig. 24). For example, well Q19A was



EXPLANATION

HYDROGEOLOGIC ZONES

U UPLANDS

TZ TRANSITION ZONE

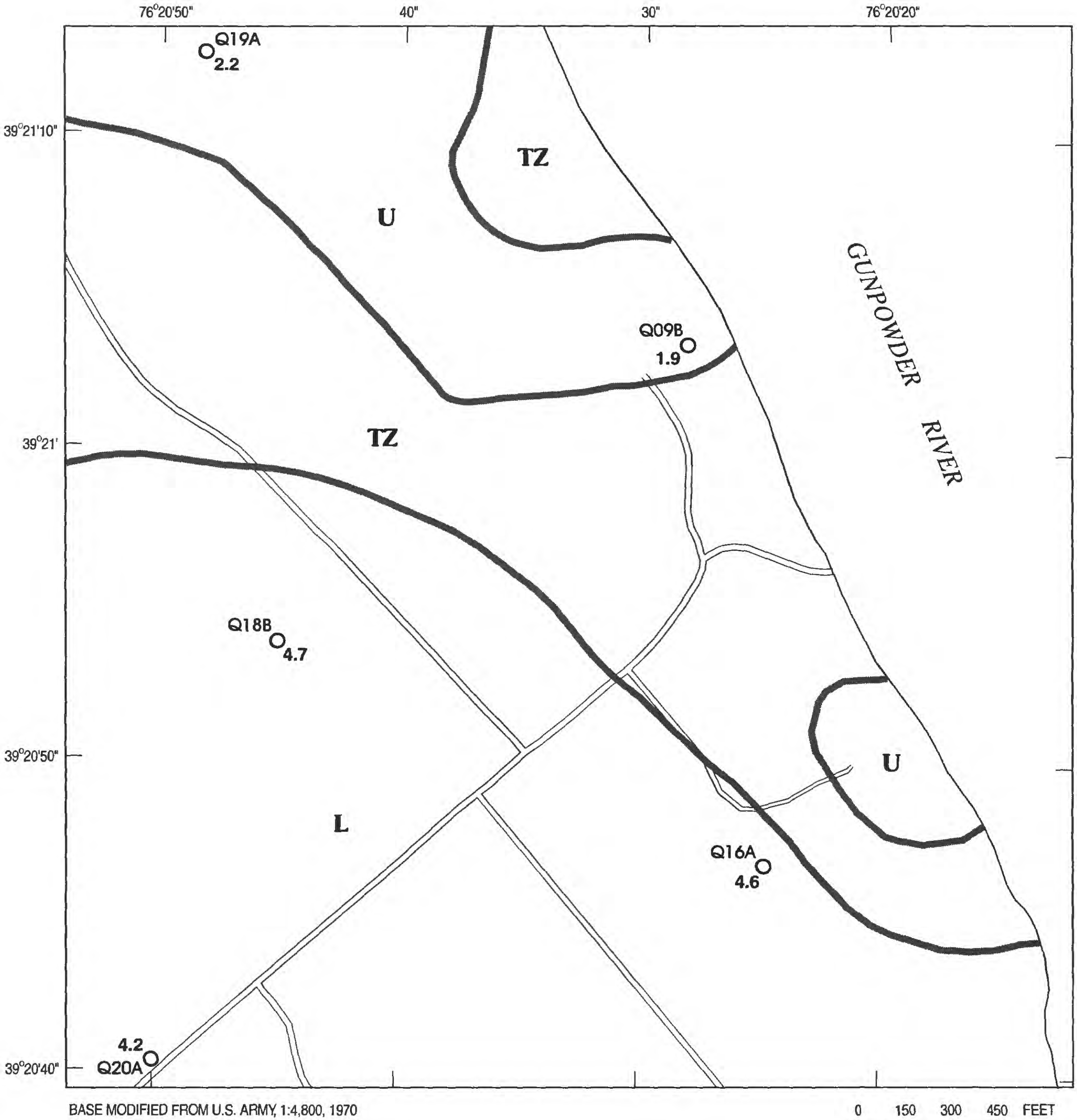
L LOWLANDS

▬ BOUNDARY OF HYDROGEOLOGIC ZONE

Q09B ○ WELL SCREENED IN CONFINED AQUIFER SYSTEM AND WELL NUMBER

-3.0 HYDRAULIC HEAD IN THE CONFINED AQUIFER SYSTEM, IN FEET. DATUM IS SEA LEVEL.

Figure 20. Hydraulic head in the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md., February 1988.



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EXPLANATION

HYDROGEOLOGIC ZONES

U	UPLANDS
TZ	TRANSITION ZONE
L	LOWLANDS
▬	BOUNDARY OF HYDROGEOLOGIC ZONE
Q09B ○	WELL SCREENED IN CONFINED AQUIFER SYSTEM AND WELL NUMBER
1.9	HYDRAULIC HEAD IN THE CONFINED AQUIFER SYSTEM, IN FEET. DATUM IS SEA LEVEL.

Figure 21. Hydraulic head in the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md., May 1988.

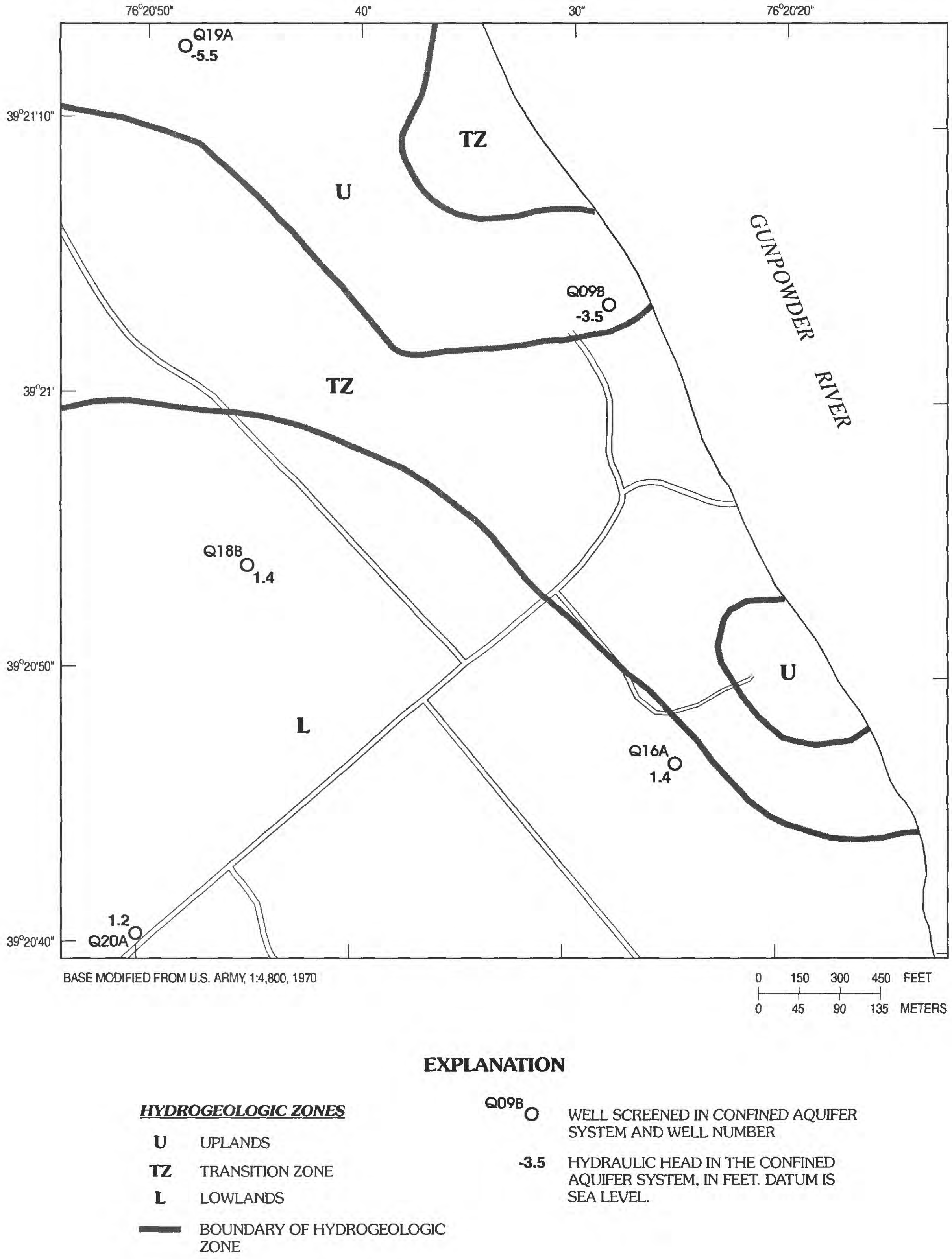

Figure 22. Hydraulic head in the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md., October 1988.

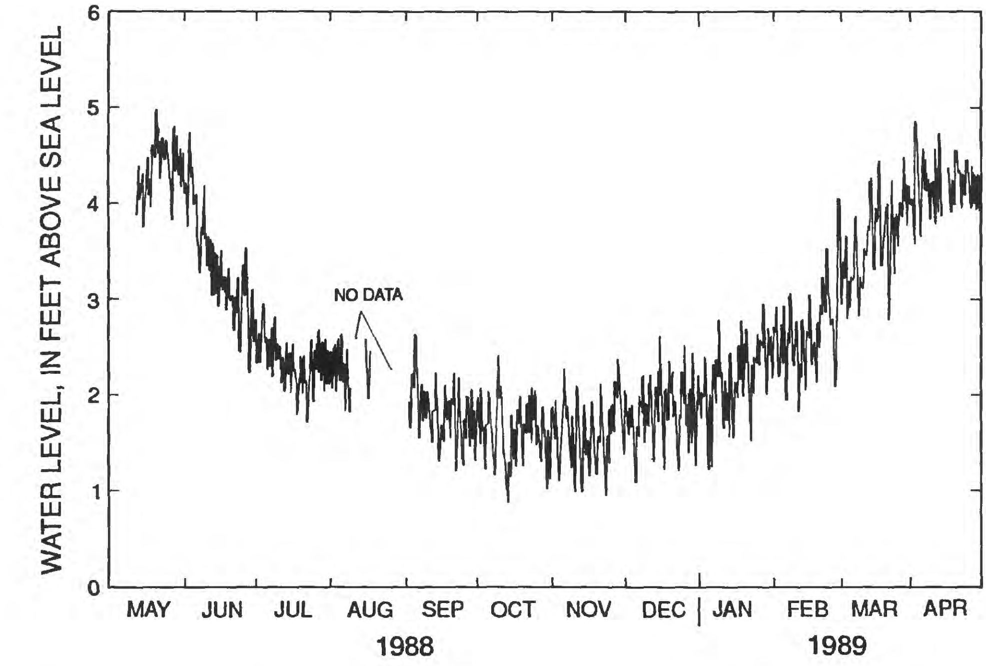

Figure 23. Water levels in lowland well Q16A screened in the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md., May 1988-April 1989. (Modified from Ham and others, 1991, fig. 17.)

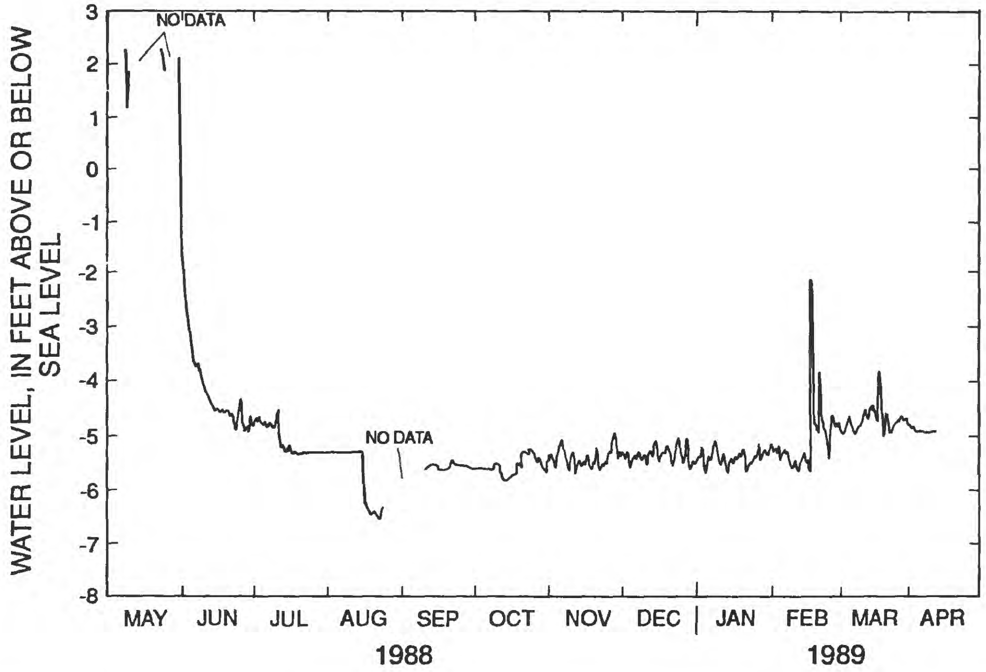

Figure 24. Water levels in upland well Q19A screened in the confined aquifer system, Graces Quarters, Aberdeen Proving Ground, Md., May 1988-April 1989. (Modified from Ham and others, 1991, fig. 21.)

installed in December 1987, and the first water-level measurement was recorded in February 1988. At that time, the water level in the well was 5.3 ft below sea level (fig. 20). In March 1988, the measured water level was 0.8 ft below sea level, which indicates either a decrease in pumpage or an increase in recharge. An ADR was installed on the well in May 1988, at which time the water level in the well was above sea level (fig. 24). In June 1988, the water level in the well declined about 7 ft within a 2-week period (fig. 24). From June 1988 until the ADR was removed in October 1989, none of the recorded water levels was above sea level. The hydraulic head in well Q09B in the upland confined aquifer system exhibited a similar pattern (Ham and others, 1991, fig. 15).

Hydraulic Properties

Slug tests were conducted in summer 1988 at each of the five wells penetrating the confined aquifer system. However, because the two upland wells (Q09B and Q19A) were drilled with the mud-rotary method, it is likely that the mud cake along the borehole wall interfered with the slug tests. Therefore, only results from tests at wells Q16A, Q18B, and Q20A are presented.

Horizontal hydraulic conductivity was calculated with the Cooper and others (1967) method and was determined to be 1 ft/d at well Q16A, 34 ft/d at well Q18B, and 68 ft/d at well Q20A. These hydraulic conductivity values were within a range that could be expected for sand. At well Q16A, no sample of the sand within the screened interval was recovered. However, the hydraulic conductivity at that well is reasonable for a silty or fine sand (Fetter, 1980, p. 75). Only a small amount of sample was recovered from the screened interval at well Q18B; the sample was a poorly sorted, medium-grained sand, subangular to subrounded. The hydraulic conductivity was reasonable for a sand of this type. No sample was recovered at well Q20A, but the hydraulic conductivity at that well was reasonable for well-sorted sand or gravel (Fetter, 1980, p. 75).

WATER QUALITY

This section of the report presents the water-quality data for the Graces Quarters area and evaluates the chemical composition of the ground water and surface water in terms of natural conditions and anthropogenic contamination. Where contamination exists, preliminary inferences regarding the source, movement, and extent of contamination are given. Water samples from 30 wells and 11 surface-water sites were collected on Graces Quarters in spring 1989 and analyzed for physical properties, major ionic constituents, trace elements, nutrients, and volatile and semivolatile organic compounds. One well, Q23, was not sampled because it yielded an insufficient amount of water. Twenty-five of the 30 ground-water samples were collected from wells in the surficial aquifer, and 5 samples were collected from the confined aquifer system. Results of these analyses are shown in table 4 (at the end of the report), and ground-water sampling-site locations are shown in figure 3. Surface-water samples were collected from ponds, ditches, marshes, and estuaries. Surface-water sampling-site locations are shown in figure 4, and the results of the chemical analyses are presented in table 5 (at the end of the report).

Chemical-warfare testing activities from the late 1940's or early 1950's to 1971 were the primary source of environmental contamination on Graces Quarters. These activities included surface releases of highly toxic agents, including BZ, VX, and HD. Other activities that led to environmental contamination included decontamination of test areas by chemical detoxification and burning and burial of test materials including containers, fragments, and test equipment.

The presence and movement of contaminants within the ground-water system depend on a number of factors, including the hydrogeologic framework, the direction and rate of ground-water flow, the amount of contaminant material applied or buried, the chemical stability of the material, the solubility of the material, and the sorptive properties of the material. Because the hydrogeology of Graces Quarters is complex, evaluation of the contaminant movement is difficult. In particular, the geology and ground-water-flow systems in the uplands and the transition zone appear to be more complex than the lowlands. The disposal area and the test-site dump are located in the uplands and are bounded by the transition zone to the west, north, and south, and by a cliff face to the east. The Graces Quarters dump and the secondary test area are located in the transition zone, and the primary test area, HD test annuli, and perimeter dump are located in the lowlands.

As part of the Safe Drinking Water Act of 1986, the USEPA (1989; 1990a; 1990b; 1990c; 1990d; 1990e; 1991a; 1991b; 1991c; 1992) established and updated two sets of regulations that set maximum levels for contaminants in treated drinking water. The primary drinking-water regulations include the Maximum Contaminant Levels (MCL), Maximum Contaminant Level Goals (MCLG), and Proposed Maximum Contaminant Levels. Secondary drinking-water regulations include the Secondary Maximum Contaminant Levels (SMCL) and Proposed Secondary Maximum Contaminant Levels. The MCL's are enforceable health-based standards with which public drinking-water supplies must be in compliance. The MCLG's are nonenforceable health goals set at the level at which no known or anticipated adverse effects to health occur. The SMCL's are nonenforceable levels which, when exceeded, pose no known health risk but may be undesirable for aesthetic reasons. None of the other drinking-water regulations is enforceable; however, all of the regulations can be useful for determining the overall quality of a water resource.

In addition to the drinking-water regulations, there are applicable water-quality criteria that are designed to protect aquatic life in the environment (U.S. Environmental Protection Agency, 1986). These Federal ambient water-quality criteria include freshwater acute (FWA), freshwater chronic (FWC), saltwater acute (SWA), and saltwater chronic (SWC).

This report discusses the presence of inorganic and organic compounds in ground-water and surface-water samples in relation to these water-quality regulations and criteria. Because ground water on Graces Quarters cannot be ruled out as a potential future drinking-water source, the MCL's, SMCL's, and Proposed MCL's are the most appropriate regulations for comparison with ground-water analyses. Results of surface-water analyses are compared to the ambient water-quality criteria, because surface water on and around Graces Quarters is not likely to be used for human consumption. Surface-water samples collected from the Gunpowder River and Dundee Creek are brackish, but results of analyses of these samples are most appropriately compared to the freshwater criteria because water in these estuaries is considered by the State of Maryland to be fresh (Code of Maryland Regulations 26.08.02.03-1B). Surface-water samples collected within the land area of Graces Quarters also are most appropriately compared to the freshwater criteria (FWA and FWC).

Some compounds detected in water samples from Graces Quarters are not covered by water-quality regulations or criteria and, in some cases, natural geochemical processes can produce water that contains concentrations of constituents in excess of an applicable water-quality regulation. Therefore, comparison of background samples from an uncontaminated area in a similar environment to samples from the area in question is desirable. Background samples were not collected for this study, but results of some water-quality analyses from similar environments are available in the published literature and from unpublished sources. Comparisons to these data sources are made in this report whenever possible.

The data presented in this report were reviewed for accuracy and verified for quality by collection of a number of quality-assurance samples as described in Tenbus and Phillips (1991). The types of quality-assurance samples analyzed included duplicate samples, split samples, trip blanks, and equipment (wash) blanks. Duplicate samples were collected sequentially at the site and analyzed for the same suite of constituents at the USATHAMA contract laboratory (Hunter/ESE Inc., Gainesville, Florida). Split samples were collected like duplicates but were analyzed at the USGS National Water-Quality Laboratory in Arvada, Colorado. Slight differences in analytical methods and reporting procedures for the two laboratories caused differences in detection levels and in rounding. Trip blanks were shipped with samples to determine whether samples were contaminated during the shipping and analysis process. Equipment blanks were collected through sample pumps and bailers after decontamination.

Duplicate samples were collected at wells Q16A, Q18A, Q21 (organic compounds only), and at surface-water site SW07. Split samples were collected at wells Q11 and Q21. Concentrations of major dissolved constituents agreed within 10 percent in nearly all cases. Concentrations of minor dissolved constituents showed greater differences, with copper, iron, and lead showing the greatest differences between duplicate and split samples. None of the duplicate or split samples contained measurable concentrations of volatile or semivolatile organic compounds. However, duplicate analyses for total organic halogens showed poor reproducibility in samples from wells Q16A and Q18A and site SW07. The cause of this is unknown.

Several organic compounds were identified in equipment blanks collected during sampling--
5.4 μg/L bis-(2-ethylhexyl)phthalate on April 11, 0.9 μg/L styrene on April 14, and 28.9 μg/L total organic halogens on April 18. Methylene chloride was detected in a trip blank on April 14; however, no samples from Graces Quarters contained detectable levels of this compound.

Physical Properties and Inorganic Constituents

Physical properties and inorganic constituents are used to describe the chemical quality of ground water and surface water. Physical properties including specific conductance, pH, temperature, and alkalinity are used to indicate the geochemical conditions that affect the stability of chemical species. Physical properties are measured onsite because pH and temperature change quickly when samples are removed from the natural environment. Major ions are those constituents that are present naturally, typically in concentrations greater than 1.0 mg/L. However, elevated concentrations of some ions, including chloride and sodium, can result from contamination. Trace elements (minor constituents) can be present naturally in small concentrations (less than 1 mg/L); however, increased concentrations can be derived from contamination sources or can be found in unique chemical environments.

Physical properties and inorganic constituents were summarized with descriptive statistics for the discussions that follow. Because concentrations of some of the constituents were censored (values less than the detection level), the median, maximum, and minimum were used to describe the sample populations. In addition, samples were grouped so comparisons could be made between samples collected from different environments. The groups included samples collected from the confined aquifer system (wells Q09B, Q16A, Q18B, Q19A, and Q20A), samples collected from the surficial aquifer (all remaining wells), samples collected from inland surface-water sites (SW04, SW06, SW07, SW08, SW09, SW10, and SW11), and samples collected from estuarine sites (SW01, SW02, SW03, and SW05). Data sets were compared with the Wilcoxon-Mann-Whitney rank sum test (Iman and Conover, 1983, p. 280-287), a nonparametric test that uses ranked data to test the likelihood that the means of two populations are equal. The level of significance (two-tailed) used in these comparisons was 0.05.

Physical Properties

Specific conductance of water samples is a physical property that is closely related to the concentration of dissolved ions in solution. In general, specific conductance of samples of ground water from Graces Quarters was low. Specific conductance of ground-water samples ranged from 41 to 393 μS/cm, with a median value of 129 μS/cm (table 6). This range is less than the range of specific conductance measured in samples from Potomac Group aquifers in the Canal Creek area of APG (Lorah and Vroblesky, 1989, p. 26-27). Conductance values in the Canal Creek aquifer and the lower confined aquifer in the Canal Creek study area ranged from 48 to 4,280 μS/cm, with a median of 263 μS/cm.

The low specific-conductance values in the ground-water samples at Graces Quarters indicate that the ground water generally is unmineralized, possibly as a result of short ground-water-flow paths and slow weathering of the geochemically stable aquifer material. However, the specific conductance of samples from the confined aquifer system, which has a longer flow path than the surficial aquifer, was lower than that of samples from the surficial aquifer. This result indicates that sources of ionic compounds are present in the surficial aquifer water that do not affect water in the confined aquifer system. The sources may be anthropogenic, such as contamination, or they may be natural, such as brackish-water intrusion or overwash.

Specific conductance of surface-water samples collected from the estuaries was higher than the conductance of the inland surface-water samples. The highest conductance (1,750 μS/cm) was measured at site SW05 in the Dundee Creek estuary southwest of Graces Quarters (fig. 4). Specific conductance of water from site SW05 was much higher than conductance of water from the Gunpowder River sites, which ranged from 302 to 368 μS/cm (table 5a, at the end of the report), possibly because the surface-water samples were collected after a storm. The Gunpowder River drains a much larger watershed than Dundee Creek, and it is likely that the samples from the Gunpowder River were diluted by runoff from the storm, whereas the

Table 6. *Range of selected physical properties of and concentrations of major inorganic constituents in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, concentrations in milligrams per liter; <, less than; MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; MCLG, Maximum Contaminant Level Goal; *, contaminant level exceeded; duplicate and split samples not included]

Property or constituent	Sample type	Number of samples	Range			Contaminant level[1]
			Maximum	Median	Minimum	
Specific conductance	All ground water	30	393	129	41	
	Surficial ground water	25	393	163	58	
	Confined ground water	5	90	57	41	
	All surface water	11	1,750	170	45	
	Inland surface water	7	212	65	45	
	Estuarine surface water	4	1,750	344	302	
pH	All ground water	30	6.85	5.38 *	3.94 *	6.5-8.5 (SMCL)
	Surficial ground water	25	6.85	5.33 *	3.94 *	
	Confined ground water	5	5.80 *	5.62 *	5.13 *	
	All surface water	11	6.91	6.18	4.56	
	Inland surface water	7	6.54	6.02	4.56	
	Estuarine surface water	4	6.91	6.64	6.12	
Dissolved oxygen	All ground water	29	12.4	4.6	.8	
	Surficial ground water	24	12.4	5.0	1.0	
	Confined ground water	5	9.0	1.5	.8	
	All surface water	10	8.5	7.0	2.1	
	Inland surface water	6	8.1	6.2	2.1	
	Estuarine surface water	4	8.5	7.8	7.5	
Alkalinity	All ground water	30	175	8	0	
	Surficial ground water	25	175	8	0	
	Confined ground water	5	26	9	3	
	All surface water	11	65	23	0	
	Inland surface water	7	65	20	0	
	Estuarine surface water	4	33	31	10	
Calcium	All ground water	30	61.0	5.84	1.30	
	Surficial ground water	25	61.0	6.52	1.30	
	Confined ground water	5	6.07	2.36	1.67	
	All surface water	11	29.0	10.6	2.57	
	Inland surface water	7	29.0	8.42	2.57	
	Estuarine surface water	4	12.0	11.4	10.6	
Magnesium	All ground water	30	9.00	2.64	.534	
	Surficial ground water	25	9.00	3.12	.534	
	Confined ground water	5	1.10	.956	.683	
	All surface water	11	35.0	4.66	1.43	
	Inland surface water	7	7.30	2.93	1.43	
	Estuarine surface water	4	35.0	8.89	7.94	

Table 6. *Range of selected physical properties of and concentrations of major inorganic constituents in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Continued*

Property or constituent	Sample type	Number of samples	Range			Contaminant level[1]
			Maximum	Median	Minimum	
Sodium	All ground water	30	61.0	7.37	2.26	
	Surficial ground water	25	61.0	7.88	2.41	
	Confined ground water	5	5.49	3.87	2.26	
	All surface water	11	280	3.03	1.11	
	Inland surface water	7	19.1	2.71	1.11	
	Estuarine surface water	4	280	41.9	32.6	
Potassium	All ground water	30	11.3	1.05	<.375	
	Surficial ground water	25	11.3	1.03	<.375	
	Confined ground water	5	3.34	1.87	.557	
	All surface water	11	13.3	2.45	<.375	
	Inland surface water	7	4.13	1.73	<.375	
	Estuarine surface water	4	13.3	3.86	3.27	
Chloride	All ground water	29	77.0	7.52	<2.12	250 (SMCL)
	Surficial ground water	24	77.0	8.58	<2.12	
	Confined ground water	5	11.7	4.51	<2.12	
	All surface water	11	540	2.93	<2.12	
	Inland surface water	7	55.0	<2.12	<2.12	
	Estuarine surface water	4	540	90.5	71.0	
Nitrite plus Nitrate	All ground water	30	4.30	.142	<.010	10 (MCL, MCLG)
	Surficial ground water	25	4.30	.140	<.010	
	Confined ground water	5	2.00	.140	<.010	
	All surface water	11	1.70	.250	<.010	
	Inland surface water	7	1.70	.013	<.010	
	Estuarine surface water	4	.990	.980	.560	
Sulfate	All ground water	29	81.7	27.5	<10.0	250 (SMCL) 400/500 (Proposed MCL, MCLG)
	Surficial ground water	24	81.7	28.9	10.7	
	Confined ground water	5	11.6	<10.0	<10.0	
	All surface water	11	91.0	14.9	<10.0	
	Inland surface water	7	22.9	11.1	<10.0	
	Estuarine surface water	4	91.0	17.1	14.9	
Silica	All ground water	29	24.7	7.00	1.31	
	Surficial ground water	24	24.7	8.05	1.31	
	Confined ground water	5	6.00	4.45	4.05	

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[1] Contaminant levels established by U.S. Environmental Protection Agency (1989, 1990a through e, 1991a through c, 1992)

Dundee Creek sample was relatively undiluted by stormwater runoff.

The pH and alkalinity (in milligrams per liter as calcium carbonate) of ground-water samples are shown in figure 25. The pH of more than 90 percent of the ground-water samples was less than the SMCL (6.5 to 8.5) established by the USEPA. These low pH values may be natural; the soils found on Graces Quarters generally are acidic (Reybold and Matthews, 1976) and would not be expected to provide much buffering capacity to the water as it infiltrates into the aquifers.

Ground-water samples from wells Q06, Q07, Q08, Q12, Q18A, and Q20B showed the lowest pH values, ranging from 4.93 to 3.94 (fig. 25). Each of these wells was completed in the surficial aquifer, and three of them (wells Q06, Q07, and Q18A) were located in soils described as very strongly acidic to extremely acidic (Reybold and Matthews, 1976). Although the samples that exhibited the lowest pH were from wells completed in the surficial aquifer, no statistical difference in pH was found between samples from the surficial aquifer and the confined aquifer system.

The pH's of ground water at Graces Quarters are similar to values reported for ground-water samples from the Potomac Group aquifers of Harford County, Maryland. The range in pH of 18 samples from the shallow aquifer in the Potomac Group was 4.51 to 7.10, with a median value of 5.32 (Drummond and Blomquist, 1993, p. 101). However, pH values at Graces Quarters are lower than those of water from the Potomac Group aquifers at Canal Creek in the Edgewood Area of APG (Lorah and Vroblesky, 1989, p. 26-27). The pH of 53 samples from the Canal Creek aquifer and the lower confined aquifer at Canal Creek ranged from 4.30 to 9.44, with a median of 5.97.

Surface-water samples were slightly less acidic than ground-water samples. The median pH of all surface-water samples was 6.18 (table 6). The median pH of the inland samples (6.02, table 6) was less than the median pH of estuarine samples (6.64). The lowest surface-water pH (4.56, table 6) was recorded for a sample from site SW11 (fig. 4), a shallow ditch located near well Q07 (fig. 3). The sample from site SW11 was collected after a storm. The sample was collected downstream from the head of the ditch where water welled up from underground. The sample was collected to represent subsurface stormflow originating at or near the disposal area (fig. 2).

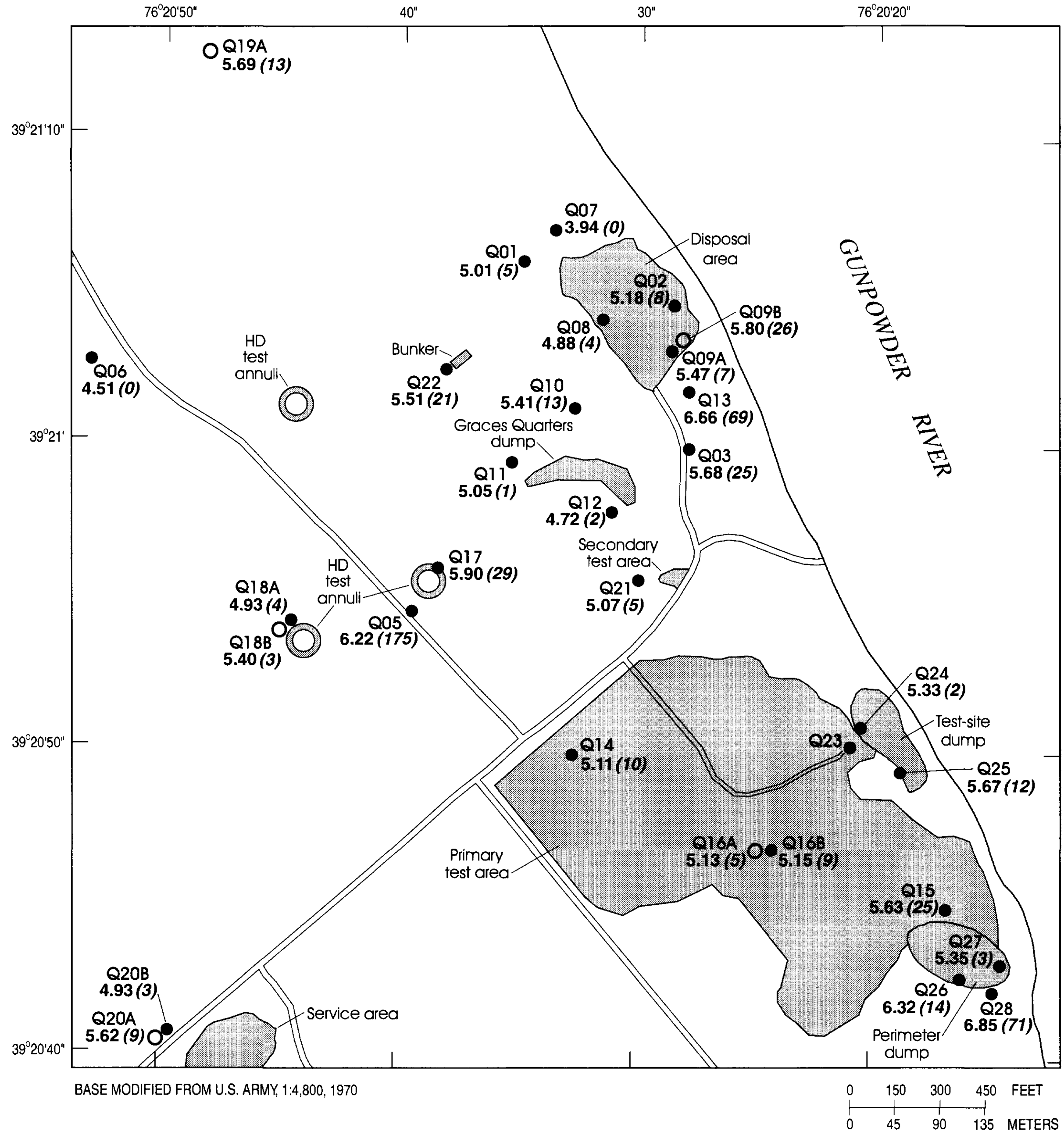
Alkalinity is defined as the capacity of solutes in a solution to react with and neutralize acid (Hem, 1989, p. 106). Alkalinities of ground-water samples ranged from 0 to 175 mg/L, with a median value of 8 mg/L (table 6). There was no statistical difference between the alkalinity of water from the surficial aquifer and that of water from the confined aquifer system. However, alkalinities of water from wells Q05, Q13, and Q28 in the surficial aquifer were noticeably high (fig. 25). Well Q05 is located near an HD test annulus, well Q13 is near the disposal area, and well Q28 is near the perimeter dump. Sodium hydroxide (NaOH) was a commonly used decontaminating agent and may be a source of increased alkalinity as well as increased sodium concentrations in water from these wells.

The median alkalinity of the surface-water samples was 23 mg/L (table 6). Although this value is apparently higher than the median alkalinity of ground-water samples, no statistical difference was shown, probably because the range of alkalinity for the surface-water samples (0 to 65 mg/L) was smaller than that for the ground-water samples. Also, no statistical difference between alkalinity of the inland surface-water samples and that of the estuarine samples could be shown with available data.

Major Ions

Laboratory analyses for major inorganic constituents in ground-water and surface-water samples included those for calcium, magnesium, sodium, potassium, chloride, nitrite plus nitrate, and sulfate. Silica analyses were available only for ground-water samples. Bicarbonate concentrations were calculated from alkalinity titrations that were done onsite. The range of values for these constituents in both ground-water and surface-water samples is shown in table 6 along with applicable water-quality regulations. No ground-water or surface-water samples contained major ions in concentrations exceeding the applicable USEPA regulations.

Data from all samples for each of the major ions except silica and bicarbonate were compared statistically using the Wilcoxon-Mann-Whitney rank sum test. Samples from the surficial aquifer were compared to those from the confined aquifer



EXPLANATION

▨	AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION	Q09B ○	OBSERVATION WELL SCREENED IN CONFINED AQUIFER SYSTEM AND WELL NUMBER
Q14 ●	OBSERVATION WELL SCREENED IN SURFICIAL AQUIFER AND WELL NUMBER	**5.47**	pH VALUE-- In standard units
		(8)	ALKALINITY CONCENTRATION-- In milligrams per liter

Figure 25. Distribution of pH and alkalinity in ground-water samples, Graces Quarters, Aberdeen Proving Ground, Md., April 1989.

system, ground-water samples were compared to surface-water samples, and inland surface-water samples were compared to estuarine samples.

Among the ground-water samples, statistical differences between the surficial aquifer and the confined aquifer system were found in the distributions of calcium, magnesium, sodium, and sulfate. Concentrations of each of these major ions were higher in the surficial-aquifer samples than they were in samples from the confined aquifer system. This result corresponds to the differences in specific conductance between the surficial aquifer and the confined aquifer system that were noted earlier.

Statistical differences in ion-concentration distributions between ground water and surface water were noted for calcium, magnesium, potassium, and sulfate. Concentrations of calcium, magnesium, and potassium were higher in surface water than in ground water, whereas sulfate concentrations were higher in ground water. The reasons for these differences are unknown. There was no significant difference in specific conductance between ground-water and surface-water samples.

Estuarine surface-water samples contained higher concentrations of magnesium, sodium, potassium, and chloride than the inland samples. This result corresponds to the higher specific-conductance values in estuarine samples noted earlier.

The analytical inorganic-constituent data for each sampling site were reviewed for accuracy with the ion-balance method described by Hem (1989, p. 164). In this method, the total concentration of anions (in milliequivalents per liter) is compared to the total concentration of cations. In natural water, the sum of cations and anions should be equal. Because these samples are dilute and because of analytical limitations, analyses were determined to be of suitable quality if the concentrations of anions and cations agreed to within 10 percent. Samples from three wells (Q01, Q06, and Q07) had balance errors greater than 10 percent. Samples from four wells (Q16A, Q18B, Q19A, and Q20A) were so dilute that the ion balances were affected by the detection level of the sulfate ion. The sulfate concentration in the water samples from these wells was less than the analytical reporting level of 10 mg/L (milligrams per liter). It is believed that the inorganic analyses for these samples were valid because the cation and anion concentrations were equal in each case if the sulfate concentration was between 0 and 10 mg/L. Well Q03 was not evaluated because the sample volume was limited, and all of the anions were not determined.

The distribution of major ions in ground-water samples from the surficial aquifer is shown by Stiff diagrams (fig. 26). These diagrams show ion concentrations in milliequivalents per liter. Cation concentrations (sodium, potassium, calcium, and magnesium) are plotted to the left of the zero vertical axis, and anion concentrations (chloride, nitrate, bicarbonate, and sulfate) are plotted to the right of the zero vertical axis. In this figure, sodium and potassium are plotted together, as are chloride and nitrate. The shapes of these diagrams show the dominant ions in the water sample. Comparison of these diagrams reveals the spatial trends and variability in major-ion composition.

The variability of chemical composition of the water samples from the surficial aquifer is illustrated in figure 26, and local patterns exist. In general, many of the samples contained low concentrations of major ions. However, total ion concentrations were higher in ground-water samples collected near the disposal area (wells Q01, Q07, Q08, and Q13) and the perimeter dump site (wells Q27 and Q28). Also, the sample from well Q05 contained much higher concentrations of calcium and bicarbonate than samples from other wells. Elevated total ion concentrations can result from anthropogenic sources or from dissolution of aquifer material.

The patterns of major-ion concentrations in seven ground-water samples from near the disposal area reflect the complexity of the surficial aquifer in the uplands and the transition zone. Stiff diagrams for samples from wells Q01, Q07, and Q08 are similar to each other, with greater proportions of sodium, chloride, and sulfate than for samples from other nearby wells. These samples also were more mineralized than samples from other disposal-area wells, which may have resulted from ground-water contamination or from more chemical weathering due to longer ground-water-flow paths. Samples from wells Q02 and Q09A contained lower ion concentrations than the other samples from this area, with sulfate as the dominant anion. Water levels in wells Q02 and Q09A varied considerably between wet and dry seasons (figs. 15 and 16). This variation and the low ion concentrations in the samples indicate that these wells are recharged locally and

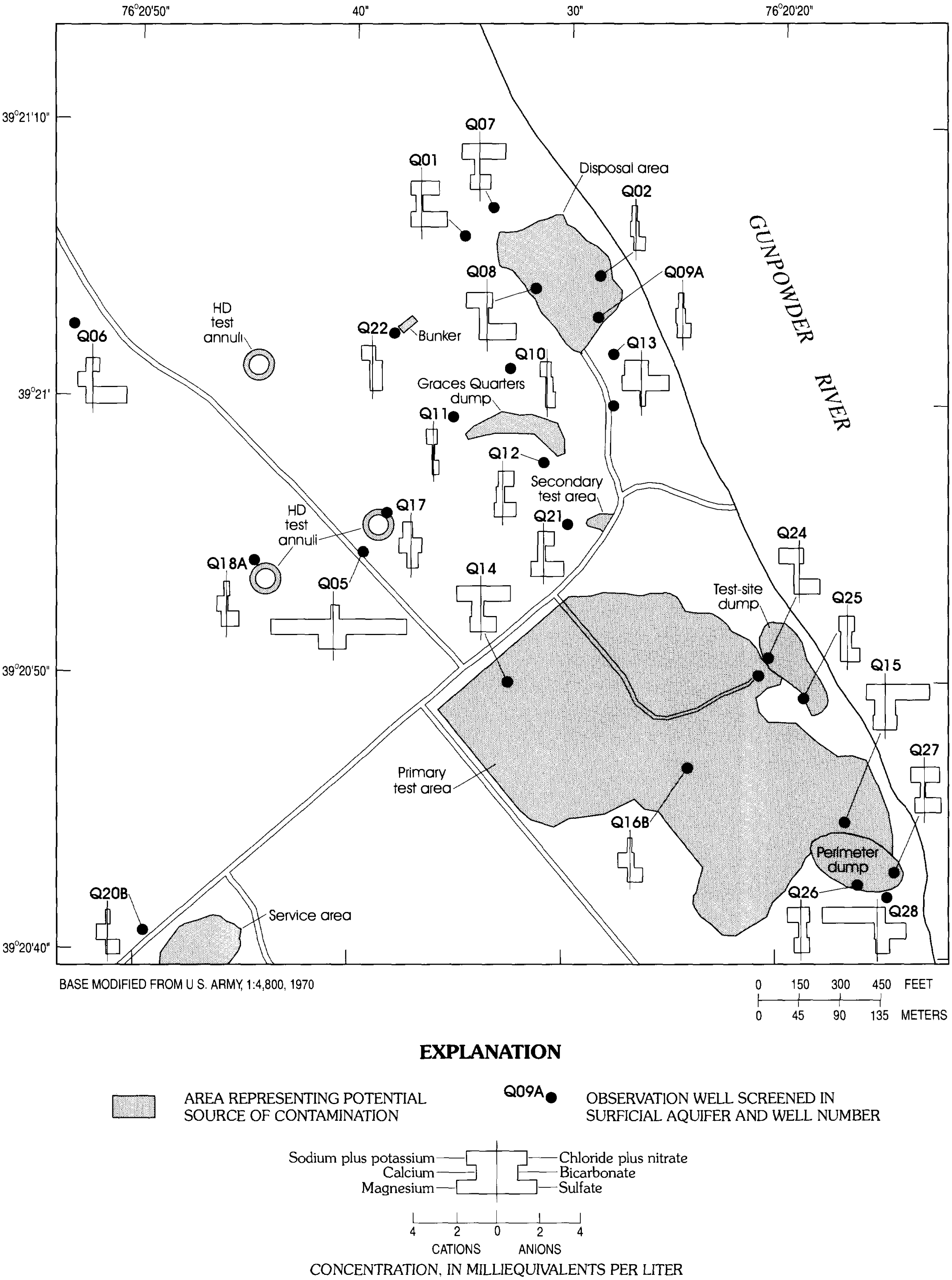


Figure 26. Stiff diagrams for water-quality samples from selected wells in the surficial aquifer at Graces Quarters, Aberdeen Proving Ground, Md., April 1989.

that the ground-water-flow paths are fairly short. Water-level contours also indicate that well Q13 is downgradient from well Q09A. Well Q13, however, is screened in the transition zone, and the underlying confining layer is not well defined. The sample from well Q13 contained much larger concentrations of sodium, potassium, and bicarbonate than samples from the upland wells. This difference, which may be due to brackish-water intrusion or aquifer mineralogy, may indicate that well Q13 is screened in a part of the surficial aquifer that is hydraulically discontinuous from the part in which the other wells in the disposal area are screened.

Differences in ion concentrations also were seen in ground-water samples from wells Q26, Q27, and Q28 in the lowlands near the perimeter dump. Ion concentrations in water from well Q27 differed considerably from those in water from downgradient wells Q26 and Q28. Water from the downgradient wells contained large concentrations of sodium and bicarbonate (fig. 26). Differences in major-ion chemistry indicate that these wells are located along different flow paths or that chemical changes occur as a result of ground-water contamination or changes in geochemical conditions. The high sodium and bicarbonate concentrations in water from wells Q26 and Q28 may have been caused by the use and burial of the decontaminating agent sodium hydroxide at the perimeter dump.

Major-ion distributions in the confined aquifer system can be seen in figure 27. Stiff diagrams for the five samples from the confined aquifer system illustrate low ion concentrations for this ground water; therefore, identification of specific water types for several of the samples is difficult. The sample from well Q09B appears to be a dilute calcium bicarbonate-type water. The Stiff diagrams for the samples from wells Q16A and Q18B are virtually identical and seem to indicate a sodium chloride-type water. Stiff diagrams for the samples from wells Q19A and Q20A do not exhibit obvious water types.

Stiff diagrams for the surface-water samples are shown in figure 28. This figure illustrates the differences between samples from brackish water in the estuaries and samples from freshwater at inland sites. Samples from sites SW01, SW02, and SW03 were from the Gunpowder River and contained similar ion concentrations (fig. 28). These samples were dominated by sodium and chloride, as expected. The sample from site SW05 from Dundee Creek contained higher ion concentrations than the other brackish-water samples and also was a sodium chloride-type water. The inland samples were more dilute than those from the estuaries. Samples SW06, SW07, SW09, and SW10 were dominated by calcium and bicarbonate. The sample from site SW08 was a sodium chloride water, and water from site SW11 seemed to be dominated by the sulfate anion, with calcium or magnesium as the predominant cation. The sample from site SW04 in the bunker was too dilute to classify.

Minor Constituents

Minor constituents measured in ground-water and surface-water samples include those inorganic compounds that typically are found in only trace concentrations except where contamination or unique geochemical conditions exist. The presence of minor constituents in water samples from Graces Quarters is summarized in table 7. The ground-water samples were filtered onsite through a 0.45-micrometer filter prior to analysis, so any metals detected would be present in the dissolved phase and not complexed with any organic matter or in a larger colloidal suspension. The surface-water samples, however, were unfiltered because the applicable water-quality criteria call for unfiltered samples. Thus, trace-element concentrations in surface-water samples represent the combination of dissolved metals, complexes of metals with dissolved and suspended organic carbon, and possibly metals that were adsorbed to suspended sediment.

Ground-water samples were analyzed for 17 trace elements. Antimony, beryllium, cadmium, selenium, and mercury either were not present in the ground-water samples, or were present in concentrations that were less than the analytical method reporting level. Barium and manganese were the only minor constituents detected in all ground-water samples; iron was present in most of the samples. Analysis results for arsenic were received for only eight of the ground-water samples; arsenic was not detected in any of these samples.

Results of laboratory analyses of surface-water samples were available for 13 of the 17 trace elements analyzed in ground-water samples. Missing trace-element analyses included those for arsenic, lead, mercury, and selenium. Beryllium, silver, and thallium were not detected in any of the surface-water samples.

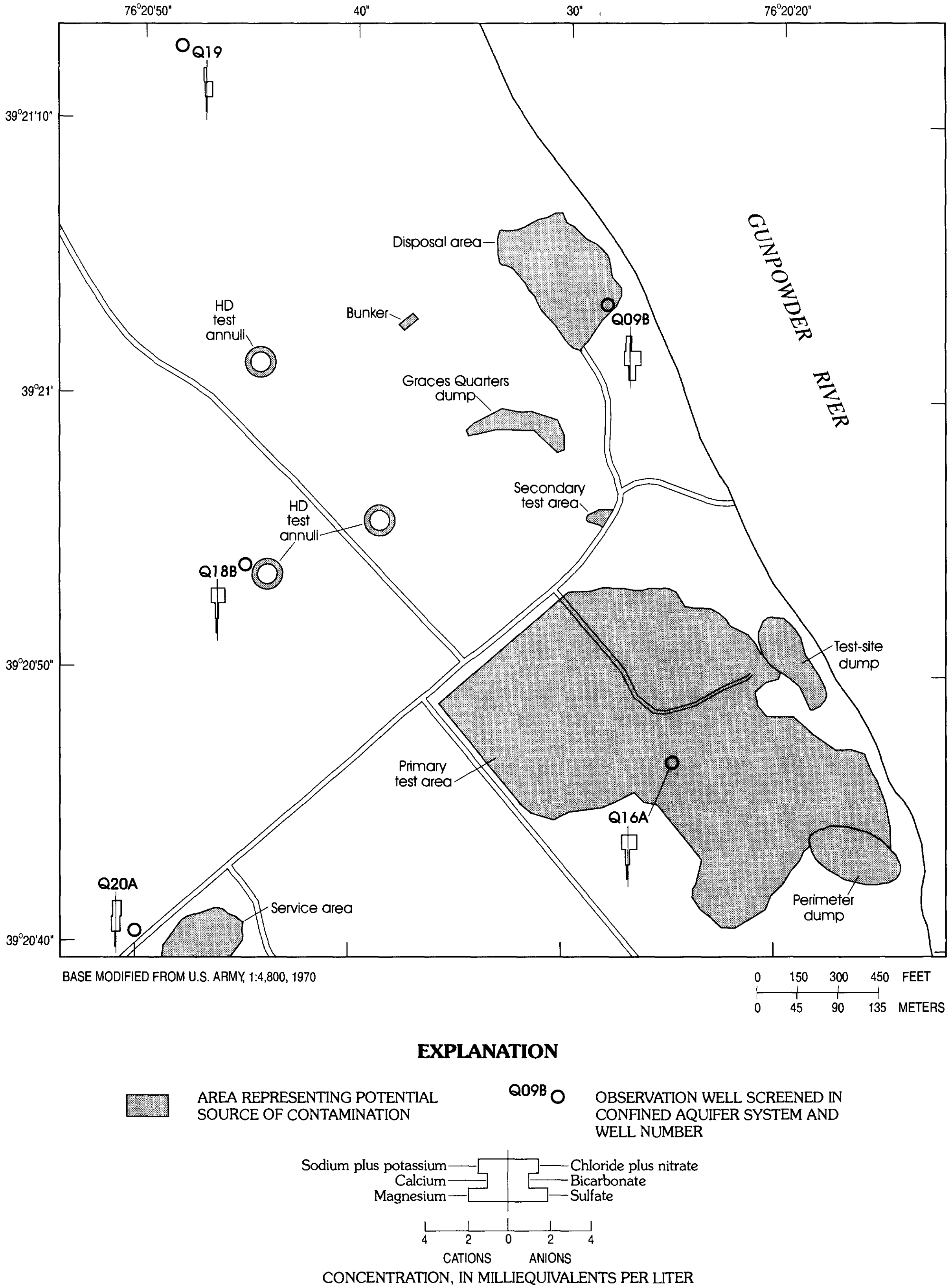


Figure 27. Stiff diagrams for water-quality samples from selected wells in the confined aquifer system at Graces Quarters, Aberdeen Proving Ground, Md., April 1989.

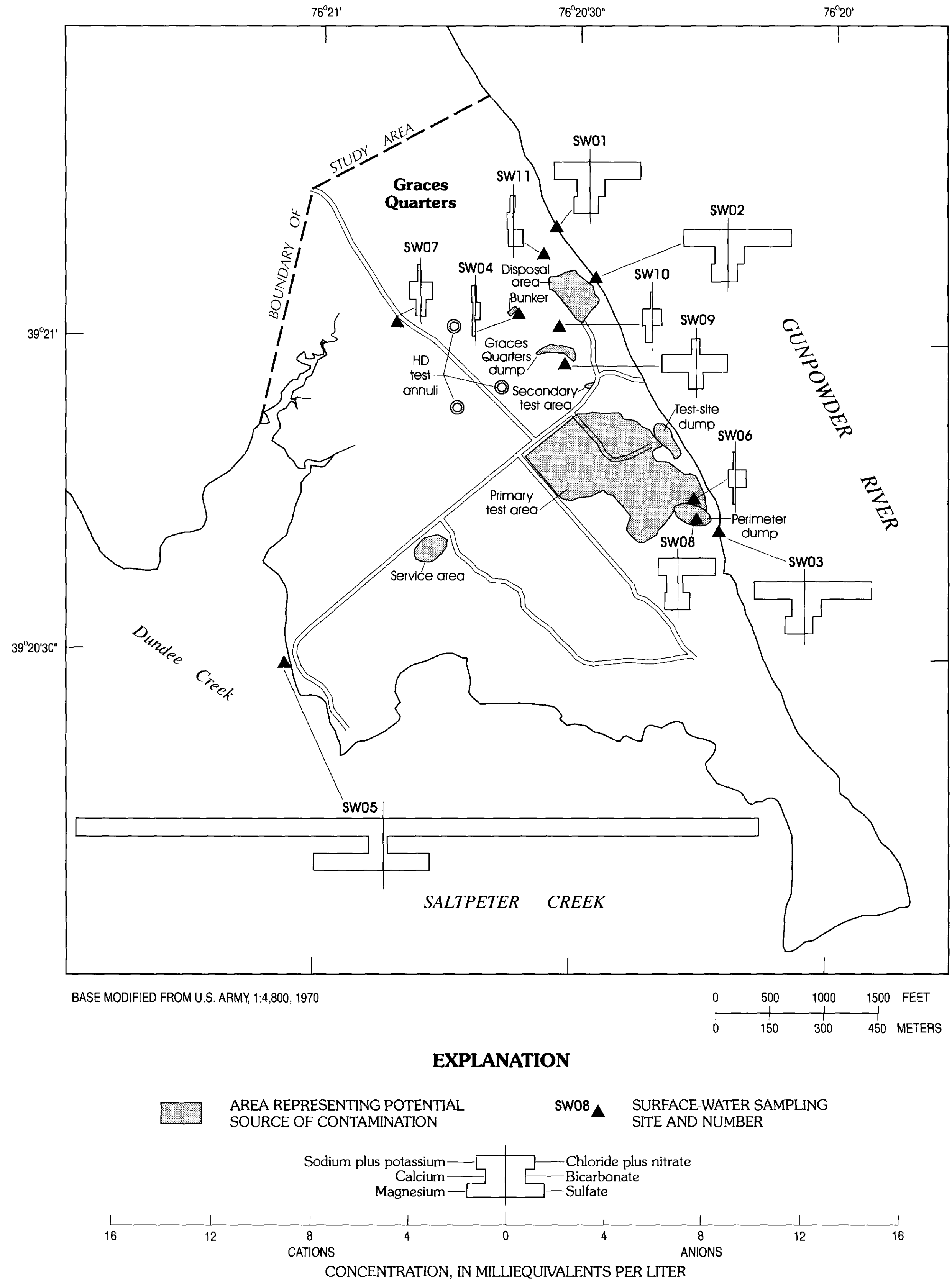


Figure 28. Stiff diagrams for water-quality samples from surface-water sampling sites, Graces Quarters, Aberdeen Proving Ground, Md., May 1989.

Table 7. *Range of concentrations of selected minor inorganic constituents in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989*

[Concentrations in micrograms per liter, <, less than; FWA, freshwater acute, FWC, freshwater chronic, MCL, Maximum Contaminant Level, MCLG, Maximum Contaminant Level Goal, SMCL, Secondary Maximum Contaminant Level; *, contaminant level exceeded; duplicate and split samples not included]

Constituent	Sample type	Number of samples	Concentration range Maximum	Median	Minimum	Contaminant level[1]
Aluminum	All ground water	30	2,110 *	<141 *	<141 *	50 to 200 (SMCL)
	Surficial ground water	25	2,110 *	<141 *	<141 *	
	Confined ground water	5	<141 *	<141 *	<141 *	
	All surface water	11	13,100 *	667 *	<141 *	750 (FWA), 87 (FWC)
	Inland surface water	7	13,100 *	657 *	<141 *	
	Estuarine surface water	4	2,020 *	783 *	667 *	
Barium	All ground water	30	82.8	20.7	8.9	2,000 (MCL, MCLG)
	Surficial ground water	25	82.8	29.4	10.8	
	Confined ground water	5	12.1	11.1	8.9	
	All surface water	11	72.2	18.2	13.5	
	Inland surface water	7	72.2	43.0	14.1	
	Estuarine surface water	4	40.8	16.9	13.5	
Cadmium	All ground water	30	<4.01	<4.01	<4.01	5 (MCL, MCLG)
	All surface water	11	12.2 *	<4.01 *	<4.01 *	3.9 (FWA), 1.1 (FWC)
	Inland surface water	7	<4.01 *	<4.01 *	<4.01 *	
	Estuarine surface water	4	12.2 *	<4.01 *	<4.01 *	
Chromium	All ground water	30	29.7	<6.02	<6.02	100 (MCL, MCLG)
	Surficial ground water	25	29.7	<6.02	<6.02	
	Confined ground water	5	<6.02	<6.02	<6.02	
	All surface water	11	16.5 *	<6.02	<6.02	16 (FWA), 11 (FWC)
	Inland surface water	7	16.1 *	<6.02	<6.02	
	Estuarine surface water	4	16.5 *	7.80	<6.02	
Copper	All ground water	30	60.7	16.0	<8.09	1,300 (Proposed MCL, MCLG)
	Surficial ground water	25	60.7	16.0	<8.09	1,000 (SMCL)
	Confined ground water	5	34.9	9.48	<8.09	
	All surface water	11	31.2 *	12.2 *	<8.09	18 (FWA), 12 (FWC)
	Inland surface water	7	30.9 *	11.2	<8.09	
	Estuarine surface water	4	31.2 *	13.8 *	<8.09	
Iron	All ground water	30	21,900 *	163	<42.7	300 (SMCL)
	Surficial ground water	25	21,900 *	154	<42.7	
	Confined ground water	5	5,710 *	650 *	<42.7	
	All surface water	11	13,300	1,270	254	
	Inland surface water	7	13,300	1,440	254	
	Estuarine surface water	4	4,020	1,007	642	

Table 7. *Range of concentrations of selected minor inorganic constituents in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Continued*

Constituent	Sample type	Number of samples	Concentration range			Contaminant level[1]
			Maximum	Median	Minimum	
Lead	All ground water	30	57.7 *	<1.26	<1.26	15 (MCL), 0 (MCLG)
	Surficial ground water	25	57.7 *	<1.26	<1.26	
	Confined ground water	5	11.2	<1.26	<1.26	
Manganese	All ground water	30	861 *	112.5 *	5.59	50 (SMCL)
	Surficial ground water	25	861 *	122 *	5.59	
	Confined ground water	5	276 *	73.9 *	29.6	
	All surface water	11	2,400	131	24.6	
	Inland surface water	7	2,400	166	54.7	
	Estuarine surface water	4	211	50.2	24.6	
Nickel	All ground water	30	272 *	<34.3	<34.3	100 (Proposed MCL, MCLG)
	Surficial ground water	25	272 *	<34.3	<34.3	
	Confined ground water	5	<34.3	<34.3	<34.3	
	All surface water	11	53.1	<34.3	<34.3	1,800 (FWA), 96 (FWC)
	Inland surface water	7	<34.3	<34.3	<34.3	
	Estuarine surface water	4	53.1	<34.3	<34.3	
Silver	All ground water	30	4.99	<4.60	<4.60	50 (MCL), 100 (SMCL)
	Surficial ground water	25	<4.60	<4.60	<4.60	
	Confined ground water	5	4.99	<4.60	<4.60	
	All surface water	11	<4.60 *	<4.60 *	<4.60 *	4.1 (FWA), 0.12 (FWC)
Thallium	All ground water	30	111 *	<81.4 *	<81.4 *	0.5 (MCLG),
	Surficial ground water	25	111 *	<81.4 *	<81.4 *	2.0/1.0 (Proposed MCL)
	Confined ground water	5	<81.4 *	<81.4 *	<81.4 *	
	All surface water	11	<81.4 *	<81.4 *	<81.4 *	1,400 (FWA), 40 (FWC)
Zinc	All ground water	30	344	31.6	<21.1	5,000 (SMCL)
	Surficial ground water	25	344	25.5	<21.1	
	Confined ground water	5	69.2	40.8	<21.1	
	All surface water	11	75.3 *	34.4	<21.1	320 (FWA), 47 (FWC)
	Inland surface water	7	75.3 *	40.0	<21.1	
	Estuarine surface water	4	65.6	26.4	<21.1	

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[1] Contaminant levels established by U.S. Environmental Protection Agency (1986, 1989, 1990a through e, 1991a through c, 1992)

The distributions of minor constituents in ground water and surface water were compared statistically. Where data were available, concentration distributions for each constituent were compared between the surficial aquifer and confined aquifer system, between ground water and surface water, and between inland surface water and estuarine water.

Few statistically significant differences between concentration distributions of minor constituents were found. Barium concentrations were significantly higher in water from the surficial aquifer than in water from the confined aquifer system, but there were no other differences in the concentration distributions in ground-water samples. Iron concentrations in ground water were higher than those in surface water, but aluminum concentrations in surface water were higher than those in ground water. There were no significant differences in minor-ion distributions between inland surface water and estuarine water.

Water-quality regulations and criteria for minor constituents were exceeded in several water samples. The concentrations of some of the minor constituents probably reflect natural hydrochemical conditions rather than ground-water contamination. The presence of minor constituents in each of the sampled environments is discussed in the following paragraphs.

Aluminum was detected in 10 ground-water samples in concentrations greater than the reporting level of 141 µg/L (table 4b, at the end of the report). All of the aluminum detections were in water from the surficial aquifer (table 7). The SMCL for aluminum ranges from 50 to 200 µg/L, depending on the pH of the water. The analytical reporting level for the water samples was greater than the lower limit of the SMCL (50 µg/L); 9 of the 10 detections in ground water were greater than 200 µg/L. The maximum concentration in ground water (2,110 µg/L) was in water from well Q06.

Aluminum is abundant in feldspars and aluminosilicate minerals, which may have been present in the aquifer material. The solubility of aluminum is largely pH-dependent. Acidified water characteristically contains elevated concentrations of dissolved aluminum (Drever, 1988, p. 210). The pH of most ground-water samples from Graces Quarters with detectable aluminum concentrations was less than 5.5. Also, aluminum has a great affinity to complex with natural organic acids. Water from well Q06 contained a total organic carbon concentration of 3.68 mg/L (table 4c, at the end of the report). Aluminum-organic complexes may have passed through the filter and been measured as dissolved aluminum.

In surface water, aluminum was present at concentrations greater than the reporting level of 141 µg/L for water from 10 of the 11 sampling sites (table 5b, at the end of the report). Because surface-water samples were unfiltered, the higher concentrations of aluminum were most likely the result of measurement of organic complexes. The pH of only one water sample, that from site SW11 (aluminum concentration 727 µg/L), was low enough (pH 4.56) to affect aluminum solubility.

The most appropriate water-quality criteria for aluminum in surface water at Graces Quarters are the freshwater acute (FWA) and freshwater chronic (FWC) criteria of 750 µg/L and 87 µg/L, respectively (table 7). Of the seven inland surface-water samples, one sample (site SW10, aluminum concentration 13,100 µg/L) exceeded the FWA criterion. Water from three of the four estuarine sites exceeded the FWA criterion for aluminum. Water from site SW02 contained an aluminum concentration of 2,020 µg/L; SW03 contained 815 µg/L; and SW05 contained 751 µg/L (table 5b, at the end of the report). Because the reporting level for aluminum was greater than the FWC criterion, water from all of the surface-water sites potentially exceeded the criterion.

Barium was present in ground-water and surface-water samples at concentrations ranging from 8.9 to 82.8 µg/L (table 7). This is much less than the MCL of 2,000 µg/L. The barium concentrations in the samples probably can be attributed to natural geochemical processes.

Cadmium was not detected in any ground-water samples at a reporting level of 4.01 µg/L. This reporting level is less than the MCL and MCLG of 5 µg/L (table 7). In surface-water samples, cadmium was detected in water from site SW01 (12.2 µg/L) and site SW03 (4.02 µg/L). Both of these are estuarine sites. The source of cadmium in these samples is unknown. The freshwater criteria (FWA = 3.9 µg/L; FWC = 1.1 µg/L) for cadmium were less than the 4.01 µg/L reporting level.

Chromium was detected in concentrations greater than the reporting level of 6.02 μg/L in ground-water samples from wells Q14 (7.98 μg/L) and Q18A (29.7 and 32.0 μg/L). None of the samples exceeded the 100-μg/L MCL and MCLG. Chromium is a contaminant typically found leaching from deposits of industrial metals. Concentrations of chromium in natural water that has not been affected by waste disposal commonly are less than 10 μg/L (Hem, 1989, p. 138). On Graces Quarters, sources of chromium may include buried shell fragments, agent containers, and equipment. No known burial of any of these sources took place in the areas where chromium was detected in ground water.

Chromium was detected in concentrations greater than the reporting level of 6.02 μg/L in four surface-water samples. Samples from sites SW01 (16.5 μg/L) and SW02 (9.57 μg/L) were collected from the Gunpowder River estuary; samples from sites SW08 (7.75 μg/L) and SW10 (16.1 μg/L) were collected at inland sites. In the estuarine samples, chromium concentrations exceeded the FWA (16 μg/L) and FWC (11 μg/L) criteria in water from site SW01. The chromium concentration in the inland sample from site SW10 exceeded the FWA and FWC criteria. Three of the sites where chromium was detected in surface water (SW01, SW02, and SW10) are located near the disposal area (fig. 2), in which some of the sources of chromium mentioned above are likely to have been buried.

Copper was detected above the reporting level of 8.09 μg/L in water from 25 of the 30 wells that were sampled. The maximum copper concentration in a ground-water sample was 60.7 μg/L, which is much lower than the SMCL of 1,000 μg/L and the Proposed MCL and MCLG of 1,300 μg/L (table 7).

Concentrations of copper in surface-water samples were similar to those in ground-water samples. However, the ambient water-quality criteria for copper in surface water are much more stringent than the regulations for copper in drinking water. Of the inland sites, copper concentrations in the sample from site SW10 (30.9 μg/L) exceeded the FWA criterion of 18 μg/L; copper concentrations in water from sites SW07 (16.2 μg/L), SW10 (30.9 μg/L), and SW11 (12.2 μg/L) exceeded the FWC criterion of 12 μg/L. The copper concentration in the duplicate sample at site SW07 (10.9 μg/L) did not exceed the FWC criterion. Both freshwater criteria were exceeded in water from one estuarine sampling site in the Gunpowder River (SW01, copper concentration 31.2 μg/L). The FWC for copper was exceeded at the other two Gunpowder River sites (SW02, 15.5 μg/L, and SW03, 12.2 μg/L) but was not exceeded in water from site SW05 in Dundee Creek, where copper was not detected. The source of copper in these surface-water samples is unknown.

Iron concentrations in ground-water samples ranged from less than 42.7 to 21,900 μg/L (table 7). Samples from 14 of the 30 wells on Graces Quarters exceeded the SMCL of 300 μg/L for dissolved iron. The iron is believed to be present naturally. Drummond and Blomquist, (1993, p. 106) report that 35 percent of Coastal Plain ground-water samples from Harford County exceeded the SMCL for iron.

Many natural sources and forms of iron are found in the Potomac Group aquifers, including ferric hydroxide, goethite, hematite, iron silicates, and pyrite (Chapelle, 1985, p. 83). The form of dissolved iron or its precipitates is largely controlled by oxidation-reduction (redox) processes and pH. Chapelle (1985) also describes the response of iron to the chemical microenvironment of the Patapsco aquifer. He presents a stoichiometric model that demonstrates the precipitation of ferric hydroxide at the interface of strongly oxidizing and strongly reducing conditions. Such precipitation has been noted at the outcrop of the Patapsco and other Coastal Plain aquifers. Similar cementation is visible along the eroding cliff face located east of the disposal area on Graces Quarters. The wide range of iron concentrations in the ground water and the presence of iron cementation at the outcrop indicate that a variety of redox conditions exist within the aquifer.

The range of iron concentrations in surface-water samples was 254 to 13,300 μg/L (table 7). These relatively high values probably result from the fact that the samples were not filtered before analysis (samples were not filtered because surface-water-quality criteria are for unfiltered water). The iron most likely was complexed with organic material in the water. Because this material was not filtered out when the sample was collected, all of the complexed iron was reported as dissolved.

Lead was detected in concentrations greater than 1.26 μg/L in samples from 12 of the 30 wells (table 4b, at the end of the report). Water in the duplicate samples from one well (Q18A, 57.7 and

96.6 μg/L) exceeded the MCL action level of 15 μg/L. However, the MCLG for lead in drinking water is zero (table 7).

The sources of lead in the ground-water samples are unknown. The samples that exceeded the MCL (duplicate samples from well Q18A) had low pH and alkalinity, which can increase the solubility of lead in water (Hem, 1989, p. 144). It is possible that practices during the chemical testing period increased the lead concentrations in ground water at Graces Quarters. However, it is also possible that concentrations of lead in these samples is not significantly different from background concentrations of lead in water. Hem (1989, p. 144) indicates that concentrations of lead in rain and snow can exceed 100 μg/L in areas subject to substantial air pollution.

Manganese was detected in samples from all wells on Graces Quarters (table 4b, at the end of the report). Concentrations of dissolved manganese exceeded the SMCL of 50 μg/L in 20 of the 30 wells, including 3 of the wells screened in the confined aquifer system (well Q09B, 276 μg/L; well Q16A, 73.9 and 72.6 μg/L; and well Q19A, 192 μg/L). Drummond and Blomquist (1993, p. 106) report that manganese concentrations exceeded the SMCL in 52 percent of the Coastal Plain wells in Harford County. Manganese response is similar to iron response in the ground-water system in that the speciation of the oxides of manganese is sensitive to pH and oxidation-reduction conditions. Manganese concentrations in surface water at Graces Quarters ranged from 24.6 to 2,400 μg/L, with the higher values generally in the inland samples. Sources of manganese include the dissolution of manganese-bearing minerals in the aquifer matrix and riverbed sediment (Drummond and Blomquist, 1993, p. 106).

Nickel was detected in concentrations above the reporting level of 34.3 μg/L in samples from wells Q06 (272 μg/L), Q07 (103 μg/L), and Q11 (77.6 and 80 μg/L). These wells are screened in the surficial aquifer and are located throughout the study area along different flow paths. The Proposed MCL and MCLG for nickel is 100 μg/L (table 7). Nickel commonly is associated with iron and manganese oxides (Hem, 1989, p. 159) but also commonly is used in stainless steel and in numerous alloys. Nickel in water samples from wells Q07 and Q11, both of which had low pH's, may be derived from buried containers and shell fragments in the disposal area and Graces Quarters dump. No known buried sources of nickel exist near well Q06.

Nickel was detected in only one surface-water sample (site SW01, 53.1 μg/L) in a concentration greater than the reporting level of 34.3 μg/L. This sample was from a site on the Gunpowder River. Neither of the freshwater criteria for nickel (table 7) was exceeded in surface-water samples.

Silver was detected at concentrations just above the reporting level of 4.60 μg/L in wells Q16A (4.68 μg/L) and Q20A (4.99 μg/L) in the confined aquifer system. Silver was not detected in the duplicate sample from well Q16A or any sample from the surficial aquifer. The MCL for silver is 50 μg/L; the SMCL is 100 μg/L (table 7).

In surface water, silver was not detected above the reporting level of 4.60 μg/L. However, the applicable water-quality criteria are less than the reporting level for silver in surface water (table 7). Therefore, meaningful comparisons of silver concentrations in surface water to the water-quality criteria are impossible.

Thallium was detected in water from well Q15, at the southern end of the primary test area, at a concentration of 111 μg/L. This concentration is only slightly greater than the reporting level of 81.4 μg/L. Thallium was not detected in the confined aquifer system. The drinking-water regulations for thallium (0.5 μg/L MCLG; 2.0/1.0 μg/L Proposed MCL) are much lower than the analytical reporting level in the ground-water samples.

Thallium was not detected in surface water in concentrations greater than the reporting level of 81.4 μg/L. The reporting level for thallium was greater than the FWC criterion of 40 μg/L (table 7).

Thallium is relatively insoluble in water and is very toxic. The use of thallium in chemical agents is not documented; however, thallium has been used in rodenticides, fungicides, and insecticides, and as catalyzing agents for organic reactions (Lucius and others, 1989, p. 434). Because many warfare agents resemble pesticides, any number of these products could be the source of thallium in this area.

Zinc was detected in water from 20 wells with a maximum concentration of 344 µg/L, which is far less than the SMCL of 5,000 µg/L. Samples from four of the five wells screened in the confined aquifer system contained detectable concentrations of zinc. The reporting level for zinc in ground-water samples was 21.1 µg/L.

Zinc concentrations in surface-water samples ranged from less than the 21.1 µg/L reporting level to 75.3 µg/L. The FWA criterion of 320 µg/L was not exceeded in any of the surface-water samples; however, the FWC criterion (47 µg/L) was exceeded in samples from estuarine site SW01 in the Gunpowder River (65.6 µg/L) and in samples from inland sites SW07 (55.4 and 64.5 µg/L), SW10 (48.6 µg/L), and SW11 (75.3 µg/L).

Organic Constituents

Fifteen organic compounds were identified in ground-water and surface-water samples from Graces Quarters (table 8). Three classes of volatile organic hydrocarbons (chlorinated alkanes, chlorinated alkenes, and aromatics) were present. Also, four semivolatile organic compounds were identified, and several unknown organic compounds were detected. Tables 4c and 4d at the end of the report list the results of all volatile and semivolatile organic chemical analyses of ground-water samples. Tables 5c and 5d at the end of the report list the results for surface-water samples. Tables 4e and 5e at the end of the report list the detections of unknown organic compounds in ground-water and surface-water samples.

The presence and distribution of each of the 15 identified organic compounds are discussed in the following sections. The spatial distribution of ground-water samples makes it difficult to assess accurately the extent of ground-water contamination. However, several areas that may require more extensive sampling to define the extent of contamination have been identified. Water from wells in seven of the nine areas of potential environmental contamination designated for chemical monitoring contained detectable concentrations of organic chemicals. In general, the concentrations of organic contaminants were less than the MCL's, and they were on the order of tenths of micrograms per liter to tens of micrograms per liter. Water from well Q14, however, contained several volatile organic compounds in concentrations as high as 6,000 µg/L (table 4c, at the end of the report).

Organic compounds typically are present in trace concentrations, and sampling for these compounds is difficult because of possible sample contamination and volatilization. To help measure concentrations of these compounds, other indicators of volatile organic compounds also were measured, including total organic halogens (TOH) and total organic carbon. The TOH analysis measures the concentration of halogens associated with hydrocarbons present in a water sample. Thus, this analysis measures a broad spectrum of the primary types of organic compounds identified by the more compound-specific gas chromatography/mass spectroscopy (GC/MS) analysis of volatile organic compounds. In contrast to the GC/MS results, TOH analysis results were greater than the detection level of 5.0 µg/L in 26 of the 30 ground-water samples and in all of the surface-water samples. Concentrations in all ground-water samples were less than 67.1 µg/L, except in the sample from well Q14 (TOH concentration 14,800 µg/L). Concentrations of total organic halogens in surface-water samples ranged from 6.20 to 112 µg/L (table 5c, at the end of the report).

Total organic carbon is a gross measure of the total organic material dissolved and suspended in solution, including chlorinated hydrocarbons, oil, grease, and natural organic material such as tannic and fulvic acids. In shallow ground and surface waters, the natural carbon compounds commonly are present in greater concentrations than are anthropogenic carbon compounds. Of 30 ground-water samples, 20 contained less than 1 mg/L total organic carbon. Water from well Q14, in which volatile organic compounds in excess of 5 mg/L were detected, was one of the samples in which the concentration of total organic carbon was less than 1 mg/L; therefore, total organic carbon is not a suitable indicator of organic contamination at this site. Total organic carbon concentrations in surface-water samples ranged from 3.67 to 20.8 mg/L.

Chlorinated Alkanes

Chlorinated alkanes are saturated, straight-chained hydrocarbons in which chloride substitutes for hydrogen atoms in the hydrocarbon structure. Water samples from nine wells and two samples of surface water from six areas on Graces Quarters contained detectable concentrations of chlorinated alkanes. These compounds were present in a wide range of concentrations, but detections were limited to the surficial-aquifer and surface-water samples. The distribution of chlorinated alkanes in water samples is shown in figure 29.

Table 8. *Locations and concentrations of selected organic compounds detected in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989*

[MCL, Maximum Contaminant Level; MCLG, Maximum Contaminant Level Goal; concentrations in micrograms per liter (µg/L); *, sites where Maximum Contaminant Level was equaled or exceeded; HD, distilled mustard]

Compound	Sample type	Number of detections	Concentration range	Location and site number where detected (figs. 3 and 4)
CHLORINATED ALKANES				
Carbon tetrachloride (5.0 µg/L MCL; 0 µg/L MCLG)[1]	Ground water	3	0.64-6,000	Disposal area (well Q03) Primary test area (well Q14*) Test-site dump (well Q25)
Chloroform (100 µg/L MCL)	Ground water	5	.93-100	Disposal area (wells Q08, Q13) Primary test area (well Q14*) HD test annuli (well Q18B) Test-site dump (well Q25)
1,1,2,2-Tetrachloroethane	Ground water	5	4.0-2,000	Disposal area (well Q09A) Primary test area (well Q14) Test-site dump (well Q25) Perimeter dump (well Q27) Bunker (well Q22)
CHLORINATED ALKENES				
1,1-Dichloroethylene (7.0 µg/L MCL, MCLG)	Ground water	1	.57	Disposal area (well Q03)
1,2-Dichloroethylene (70.0 µg/L MCL, MCLG)	Ground water	2	2.1-3.4	Primary test area (well Q15) Perimeter dump (well Q27)
Trichloroethylene (5.0 µg/L MCL; 0 µg/L MCLG)	Ground water	3	.5-1,000	Primary test area (well Q14*) Test-site dump (well Q25*) Perimeter dump (well Q27)
AROMATICS				
Benzene (5.0 µg/L MCL; 0 µg/L MCLG)	Ground water	1	.94	Disposal area (well Q08)
Ethylbenzene (7.0 µg/L MCL, MCLG)	Ground water	1	3.2	Disposal area (well Q08)
Toluene (1,000 µg/L MCL, MCLG)	Ground water	1	13	Disposal area (well Q08)
Xylenes (10,000 µg/L MCL, MCLG)	Ground water	2	.80-17	Disposal area (well Q08) Perimeter dump (well Q26)
Phenols	Surface water	3	9.43-17.6	Perimeter dump (site SW08) Graces Quarters dump (site SW09) Disposal area (site SW10)

Table 8. *Locations and concentrations of selected organic compounds detected in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Continued*

Compound	Sample type	Number of detections	Concentration range	Location and site number where detected (figs. 3 and 4)
SEMIVOLATILE ORGANIC COMPOUNDS				
Bis(2-ethylhexyl) phthalate	Ground water	8	5.4-300	Primary test area (wells Q15, Q16A, Q16B) HD test annuli (well Q18B) Uplands (confined aquifer system) (well Q19A) Perimeter dump (wells Q26, Q28) Service area (well Q20A)
	Surface water	5	4.5-7.5	Perimeter dump (site SW03) Bunker (site SW04) Primary test area (site SW06) HD test annuli (site SW07) Graces Quarters dump (site SW09)
1,2-Epoxycyclohexene	Ground water	5	1.0-2.0	Perimeter dump (well Q28) HD test annuli (well Q18B) Test-site dump (well Q24) Primary test area (well Q14) Disposal area (well Q07)
2-Ethyl-1-hexanol	Ground water	3	3.0	Primary test area (well Q16A) Uplands (confined aquifer system) (well Q19A) HD test annuli (well Q18B)
Tridecane	Ground water	1	10	Disposal area (well Q03)

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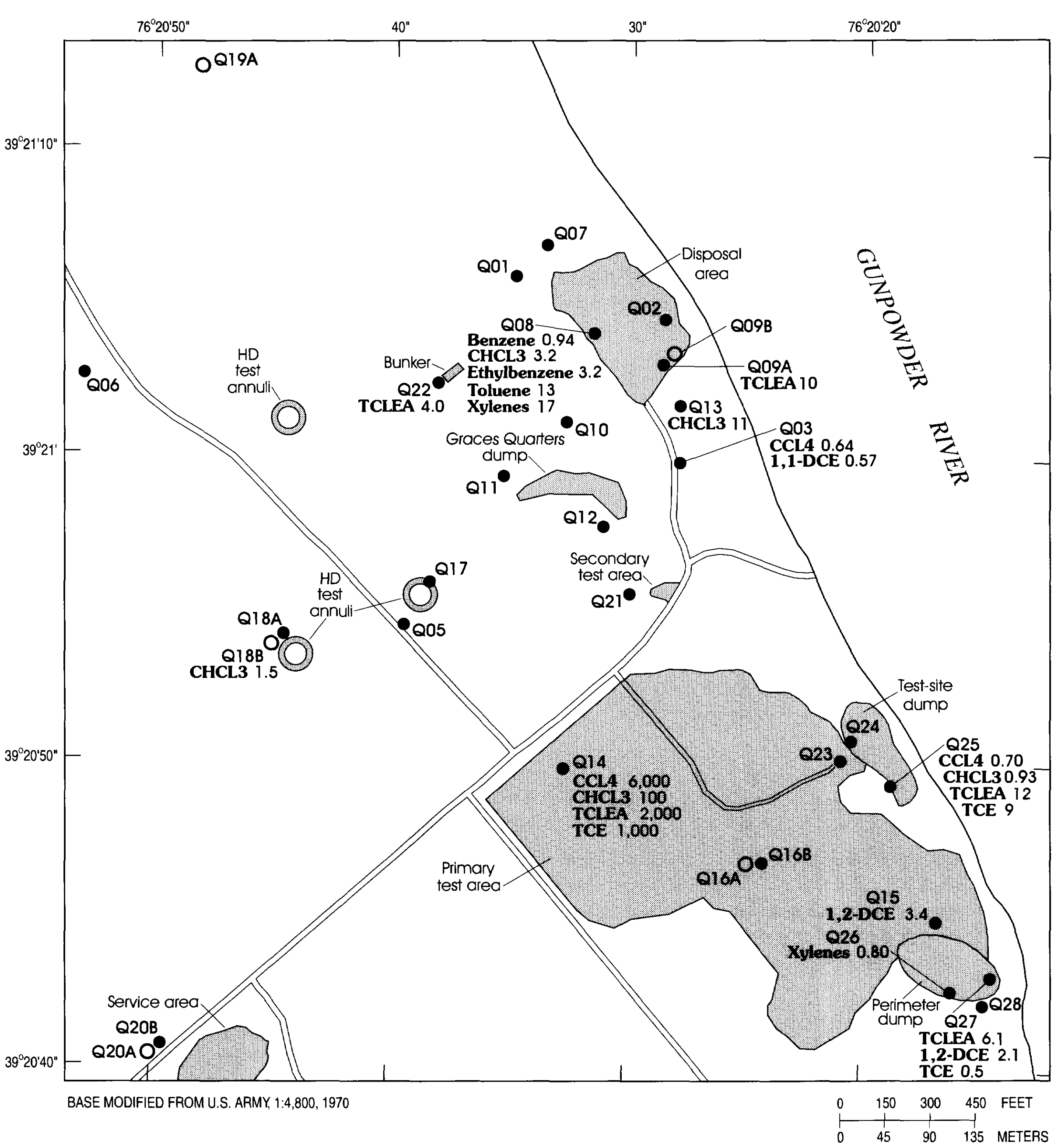
[1] Contaminant levels established by U.S. Environmental Protection Agency (1989, 1990a, b, c, and e, 1991a, 1992).



EXPLANATION

▨ AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION

Q09A ● OBSERVATION WELL SCREENED IN SURFICIAL AQUIFER AND WELL NUMBER

Q09B ○ OBSERVATION WELL SCREENED IN CONFINED AQUIFER SYSTEM AND WELL NUMBER

CHLORINATED ALKANES		*CHLORINATED ALKENES*		*AROMATIC HYDROCARBONS*	
CCL4	CARBON TETRACHLORIDE	**1,1-DCE**	1,1-DICHLOROETHYLENE	**Benzene**	**Toluene**
CHCL3	CHLOROFORM	**1,2-DCE**	1,2-DICHLOROETHYLENE	**Ethylbenzene**	**Xylenes**
TCLEA	1,1,2,2-TETRACHLOROETHANE	**TCE**	TRICHLOROETHYLENE		

0.94 CHEMICAL CONCENTRATION-- In micrograms per liter

Figure 29. Distribution of chlorinated alkanes, chlorinated alkenes, and aromatic hydrocarbons detected in ground-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989.

Carbon Tetrachloride

Carbon tetrachloride was identified in three ground-water samples in concentrations of 0.64 to 6,000 μg/L (table 8). The wells in which carbon tetrachloride was detected are located in the primary test area (well Q14), in the test-site dump (well Q25), and near the disposal area (well Q03); the highest concentration was present in water from well Q14. Lower concentrations of carbon tetrachloride were detected in the sample from well Q03, near the disposal area, and in well Q25, downgradient from the test site dump. These wells contained carbon tetrachloride concentrations of 0.64 and 0.70 μg/L, respectively (less than the MCL of 5.0 μg/L for carbon tetrachloride). The MCLG for carbon tetrachloride is zero.

Carbon tetrachloride was used for a number of purposes in the processing and handling of chemical agents. Its greatest use in the Graces Quarters area probably was as a decontaminating agent or as a solvent for chemical-agent mixtures. Lorah and Vroblesky (1989, p. 69) reported the use of carbon tetrachloride to decontaminate equipment and spills of mustard during World War II. Carbon tetrachloride also may have been used to decontaminate the ground and equipment following testing activities on Graces Quarters; additionally, it was used as a solvent in the tear-gas mixture CNB. Any testing of CNB or disposal of equipment used in CNB testing may have resulted in the presence of carbon tetrachloride in ground water.

The high concentration of carbon tetrachloride in the water sample from well Q14 indicates that a point source of contamination may exist at or near this well. However, an electromagnetic survey and a survey of historical aerial photographs did not produce evidence of burial pits that may act as a point source of carbon tetrachloride and other organic chemicals to well Q14. Therefore, the organic contamination in well Q14 may be related to surficial testing and decontamination of chemical agents within the primary test area. If organic chemicals were applied to the ground surface during testing or decontamination, they might have migrated downward into the aquifer because the soil encountered during drilling at well Q14 was sandy and would not be expected to impede contaminant migration. More extensive sampling and analysis in the primary test area is required to define further the source and extent of contamination at this site.

Chloroform

Chloroform was detected in five ground-water samples in concentrations of 0.93 to 100 μg/L (table 8). Water from two wells in the disposal area (wells Q08 and Q13) and from one well each near the test site dump (well Q25), primary test area (well Q14), and HD test annuli (well Q18B) contained some chloroform (fig. 29). The concentration of chloroform in the sample from well Q14 equaled the MCL, which is 100 μg/L (table 8).

The use of chloroform as a chemical agent, solvent, and decontaminating agent is not documented. However, Nemeth (1989, p. 147) indicates that chloroform and dye were used to simulate chemical agents in tests on Carroll Island. Similar testing may have caused chloroform contamination in the ground water at Graces Quarters. Also, chloroform can be formed as a product of hydrogenolysis of carbon tetrachloride (Lorah and Vroblesky, 1989, p. 86). The presence of chloroform in the sample from well Q18B was unexpected because this well is screened in the confined aquifer system and the shallow well at this site showed no sign of contamination. Contamination during sampling or analysis may have resulted in the small concentration (1.5 μg/L) of chloroform in this sample.

1,1,2,2-Tetrachloroethane

Samples from five wells (Q09A, Q14, Q22, Q25, and Q27) located in five different areas (disposal area, primary test area, bunker, test-site dump, and perimeter dump) contained detectable concentrations of 1,1,2,2-tetrachloroethane (fig. 29). Concentrations in ground-water ranged from 4.0 to 2,000 μg/L (table 8).

The compound 1,1,2,2-tetrachloroethane has had many uses as a solvent and as a decontamination agent. The primary application of 1,1,2,2,-tetrachloroethane on Graces Quarters probably would have been as a solvent in the decontaminating agent DANC (decontamination-agent noncorrosive), which was reported to contain 90 to 95 percent 1,1,2,2,-tetrachloroethane mixed with a chlorinating compound (Nemeth, 1989, p. 177). The decontaminant DANC was used to neutralize mustard, lewisite, and VX by chlorination, and it also may have been used to chlorinate other chemical agents (Nemeth, 1989, p. 178). Contamination detected in water from well Q14 is most likely from the use of DANC to decontaminate the primary test area following chemical-agent testing.

Chlorinated Alkenes

Chlorinated alkenes are straight-chained hydrocarbons that are similar in structure to the alkanes. Alkenes, however, are unsaturated hydrocarbons and contain carbon-carbon double bonds. Chlorinated alkenes were present in ground-water samples from four of the potentially contaminated areas on Graces Quarters (table 8; fig. 29). These areas include the disposal area (well Q03), the perimeter dump (well Q27), the test-site dump (well Q25), and the primary test area (wells Q14 and Q15). The compounds detected are 1,1-dichloroethylene, 1,2-dichloroethylene, and trichloroethylene.

1,1-Dichloroethylene

Only one ground-water sample contained a detectable concentration of 1,1-dichloroethylene. The sample from well Q03, located downgradient from the disposal area, contained this compound in a concentration of 0.57 µg/L. The MCL and MCLG for 1,1-dichloroethylene is 7.0 µg/L (table 8). The source of 1,1-dichloroethylene in this sample is unknown. No other nearby wells contained detectable concentrations of this compound, so the contamination may have come from an isolated source close to well Q03. Lorah and Vroblesky (1989, p. 87) describe an abiotic process in which 1,1-dichloroethylene is a secondary product of the dehydrohalogenation of 1,1,2-trichloroethane. This process, however, is presumed to occur slowly. The parent compounds of this reaction were detected in low concentrations in water from well Q09A in the disposal area, and in surface-water samples collected near the disposal area.

1,2-Dichloroethylene

The compound 1,2-dichloroethylene was detected in water from well Q15 (3.4 µg/L), at the southern end of the primary test area, and in water from well Q27 (2.1 µg/L), downgradient from the perimeter dump (fig. 29; table 8). These concentrations are considerably less than the MCL and MCLG of 70 µg/L. This compound was not commonly used in chemical or decontaminating agents but may be formed as a secondary contaminant by dihalo-elimination (the loss of two halogen atoms from adjacent carbons on a polyhalogenated alkane) of tetrachloroethane (Lorah and Vroblesky, 1989, p. 88).

Trichloroethylene

Trichloroethylene is a widely used degreasing agent that can be expected to be found as a contaminant in ground water at any location where metal equipment may have been cleaned and maintained. Trichloroethylene was detected in water samples from three wells on Graces Quarters, in the test-site dump, the perimeter dump, and the primary test area, in concentrations ranging from 0.5 to 1,000 µg/L (table 8). Samples from wells Q25 (9 µg/L) and Q14 (1,000 µg/L) exceeded the MCL of 5.0 µg/L. The MCLG for trichloroethylene is zero.

No documented records regarding the use of trichloroethylene as a solvent for chemical agents or as a decontaminating agent are available. However, because of its wide use in maintenance and metal cleaning, low levels of contamination in the dump areas in which maintenance supplies may have been buried can be expected. The elevated concentration in the sample from well Q14 is not explained easily because no known dumping or burial occurred near this well. The contamination may have resulted from the breakdown of other chlorinated hydrocarbons that were used as solvents and decontaminating agents. Dehydrohalogenation of 1,1,2,2-trichloroethane can produce trichloroethylene (Lorah and Vroblesky, 1989, p. 87). Samples from all three wells on Graces Quarters in which trichloroethylene was detected also contained 1,1,2,2-trichloroethane.

Aromatic Compounds

Aromatic compounds are characterized by their cyclic structure of six carbon atoms in what is termed a "benzene ring". In the benzene ring, each carbon atom bonds with a free hydrogen atom and two other carbon atoms by a double and a single bond. Aromatic compounds are noted for their pungent gasoline-like odor.

Aromatic compounds were detected in ground-water samples from two wells on Graces Quarters, wells Q08 and Q26, located in the disposal area and perimeter dump, respectively (fig. 29). Water from well Q08 contained benzene, ethylbenzene, toluene, and xylenes, whereas water from well Q26 contained only xylenes. None of the aromatic compounds detected were in concentrations greater than the MCL regulations established by the USEPA (table 8); however, the MCLG of benzene is zero.

Aromatic compounds, including those detected in water from well Q08, commonly are used as solvents and are present in many fuel products both before and after combustion. The most notable use of benzene at the Edgewood Arsenal was as a product in the manufacture of CN (tear gas). Following chemical testing, used equipment and containers often were decontaminated by open-pit burning. Volatile fuels, such as gasoline and napalm, were used to initiate the burning (Nemeth, 1989, p. 175). Because open-pit burning produces less heat than incineration, residual material from both fuel and chemical agents may have persisted after burning. Also, vegetation was controlled with field burning. As with open-pit burning, volatile fuels were used to initiate and control the burning. The four aromatic compounds detected in water from well Q08 may have been residue from burning during disposal activities.

Well Q26 is located downgradient from the perimeter dump; the water sample from the well contained 0.80 µg/L xylenes--much lower than the 17 µg/L found in water from well Q08. No other contaminants of any type were identified in water from this well. The source of the xylenes is unknown; contamination may have occurred during sample collection and analysis.

Phenols were detected in three surface-water samples in concentrations of 9.43 to 17.6 µg/L (table 8). Phenols have no documented use in the manufacture or decontamination of chemical agents or as solvents. However, phenols are present in many products, including disinfectants and petroleum products. Phenols were not detected in any ground-water samples. No USEPA regulations have been established for phenols in water.

Phenols were detected near the disposal area in surface water from SW10 (17.6 µg/L), near the Graces Quarters dump in water from site SW09 (9.43 µg/L), and near the perimeter dump in water from site SW08 (10.7 µg/L). In all cases, phenols may have originated from buried waste or from phenolic residues left in the soils following burning or pesticide application.

Semivolatile Organic Compounds

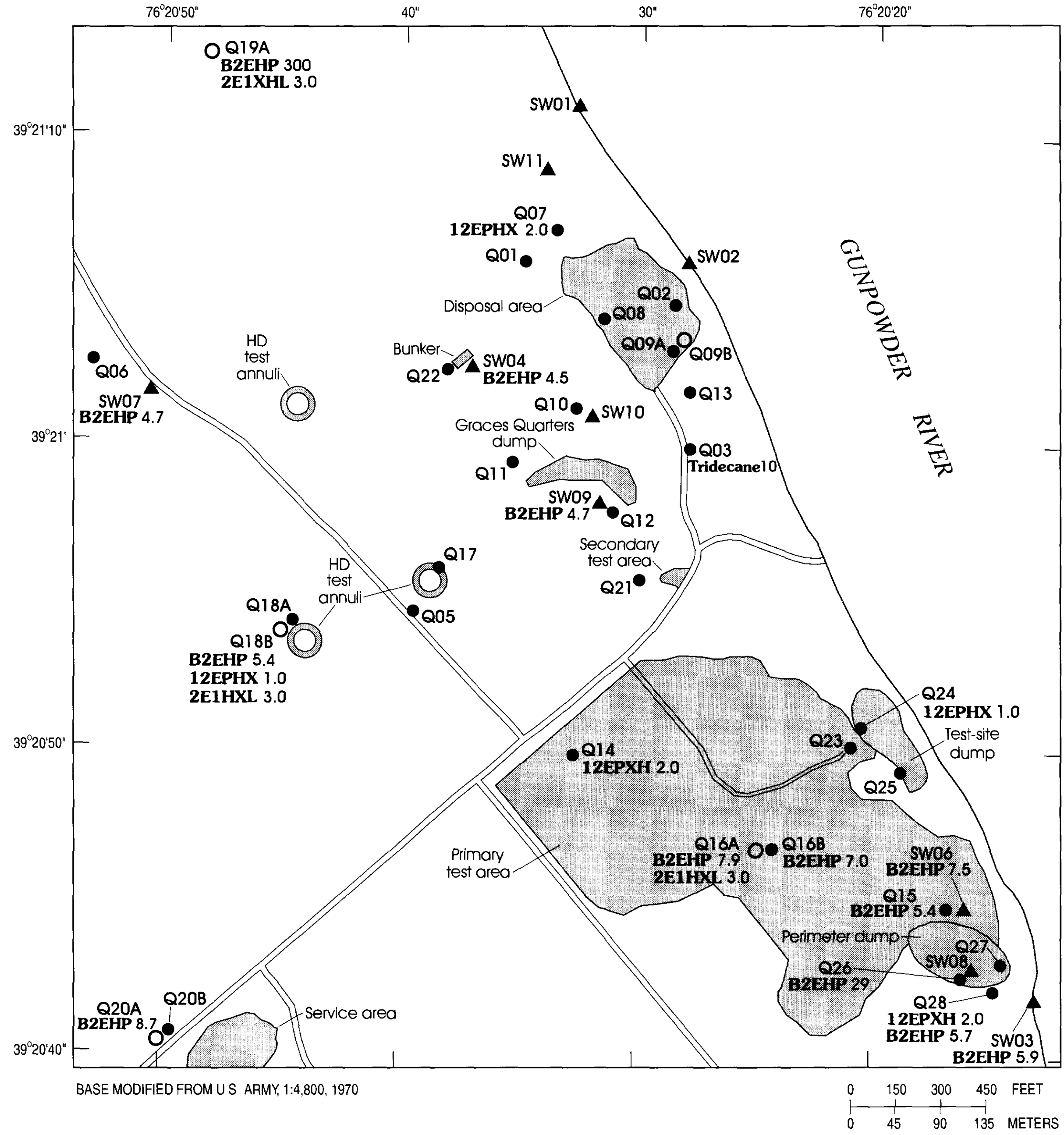
Semivolatile organic compounds are those compounds that do not readily volatilize under atmospheric conditions. This class of compounds also is termed "BNA's" (base-neutral acid-extractables) because of their analytical properties. Three semivolatile compounds were detected as part of the BNA analysis of surface-water samples. Bis(2-ethylhexyl) phthalate was detected in eight ground-water and five surface-water samples. Three ground-water samples contained detectable concentrations of 2-ethyl-1-hexanol. Five ground-water samples contained detectable concentrations of 1,2-epoxycyclohexene. Tridecane was detected in one ground-water sample (fig. 30). No USEPA water-quality regulations have been established for these constituents.

Bis(2-ethylhexyl) phthalate

Bis(2-ethylhexyl) phthalate was found in eight ground-water samples at concentrations ranging from 5.4 to 300 µg/L and in five surface-water samples at concentrations ranging from 4.5 to 7.5 µg/L. The highest concentration (300 µg/L) was detected in a sample from well Q19A, which is screened in the confined aquifer system north of all known testing and disposal areas. The hydraulic head in this well is affected by offsite pumpage, so it is possible that the well is located along a flow path from one of the testing or disposal areas. However, the concentration of bis(2-ethylhexyl) phthalate in this sample was two orders of magnitude higher than the concentration in water from any other well on Graces Quarters, and the well is screened beneath a 100-ft confining unit. Therefore, it is considered unlikely that this detection represented the true concentration of the compound in ground water at this well.

Bis(2-ethylhexyl) phthalate was found in the primary test area in the water samples from wells Q15 and Q16B, which are screened in the surficial aquifer, and in the sample from well Q16A, which is screened in the uppermost confined aquifer. Detections also were noted in water from well Q20A in the confined aquifer system at the service area, in water from well Q18B in the confined aquifer system at the HD test annuli, and in water from wells Q26 and Q28 in the surficial aquifer at the perimeter dump. Bis(2-ethylhexyl) phthalate also was detected in five surface-water samples from near the bunker (site SW04), the primary test area (site SW06), the HD test annuli (site SW07), the Graces Quarters dump (site SW09), and the Gunpowder River estuary near the perimeter dump (site SW03).

Several of the detections of bis(2-ethylhexyl) phthalate mentioned are suspect. Duplicate samples were collected at well Q16A, and bis(2-ethyl-



EXPLANATION

▨	AREA REPRESENTING POTENTIAL SOURCE OF CONTAMINATION	Q09A ●	OBSERVATION WELL SCREENED IN SURFICIAL AQUIFER AND WELL NUMBER
SW08 ▲	SURFACE-WATER SAMPLING SITE AND NUMBER	Q09B ○	OBSERVATION WELL SCREENED IN CONFINED AQUIFER SYSTEM AND WELL NUMBER

SEMIVOLATILE ORGANIC COMPOUNDS

B2EHP	BIS-(2-ETHYLHEXYL)PHTHALATE	**2E1XHL**	2-ETHYL-1-HEXANOL
12EPHX	1,2-EPOXYCYLOHEXENE	**Tridecane**	

5.4 CHEMICAL CONCENTRATION-- In micrograms per liter

Figure 30. Distribution of semivolatile organic compounds detected in ground-water and surface-water samples, Graces Quarters, Aberdeen Proving Ground, Md., spring 1989.

hexyl) phthalate was detected in one but not the other. In addition, the compound was detected in an equipment wash blank at a concentration of 5.4 µg/L the same day that wells Q15, Q16A, Q16B, and Q20A were sampled. The concentration of bis(2-ethylhexyl) phthalate in those samples ranged from 5.4 to 8.7 µg/L. This indicates that the detections may have resulted from contaminated sampling equipment or wash water.

Phthalates commonly are used as plasticizers in polymers of vinyl chloride, propylene, ethylene, and styrene (Smith and others, 1988, p. 56) Phthalates are poorly soluble in water and tend to partition with sediment and lipids (Smith and others, 1988, p. 58). It is possible that, because of the ubiquitous nature of phthalates, the presence of bis(2-ethylhexyl) phthalate in samples from Graces Quarters is unrelated to any chemical testing or disposal activities. Well-construction materials, water-sample containers, and atmospheric deposition from distant sources may have contributed to the concentrations detected on Graces Quarters. Although the use of phthalates is undocumented in chemical-agent manufacture, the chemical properties of phthalates make them well suited for use as thickeners and as stabilizers for the chemical agents that were tested at Graces Quarters. Phthalates are stable in the environment. If they were used in chemical agents, they would be expected to be present throughout the ground water and surface water of Graces Quarters and to be sorbed to the sediment.

1,2-Epoxycyclohexene

Five ground-water samples contained detectable concentrations (1.0 to 2.0 µg/L) of 1,2-epoxycyclohexene (table 8). The samples were from wells located in five of the potentially contaminated areas, including the perimeter dump (well Q28), the HD test annuli (well Q18B), the disposal area (well Q07), the test-site dump (well Q24), and the primary test area (well Q14). No USEPA regulations exist concerning the presence of this compound in water. Cyclohexene is used in organic synthesis and can be found in coal tar and as a stabilizer in fuels. Because of the spatial extent of 1,2-epoxycyclohexene and the low concentrations detected, the presence of this compound may indicate sample contamination during sampling and analysis. More sampling may be required to verify the presence of 1,2-epoxycyclohexene in the ground water at Graces Quarters.

2-Ethyl-1-hexanol

The compound 2-ethyl-1-hexanol was detected in three ground-water samples from the confined aquifer system. The compound was detected in samples from wells Q16A (3.0 µg/L), Q18B (3.0 µg/L), and Q19A (3.0 µg/L). One of the wells (Q19A) is screened in the confined aquifer system in the uplands beneath a thick clay confining layer. No known sources of 2-ethyl-1-hexanol are in the Graces Quarters area, and the compound was not detected in the surficial aquifer. The low concentrations of this compound in water from the confined aquifer system may result from contamination during the collection, processing, or handling of the samples.

Tridecane

Tridecane is a 13-carbon alkane (straight-chained saturated hydrocarbon) that was detected in water from well Q03 at a concentration of 10.0 µg/L. The source of the tridecane in this sample is unknown. Water from well Q03 also contained detectable concentrations of carbon tetrachloride, and the tridecane may have come from the same localized source. However, this value may be anomalous and a result of laboratory contamination. Further sampling may be necessary to verify the presence of tridecane in water from this well. No MCL or Proposed MCL for tridecane in drinking water has been established by the USEPA.

SUMMARY AND CONCLUSIONS

Graces Quarters was used for open-air testing of chemical-warfare agents from the late 1940's until 1971. Testing took place in three areas known as the primary test area, the HD test annuli, and the secondary test area. Disposal of waste from test activities took place in at least four areas known as the disposal area, the Graces Quarters dump, the test-site dump, and the perimeter dump.

The Graces Quarters peninsula is located in the Atlantic Coastal Plain Physiographic Province and is underlain by Cretaceous sediment of the Potomac Group. The Potomac Group sediment consists of unconsolidated clay, sand, and silt most likely of continental origin. The rock unit of the Potomac Group that crops out on Graces Quarters is the Patapsco Formation.

Surface water in the area consists mainly of the estuarine tributaries of the Chesapeake Bay that surround Graces Quarters, along with ponding, intermittent runoff, and tidal marshes. Soils on Graces Quarters are classified into two general soil associations, the Mattapex-Barclay-Othello association and the Sassafras-Woodstown-Fallsington association. The soils on Graces Quarters range from poorly drained to well drained and are strongly acidic to extremely acidic.

The aquifers and confining units identified on Graces Quarters include the surficial aquifer, the upper confining unit, and one or more confined aquifers and lower confining units. The local aquifer system is complex because of the lenticular nature of the Patapsco Formation sediment on Graces Quarters. Because the system is complex, definition of the aquifers and confining units is difficult. However, the available borehole and topographic data allow the peninsula to be divided into three hydrogeologic areas: the uplands, which are discontinuous areas characterized by a thick, dense clay at or near the land surface; the transition zone, which is gently sloping and adjacent to the uplands; and the lowlands, which are flat and low-lying. The dense clay is either less well-defined or is present at greater depth, and the sediments are sandier in the transition zone and lowlands than in the uplands.

The surficial aquifer consists of sand, silt, and clay, and ranges in thickness from near 0 to almost 70 ft. Hydraulic head in the surficial aquifer is affected by the hydrogeologic framework and by recharge, discharge, and evapotranspiration. There are no known pumpage effects on the surficial aquifer. During spring 1988, which was a wet time of year, the hydraulic head was highest at two sites (the disposal area and the bunker) within the uplands. Hydraulic-head gradients between these areas and the adjoining transition zone were steep, indicating low hydraulic conductivity between the uplands and the transition zone in these areas. During fall 1988, some of the wells in upland parts of the surficial aquifer went dry.

Flow directions in the surficial aquifer on Graces Quarters varied with space and time. At the disposal area, flow during spring 1988 was away from the area in all directions except northwest; during fall 1988, the aquifer in the disposal area was nearly dry. At the bunker, hydraulic head was high during spring and fall, and flow directions were to the south, west, and east. At the Graces Quarters dump, flow directions seemed to converge on an area west of the dump. If a breach exists in the upper confining unit in this area, the surficial aquifer at this location would represent a recharge zone for the underlying confined aquifer system. Another explanation is that the hydraulic head in the surficial aquifer at the bunker site has little effect on flow direction in this area. If this is the case, the likely flow direction in this area is to the west.

At the test-site dump in the primary test area, ground water may flow in several directions, including toward the cliff face east of the site. At the perimeter dump, flow direction varies with time. The perimeter dump site appears to be an area of ground-water discharge because there is evidence of an upward hydraulic gradient within the surficial aquifer. During the fall, the hydraulic head in the surficial aquifer at the perimeter dump declines below sea level, indicating that ground water is affected by evapotranspiration in this area.

Horizontal hydraulic conductivity in the surficial aquifer ranged from less than 0.02 to 24 ft/d. The hydraulic conductivity calculated from slug tests was within ranges commonly measured in the aquifer materials in which the wells were screened.

The upper confining unit on Graces Quarters consists of what appears to be two different clay units. One of the clay units was present at altitudes above sea level and was more than 100 ft thick in the uplands. In the transition zone and lowlands, the clay that comprises the upper confining unit is less dense and possibly less continuous than the clay in the uplands. The clay within the transition zone and lowlands ranged in thickness from 20 to 65 ft in the boreholes in which it was present. The upper confining unit probably is not continuous over the entire study area. Available data from boreholes in the transition zone indicate the possible presence of breaches in the upper confining unit in that area.

The confined aquifer system at Graces Quarters was encountered at five borehole locations; however, the thickness of the aquifer system was not defined. The aquifer system consists of layers of interbedded sand and clay. The confined aquifer system beneath the uplands most likely is different from the confined aquifer system beneath the lowlands. This is apparent from the stratigraphic position of the lithologic units and the patterns of hydraulic-head fluctuations observed within the two parts of the aquifer. The hydraulic head in the lowlands showed a seasonal and tidal fluctuation. The hydraulic head in the uplands showed tidal fluctuation, but also was affected by pumpage from an unknown location. Horizontal hydraulic conductivity in the lowlands part of the confined aquifer system ranged from 1 to 68 ft/d. In the uplands part of the confined aquifer system, determination of hydraulic conductivity in the two boreholes was impossible as a result of the presence of residual bentonite mud from drilling.

Water from 30 wells and 11 surface-water sites was sampled for chemical analysis to determine the extent of contamination on Graces Quarters. Of the 30 wells, 25 were screened in the surficial aquifer and 5 were screened in the confined aquifer system. Seven of the 11 surface-water sampling sites were located in ponds, marshes, and ditches on the inland part of the peninsula; the other 4 surface-water sites were located in the estuaries surrounding Graces Quarters.

Sampling sites were located primarily to detect contamination from the nine areas that were identified as potential contaminant sources. Possible sources of ground-water contamination at the test sites include infiltration of chemical-warfare agents or decontaminating agents applied to the ground surface during testing activities. The decontaminating agents often contained chlorinating compounds mixed with organic solvents. Chemical contamination in the disposal areas may have originated from buried chemical-agent test equipment and supplies, which would have been decontaminated by a number of measures including burning and chemical treatment. Also, containers of untreated chemical agents may be buried at these sites.

Ground-water and surface-water samples were analyzed for a wide range of properties and inorganic and organic constituents, including physical properties, major ions, minor constituents, and volatile and semivolatile organic compounds. The results of the analyses were compared with applicable USEPA water-quality regulations and criteria to determine the suitability of the water as a resource and with published and unpublished data from studies in similar environments to determine whether concentrations were significantly different from expected background conditions.

The physical properties measured for this study were specific conductance, pH, and alkalinity. In ground-water samples, specific conductance ranged from 41 to 393 μS/cm, with a median of 129 μS/cm. These relatively low values resulted from slow weathering of the unreactive and geochemically stable aquifer material. Specific conductance of water samples from the confined aquifer system were lower than those of the surficial-aquifer samples. Ground-water samples at Graces Quarters tended to be acidic and poorly buffered. Median pH and alkalinity values were 5.38 units and 8 mg/L, respectively. The pH's of more than 90 percent of the ground-water samples were lower than the SMCL (6.5 to 8.5) established by the USEPA for drinking water. Alkalinity in ground-water samples ranged from 0 to 175 mg/L. Samples from three wells (Q05, Q13, and Q28) in three different areas (the HD test annuli, the disposal area, and the perimeter dump) contained alkalinity concentrations that were higher than those in most of the other samples. Sodium hydroxide, a commonly used decontaminating agent, may have been the source of the increased alkalinity in water from these wells.

Specific conductance in surface-water samples ranged from 45 to 1,750 μS/cm; the higher values were associated with brackish-water sites in the Gunpowder River and Dundee Creek. The highest specific conductance in surface water was measured in the sample from Dundee Creek. Specific conductance of the Gunpowder River samples was lower than the conductance of the sample from Dundee Creek, possibly as a result of an antecedent storm that caused an influx of freshwater into the Gunpowder River estuary but had less effect on the Dundee Creek estuary, which has a much smaller watershed area than the Gunpowder River.

Surface-water samples were slightly less acidic than ground-water samples (median pH 6.18), but the alkalinity distribution was not significantly different from the ground-water alkalinity distribution. The median alkalinity in surface-water samples was 23 mg/L (compared to 8 mg/L for ground water), but the range in alkalinity of surface-water samples (0 to 65 mg/L) was smaller than the range in alkalinity of ground-water samples.

The major-ion chemistry of ground water at Graces Quarters varied spatially and with depth. The variability of major-ion chemistry probably is related to the complexity of the local geology and flow paths. Calcium, magnesium, sodium, and sulfate concentrations were significantly higher in samples from the surficial aquifer than in samples from the confined aquifer system. In general, many of the ground-water samples from both aquifers contained low concentrations of major ions. However, some surficial-aquifer samples collected near the disposal area and the perimeter dump contained higher total ion concentrations than the rest of the samples. Also, increased concentrations of bicarbonate and sodium in wells Q26 and Q28 near the perimeter dump may have resulted from historical use of sodium hydroxide as a decontamination agent.

Surface-water samples generally contained higher concentrations of calcium, magnesium, and potassium than did ground-water samples. However, sulfate concentrations in surface water generally were lower than the concentrations in ground water. As expected, concentrations of several of the major ions were significantly higher in the estuarine surface-water samples than in the inland surface-water samples.

Trace elements (minor constituents) were determined in both ground-water and surface-water samples. Concentrations of the minor constituents in ground-water samples were compared to USEPA drinking-water regulations (MCL, SMCL, and Proposed MCL); concentrations in surface-water samples were compared to Federal ambient water-quality criteria for freshwater (FWA and FWC).

In ground water, the health-based MCL drinking-water regulation for lead was exceeded in one sample (well Q18A) from the surficial aquifer at one of the HD test annuli. The SMCL regulations, which are aesthetically based, were exceeded in at least 9 samples for aluminum, in 14 samples for iron, and in 20 samples for manganese. All of the wells in which aluminum was detected were screened in the surficial aquifer. These wells were located at or near the disposal area; at the Graces Quarters dump; at or near the HD test annuli; and at the secondary test area, the bunker, and the perimeter dump. The iron and manganese concentrations detected in the ground-water samples are similar to those found in other Potomac Group aquifers and may be present naturally.

Surface-water criteria were exceeded for several of the minor constituents. The FWA criterion for aluminum was exceeded in water from one of the seven inland sites (site SW10, near the disposal area) and three of the four estuarine sites (SW02, SW03, and SW05). The FWC criterion for aluminum was less than the reporting level in surface water. Cadmium was detected at two estuarine sites in the Gunpowder River (sites SW01 and SW03), but the FWA and FWC criteria were less than the reporting level for cadmium. Chromium was detected in water from two sites in the Gunpowder River (sites SW01 and SW02) and in water from two inland sites (SW08 in the primary test area and SW10 near the disposal area). Of these detections, water from one estuarine site (SW01) exceeded the FWA and FWC criteria, and water from one inland site (SW10) exceeded the FWC and FWA criteria. The FWA for copper was exceeded in water from one inland site (SW10) and one estuarine site (SW01), and the FWC was exceeded in water from three inland sites (SW07, which may be downgradient from one of the HD test annuli, and SW10 and SW11, near the disposal area) and in water from three estuarine sites (SW01, SW02, and SW03). Silver and thallium were not detected in any surface-water samples, but the reporting levels were less than both criteria for silver and the FWC for thallium. The FWC criterion for zinc was exceeded in one estuarine sample (site SW01) and three inland samples (sites SW07, SW10, and SW11).

Sampling and analysis of ground-water and surface-water samples included volatile and semivolatile organic compounds. Three classes of volatile organic compounds were identified in ground-water and surface-water samples. These include chlorinated alkanes, chlorinated alkenes, and aromatic hydrocarbons. Volatile organic compounds were identified in seven of the nine potentially contaminated areas on Graces Quarters in concentrations ranging from 0.5 to 6,000 µg/L. Also, four semivolatile organic compounds were identified. These compounds were bis(2-ethylhexyl) phthalate, 1,2-epoxycyclohexene, 2-ethyl-1-hexanol, and tridecane. Samples from two wells (Q14 in the primary test area and Q25 at the test-site dump) exceeded MCL regulations for organic compounds in drinking water. The sample from well Q14 exceeded the MCL for carbon tetrachloride, chloroform, and trichloroethylene; the sample from well Q25 exceeded the MCL for trichloroethylene.

The highest concentration of volatile organic compounds was present in a water sample from well Q14 in the primary test area. Water from this well also contained the widest variety of compounds. The compounds detected include carbon tetrachloride (6,000 µg/L), chloroform (100 µg/L), 1,1,2,2-tetrachloroethane (2,000 µg/L), and trichloroethylene (1,000 µg/L). These compounds were used commonly as solvents for chemical agents and decontaminating agents. They also may be products of the degradation of other solvents. Because preliminary assessments showed no buried source of contamination in the vicinity of well Q14, the contamination is presumed to result from surface application during chemical testing. More information is required to determine the extent of contamination in the primary test area.

Comparatively low concentrations of volatile organic compounds (0.5 to 17 µg/L) were detected in areas near the test-site dump, perimeter dump, disposal area, HD test annuli, Graces Quarters dump, and bunker. Because the ground-water-flow system near these sites is complex, the extent and direction of contaminant migration cannot be ascertained at this time. Water from well Q25 at the test-site dump and well Q27 near the perimeter dump contained detectable concentrations of 1,2-dichloroethylene. Chloroform was detected in water from five wells, including wells Q08, Q14, Q25, Q13, and Q18A.

Detections of aromatic hydrocarbons were limited to water from well Q08 in the disposal area and well Q26 at the perimeter dump. Benzene, ethylbenzene, toluene, and xylenes were detected in water from well Q08, and xylenes were detected in water from well Q26. The concentrations did not exceed the MCL's for these compounds.

Four semivolatile organic compounds were detected in ground-water and surface-water samples. Bis(2-ethylhexyl) phthalate was detected in eight ground-water samples from the surficial and confined aquifers in concentrations ranging from 5.4 to 300 µg/L and in five surface-water samples (in the estuary at site SW03 and at inland sites SW04, SW06, SW07, and SW09) in concentrations ranging from 4.5 to 7.5 µg/L. The highest concentration was detected in water from well Q19A, which is screened in the confined aquifer system north of all known testing and disposal areas. Although their use at Graces Quarters is undocumented, phthalates may have been used in chemical agents as plasticizers. The compound 2-ethyl-1-hexanol was detected at a concentration of 3.0 µg/L in water from wells Q16A, Q18B, and Q19A completed in the confined aquifer system; 1,2-epoxycyclohexane was detected in water from wells Q07 (2.0 µg/L), Q14 (2.0 µg/L), Q24 (1.0 µg/L), and Q28 (4.0 µg/L) in the surficial aquifer, and well Q18B (1.0 µg/L) in the confined aquifer; and tridecane (10.0 µg/L) was detected in well Q03 in the surficial aquifer. Sources of these compounds have not been determined; it is possible that the samples were contaminated during handling.

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Table 4a. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground,Md., spring 1989-- Physical properties, major dissolved constituents, and nutrients*

[µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter;--, missing data; <, less than; D, duplicate sample; S, split sample]

Well no. (fig. 3)	Sampling date	Specific conductance (uS/cm)	pH (units)	Temperature (°C)	Oxygen (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)
Surficial-aquifer samples									
Q01	04-13-89	177	5.01	10.0	2.9	5.00	6.37	12.4	<0.375
Q02	04-13-89	78	5.18	11.5	8.5	4.83	2.22	5.30	<.375
Q03	04-17-89	226	5.68	14.0	7.0	8.21	4.03	25.7	9.14
Q05	04-19-89	393	6.22	10.0	7.5	61.0	9.00	2.41	2.44
Q06	04-19-89	211	4.51	11.0	2.2	15.0	3.62	7.39	1.25
Q07	04-13-89	219	3.94	10.0	1.8	3.94	5.11	19.0	.854
Q08	04-13-89	204	4.88	10.5	9.3	7.36	4.01	23.1	<.375
Q09A	04-17-89	84	5.47	12.0	--	6.00	3.11	4.13	1.08
Q10	04-17-89	88	5.41	16.0	2.0	2.05	1.37	7.27	1.27
Q11	04-18-89	58	5.05	15.0	4.6	1.30	.534	7.35	2.00
Q11 (S)	04-18-89	58	5.05	15.0	4.6	1.4	.67	7.7	1.8
Q12	04-18-89	126	4.72	13.5	4.6	6.77	5.45	4.70	2.57
Q13	04-18-89	173	6.66	16.0	2.4	18.3	.942	12.6	11.3
Q14	04-13-89	264	5.11	11.5	1.0	8.74	5.96	26.6	1.03
Q15	04-11-89	335	5.63	10.0	4.6	10.6	7.22	21.4	<.375
Q16B	04-11-89	101	5.15	8.5	12.4	11.6	1.52	3.10	<.375
Q17	04-19-89	113	5.90	11.0	9.4	10.8	1.80	7.86	1.05
Q18A	04-14-89	111	4.93	10.5	5.0	9.00	2.83	3.04	1.01
Q18A (D)	04-14-89	111	4.93	10.5	5.0	8.87	2.87	2.81	.706
Q20B	04-11-89	97	4.93	10.0	9.0	10.7	1.23	2.71	<.375
Q21	04-17-89	163	5.07	10.5	8.4	6.52	8.00	6.68	1.65
Q21 (S)	04-18-89	163	5.07	10.5	8.4	7.2	8.8	6.8	2.1
Q22	04-18-89	102	5.51	11.5	5.0	3.15	1.72	12.9	1.18
Q24	04-13-89	180	5.33	12.0	6.7	4.28	2.46	21.9	1.41
Q25	04-13-89	141	5.67	13.5	3.5	5.68	3.12	7.88	.606
Q26	04-12-89	132	6.32	11.0	9.9	2.95	3.86	15.3	<.375
Q27	04-11-89	179	5.35	10.0	5.0	4.11	6.05	16.2	<.375
Q28	04-12-89	258	6.85	11.0	4.5	3.00	1.02	61.0	.780
Confined-aquifer-system samples									
Q09B	04-19-89	90	5.80	13.5	.8	6.07	1.04	3.87	2.26
Q16A	04-11-89	66	5.13	11.5	3.0	2.36	1.10	5.49	3.34
Q16A (D)	04-11-89	66	5.13	11.5	3.0	2.21	1.16	5.48	3.18
Q18B	04-14-89	57	5.40	12.0	1.5	2.04	.956	5.22	1.87
Q19A	04-14-89	41	5.69	13.0	1.4	1.67	.690	2.26	.557
Q20A	04-11-89	56	5.62	12.0	9.0	4.63	.683	3.40	1.20

Table 4a. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground,Md., spring 1989--*
Physical properties, major dissolved constituents, and nutrients--Continued

Well no. (fig. 3)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Silica (mg/L as SiO_2)	Nitrogen (mg/L as NO_2+NO_3)
Surficial-aquifer samples								
Q01	5	6	62.6	31.5	<1.23	<1.0	19.0	0.144
Q02	8	9	20.6	3.63	<1.23	<1.0	6.50	.075
Q03	25	30	--	--	--	--	--	1.30
Q05	175	213	26.7	<2.12	<1.23	<1.0	2.00	3.50
Q06	0	0	81.7	12.0	<1.23	<1.0	7.00	<.010
Q07	0	0	28.8	46.0	<1.23	<1.0	24.7	<.010
Q08	4	5	67.8	10.5	<1.23	<1.0	9.30	.125
Q09A	7	8	21.7	2.57	<1.23	<1.0	4.55	.330
Q10	13	16	17.4	6.66	<1.23	<1.0	11.0	.140
Q11	1	2	12.2	7.11	<1.23	<1.0	10.0	.092
Q11 (S)	1	2	12	6.3	.10	<.01	22	.100
Q12	2	3	27.5	8.06	<1.23	<1.0	7.00	4.30
Q13	69	84	10.7	11.3	<1.23	<1.0	16.5	.400
Q14	10	12	36.0	49.0	<1.23	<1.0	8.80	.930
Q15	25	31	28.1	77.0	<1.23	<1.0	7.70	<.010
Q16B	9	11	29.0	3.40	<1.23	<1.0	2.70	.192
Q17	29	35	19.0	2.66	<1.23	<1.0	1.31	.180
Q18A	4	5	29.8	2.86	<1.23	<1.0	2.50	1.20
Q18A (D)	4	5	30.4	2.84	<1.23	<1.0	2.50	1.30
Q20B	3	3	29.1	3.40	<1.23	<1.0	3.10	.023
Q21	5	6	46.7	6.56	<1.23	<1.0	11.0	2.20
Q21 (S)	5	6	47	6.1	.10	.01	23	--
Q22	21	25	20.7	3.15	<1.23	<1.0	6.50	.700
Q24	2	2	51.1	9.09	<1.23	<1.0	14.0	.011
Q25	12	15	31.8	12.1	<1.23	<1.0	9.20	.034
Q26	14	17	19.9	15.9	<1.23	<1.0	6.80	<.010
Q27	3	4	38.0	26.9	<1.23	<1.0	14.0	<.010
Q28	71	86	29.7	12.8	<1.23	<1.0	8.40	.014
Confined-aquifer-system samples								
Q09B	26	32	11.6	3.18	<1.23	<1.0	4.10	<.010
Q16A	5	6	<10.0	11.7	<1.23	<1.0	6.00	1.40
Q16A (D)	5	6	<10.0	11.4	<1.23	<1.0	6.00	1.60
Q18B	3	3	<10.0	7.52	<1.23	<1.0	4.05	1.90
Q19A	13	16	<10.0	<2.12	<1.23	<1.0	5.00	<.010
Q20A	9	11	<10.0	4.51	<1.23	<1.0	4.45	2.00

Table 4b. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Minor constituents*

[All concentrations are for dissolved constituents in micrograms per liter; --, missing data; <, less than; D, duplicate sample; S, split sample]

Well no. (fig. 3)	Sampling date	Aluminum (as Al)	Antimony (as Sb)	Arsenic (as As)	Barium (as Ba)	Beryllium (as Be)	Cadmium (as Cd)	Chromium (as Cr)	Copper (as Cu)
Surficial-aquifer samples									
Q01	04-13-89	301	<38	--	29.4	<5	<4.01	<6.02	24.8
Q02	04-13-89	<141	<38	--	16.3	<5	<4.01	<6.02	16.0
Q03	04-17-89	<141	<38	--	29.8	<5	<4.01	<6.02	16.0
Q05	04-19-89	<141	<38	--	19.7	<5	<4.01	<6.02	18.1
Q06	04-19-89	2,110	<38	--	32.8	<5	<4.01	<6.02	21.3
Q07	04-13-89	354	<38	--	47.1	<5	<4.01	<6.02	16.8
Q08	04-13-89	191	<38	--	38.1	<5	<4.01	<6.02	20.3
Q09A	04-17-89	464	<38	--	34.0	<5	<4.01	<6.02	11.6
Q10	04-17-89	<141	<38	--	14.6	<5	<4.01	<6.02	16.5
Q11	04-18-89	<141	<38	--	30.3	<5	<4.01	<6.02	59.0
Q11 (S)	04-18-89	40	<1	<1	34	<.5	<1	<5	20
Q12	04-18-89	232	<38	--	75.0	<5	<4.01	<6.02	23.8
Q13	04-18-89	<141	<38	--	82.8	<5	<4.01	<6.02	24.2
Q14	04-13-89	<141	<38	--	38.6	<5	<4.01	7.98	18.2
Q15	04-11-89	<141	<38	<2.54	43.5	<5	<4.01	<6.02	<8.09
Q16B	04-11-89	<141	<38	<2.54	15.7	<5	<4.01	<6.02	8.38
Q17	04-19-89	<141	<38	--	12.2	<5	<4.01	<6.02	25.4
Q18A	04-14-89	339	<38	--	31.7	<5	<4.01	29.7	11.2
Q18A (D)	04-14-89	352	<38	--	43.2	<5	<4.01	32.0	11.2
Q20B	04-11-89	<141	<38	<2.54	11.7	<5	<4.01	<6.02	<8.09
Q21	04-17-89	268	<38	--	21.7	<5	<4.01	<6.02	8.38
Q21 (S)	04-18-89	210	<1	<1	26	<.5	<1	<5	20
Q22	04-18-89	293	<38	--	17.6	<5	<4.01	<6.02	60.7
Q24	04-13-89	<141	<38	--	26.4	<5	<4.01	<6.02	12.3
Q25	04-13-89	<141	<38	--	33.7	<5	<4.01	<6.02	11.0
Q26	04-12-89	<141	<38	<2.54	10.8	<5	<4.01	<6.02	9.44
Q27	04-11-89	<141	<38	<2.54	14.9	<5	<4.01	<6.02	<8.09
Q28	04-12-89	423	<38	<2.54	10.8	<5	<4.01	<6.02	9.14
Confined-aquifer-system samples									
Q09B	04-19-89	<141	<38	--	12.1	<5	<4.01	<6.02	<8.09
Q16A	04-11-89	<141	<38	--	9.8	<5	<4.01	<6.02	9.48
Q16A (D)	04-11-89	<141	<38	<2.54	9.8	<5	<4.01	<6.02	<8.09
Q18B	04-14-89	<141	<38	--	11.9	<5	<4.01	<6.02	23.8
Q19A	04-14-89	<141	<38	--	8.9	<5	<4.01	<6.02	34.9
Q20A	04-11-89	<141	<38	<2.54	11.1	<5	<4.01	<6.02	<8.09

Table 4b. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Minor constituents--Continued*

Well no. (fig. 3)	Iron (as Fe)	Lead (as Pb)	Manganese (as Mn)	Mercury (as Hg)	Nickel (as Ni)	Selenium (as Se)	Silver (as Ag)	Thallium (as Tl)	Zinc (as Zn)
Surficial-aquifer samples									
Q01	<42.7	3.14	149	<0.243	<34.3	<3.02	<4.60	<81.4	57.5
Q02	48.5	<1.26	47.6	<.243	<34.3	<3.02	<4.60	<81.4	29.5
Q03	<42.7	<1.26	27.7	<.243	<34.3	<3.02	<4.60	<81.4	60.6
Q05	84.2	<1.26	18.6	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q06	3,410	2.28	68.5	<.243	272	<3.02	<4.60	<81.4	344
Q07	540	<1.26	861	<.243	103	<3.02	<4.60	<81.4	101
Q08	<42.7	1.63	161	<.243	<34.3	<3.02	<4.60	<81.4	25.5
Q09A	301	1.52	38.9	<.243	<34.3	<3.02	<4.60	<81.4	33.6
Q10	4,980	<1.26	803	<.243	<34.3	<3.02	<4.60	<81.4	67.0
Q11	154	<1.26	71.5	<.243	77.6	<3.02	<4.60	<81.4	54.7
Q11 (S)	110	<10	51	--	80	<1	2.0	--	56
Q12	66.5	<1.26	194	<.243	<34.3	<3.02	<4.60	<81.4	25.1
Q13	309	<1.26	211	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q14	<42.7	<1.26	171	<.243	<34.3	<3.02	<4.60	<81.4	96.2
Q15	21,900	<1.26	139	<.243	<34.3	<3.02	<4.60	111	<21.1
Q16B	129	<1.26	5.59	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q17	<42.7	<1.26	10.6	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q18A	<42.7	57.7	122	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q18A (D)	<42.7	96.6	119	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q20B	<42.7	9.98	12.8	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q21	<42.7	5.31	30.3	<.243	<34.3	<3.02	<4.60	<81.4	22.6
Q21 (S)	16	20	31	<.1	10	<1	1.0	--	27
Q22	320	1.95	246	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q24	579	2.28	96.6	<.243	<34.3	<3.02	<4.60	<81.4	42.6
Q25	5,720	3.36	232	<.243	<34.3	<3.02	<4.60	<81.4	42.0
Q26	172	<1.26	328	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q27	2,240	<1.26	213	<.243	<34.3	<3.02	<4.60	<81.4	55.2
Q28	654	<1.26	103	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Confined-aquifer-system samples									
Q09B	5,710	<1.26	276	<.243	<34.3	<3.02	<4.60	<81.4	<21.1
Q16A	650	1.41	73.9	<.243	<34.3	<3.02	4.68	<81.4	40.8
Q16A (D)	859	<1.26	72.6	<.243	<34.3	<3.02	<4.60	<81.4	36.8
Q18B	<42.7	11.2	43.2	<.243	<34.3	<3.02	<4.60	<81.4	69.2
Q19A	3,510	<1.26	192	<.243	<34.3	<3.02	<4.60	<81.4	57.5
Q20A	<42.7	<1.26	29.6	<.243	<34.3	<3.02	4.99	<81.4	39.7

Table 4c. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Volatile organic compounds and total organic halogens*

[Concentrations in micrograms per liter unless specified. mg/L, milligrams per liter; --, missing data; <, less than; D, duplicate sample; S, split sample]

Well no. (fig. 3)	Sampling date	Carbon, organic, total (mg/L as C)	Phenols, non-specific, total	Halide, total organic	Benzene	Bromo-di-chloro-methane	Bromo-form	Carbon tetra-chlo-ride	Chloro-benzene
Surficial-aquifer samples									
Q01	04-13-89	1.80	<7.12	24.2	<0.50	<0.59	<2.6	<0.58	<0.50
Q02	04-13-89	2.77	<7.12	14.7	<.50	<.59	<2.6	<.58	<.50
Q03	04-17-89	1.71	<7.12	24.3	<.50	<.59	<2.6	.64	<.50
Q05	04-19-89	2.15	<7.12	6.20	<.50	<.59	<2.6	<.58	<.50
Q06	04-19-89	3.68	<7.12	63.2	<.50	<.59	<2.6	<.58	<.50
Q07	04-13-89	<1.00	<7.12	40.0	<.50	<.59	<2.6	<.58	<.50
Q08	04-13-89	1.47	<7.12	25.2	.94	<.59	<2.6	<.58	<.50
Q09A	04-17-89	5.00	<7.12	51.5	<.50	<.59	<2.6	<.58	<.50
Q10	04-17-89	<1.00	<7.12	12.2	<.50	<.59	<2.6	<.58	<.50
Q11	04-18-89	<1.00	<7.12	11.4	<.50	<.59	<2.6	<.58	<.50
Q11 (S)	04-18-89	--	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
Q12	04-18-89	<1.00	<7.12	6.38	<.50	<.59	<2.6	<.58	<.50
Q13	04-18-89	<1.00	<7.12	8.96	<.50	<.59	<2.6	<.58	<.50
Q14	04-13-89	<1.00	<7.12	14,800	<50	<60	<300	6,000	<.50
Q15	04-11-89	<1.00	<7.12	39.4	<.50	<.59	<2.6	<.58	<.50
Q16B	04-11-89	<1.00	<7.12	16.9	<.50	<.59	<2.6	<.58	<.50
Q17	04-19-89	<1.00	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50
Q18A	04-14-89	1.15	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50
Q18A (D)	04-14-89	<1.00	<7.12	21.8	<.50	<.59	<2.6	<.58	<.50
Q20B	04-11-89	<1.00	<7.12	24.9	<.50	<.59	<2.6	<.58	<.50
Q21	04-17-89	<1.00	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50
Q21 (D)	04-17-89	1.97	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50
Q21 (S)	04-18-89	1.9	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
Q22	04-18-89	7.64	<7.12	9.54	<.50	<.59	<2.6	<.58	<.50
Q24	04-13-89	<1.00	<7.12	11.4	<.50	<.59	<2.6	<.58	<.50
Q25	04-13-89	<1.00	<7.12	25.1	<.50	<.59	<2.6	.70	<.50
Q26	04-12-89	2.43	<7.12	58.9	<.50	<.59	<2.6	<.58	<.50
Q27	04-11-89	<1.00	<7.12	21.2	<.50	<.59	<2.6	<.58	<.50
Q28	04-12-89	3.66	<7.12	67.1	<.50	<.59	<2.6	<.58	<.50
Confined-aquifer-system samples									
Q09B	04-19-89	<1.00	<7.12	33.0	<.50	<.59	<2.6	<.58	<.50
Q16A	04-11-89	<1.00	<7.12	10.1	<.50	<.59	<2.6	<.58	<.50
Q16A (D)	04-11-89	<1.00	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50
Q18B	04-14-89	<1.00	<7.12	10.8	<.50	<.59	<2.6	<.58	<.50
Q19A	04-14-89	<1.00	<7.12	13.3	<.50	<.59	<2.6	<.58	<.50
Q20A	04-11-89	<1.00	<7.12	<5.00	<.50	<.59	<2.6	<.58	<.50

Table 4c. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--*
Volatile organic compounds and total organic halogens--Continued

Well no. (fig. 3)	Chloro-di-bromo-methane	Chloro-ethane	2-Chloro-ethyl-vinyl-ether	Chloro-form	Chloro-methane	1,2-Di-chloro-benzene	1,3-Di-chloro-benzene	1,4-Di-chloro-benzene	1,1-Di-chloro-ethane
Surficial-aquifer samples									
Q01	<0.67	<1.9	<0.71	<0.50	<3.2	<1.7	<1.7	<1.7	<0.68
Q02	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q03	<.67	<1.9	<.71	<.50	<3.2	<2.0	<2.0	<2.0	<.68
Q05	<.67	<1.9	<.71	<.50	<3.6	<1.7	<1.7	<1.7	<.68
Q06	<.67	<1.9	<.71	<.50	<3.6	<1.7	<1.7	<1.7	<.68
Q07	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q08	<.67	<1.9	<.71	3.2	<3.2	<1.7	<1.7	<1.7	<.68
Q09A	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q10	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q11	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q11 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<5.0	<5.0	<5.0	<3.0
Q12	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q13	<.67	<1.9	<.71	11	<3.6	<1.7	<1.7	<1.7	<.68
Q14	<70	<200	<70	100	<300	<1.7	<1.7	<1.7	<70
Q15	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q16B	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q17	<.67	<1.9	<.71	<.50	<3.6	<1.7	<1.7	<1.7	<.68
Q18A	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q18A (D)	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q20B	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q21	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q21 (D)	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q21 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<5.0	<5.0	<5.0	<3.0
Q22	<.67	<1.9	<.71	<.50	<3.6	<1.7	<1.7	<1.7	<.68
Q24	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q25	<.67	<1.9	<.71	.93	<3.2	<1.7	<1.7	<1.7	<.68
Q26	<.67	<1.9	<.71	<.50	<3.2	<3.0	<3.0	<3.0	<.68
Q27	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q28	<.67	<1.9	<.71	<.50	<3.2	<3.0	<3.0	<3.0	<.68
Confined-aquifer-system samples									
Q09B	<.67	<1.9	<.71	<.50	<3.6	<1.7	<1.7	<1.7	<.68
Q16A	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q16A (D)	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q18B	<.67	<1.9	<.71	1.5	<3.2	<1.7	<1.7	<1.7	<.68
Q19A	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Q20A	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68

Table 4c. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Volatile organic compounds and total organic halogens--Continued*

Well no. (fig. 3)	1,2-Di-chloro-ethane	1,1-Di-chloro-ethylene	1,2-Di-chloro-ethylene	1,2-Di-chloro-propane	*cis*-1,3-Di-chloro-propene	*trans*-1,3-Di-chloro-propene	Ethyl-benzene	Fluor-ene	Methyl-ene chlo-ride
Surficial-aquifer samples									
Q01	<0.50	<0.50	<0.50	<0.50	<0.58	<0.70	<0.50	<3.7	<2.3
Q02	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q03	<.50	.57	<.50	<.50	<.58	<.70	<.50	<4.0	<2.3
Q05	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q06	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q07	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q08	<.50	<.50	<.50	<.50	<.58	<.70	3.2	<3.7	<2.3
Q09A	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q10	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q11	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q11 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<5.0	<3.0
Q12	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q13	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q14	<50	<50	<50	<50	<60	<70	<50	<3.7	<200
Q15	<.50	<.50	3.4	<.50	<.58	<.70	<.50	<3.7	<2.3
Q16B	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q17	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q18A	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q18A (D)	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q20B	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q21	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q21 (D)	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q21 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<5.0	<3.0
Q22	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q24	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q25	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q26	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q27	<.50	<.50	2.1	<.50	<.58	<.70	<.50	<7.0	<2.3
Q28	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<7.0	<2.3
Confined-aquifer-system samples									
Q09B	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q16A	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q16A (D)	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q18B	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q19A	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Q20A	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3

Table 4c. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Volatile organic compounds and total organic halogens--Continued*

Well no. (fig. 3)	1,1,2,2-Tetra-chloro-ethane	Tetra-chloro-ethyl-ene	Toluene	1,1,1-Tri-chloro-ethane	1,1,2-Tri-chloro-ethane	Tri-chloro-ethyl-ene	Tri-chloro-fluoro-methane	Vinyl chlo-ride	Xylenes, total
Surficial-aquifer samples									
Q01	<0.51	<1.6	<0.50	<0.50	<1.2	<0.5	<1.4	<2.6	<0.84
Q02	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q03	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q05	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q06	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q07	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q08	<.51	<1.6	13	<.50	<1.2	<.5	<1.4	<2.6	17
Q09A	10	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q10	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q11	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q11 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0
Q12	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q13	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q14	2,000	<200	<50	<50	<100	1,000	<100	<300	<80
Q15	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q16B	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q17	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q18A	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q18A (D)	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q20B	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q21	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q21 (D)	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q21 (S)	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0
Q22	4.0	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q24	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q25	12	<1.6	<.50	<.50	<1.2	9	<1.4	<2.6	<.84
Q26	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	.80
Q27	6.1	<1.6	<.50	<.50	<1.2	.5	<1.4	<2.6	<.84
Q28	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Confined-aquifer-system samples									
Q09B	<.51	<1.6	<0.50	<.50	<1.2	<.5	<1.4	<2.9	<.84
Q16A	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q16A (D)	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q18B	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q19A	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Q20A	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989-- Semivolatile organic compounds*

[Concentrations in micrograms per liter; <, less than; --, missing data; D, duplicate sample; S, split sample]

Well no. (fig. 3)	Ace-naph-thene	Ace-naph-thylene	Acetic acid, vinyl ester	Acetone	Acro-lein	Acrylo-ni-trile	Aldrin	An-thra-cene	alpha-Benzene hexa-chlor-ide
Surficial-aquifer samples									
Q01	<1.7	<0.50	<8.3	<13.0	<100	<100	<4.7	<0.50	<4.0
Q02	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q03	<2.0	<.60	<9.3	<13.0	<100	<100	<6.0	<.60	<5.0
Q05	<1.7	<.50	<9.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q06	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q07	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q08	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q09A	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q10	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q11	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q11 (S)	<5.0	<5.0	--	--	--	--	<.01	<5.0	<.01
Q12	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q13	<1.7	<.50	<9.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q14	<1.7	<.50	<800	<1,000	<1,000	<1,000	<4.7	<.50	<4.0
Q15	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q16B	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q17	<1.7	<.50	<9.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q18A	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q18A (D)	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q20B	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q21	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q21 (D)	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q21 (S)	<5.0	<5.0	--	--	--	--	<.01	<5.0	<.01
Q22	<1.7	<.50	<9.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q24	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q25	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q26	<3.0	<1.0	<8.3	<13.0	<100	<100	<10	<1.0	<8.0
Q27	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q28	<3.0	<1.0	<8.3	<13.0	<100	<100	<10	<1.0	<8.0
Confined-aquifer-system samples									
Q09B	<1.7	<.50	<9.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q16A	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q16A (D)	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q18B	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q19A	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Q20A	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	beta-Benzenehexachloride	delta-Benzenehexachloride	Benzidine	Benzo [a] anthracene	Benzo [b] fluoranthene	Benzo[k] fluoranthene	Benzoic acid	Benzo[g,h,i] perylene	Benzo [a] pyrene
Surficial-aquifer samples									
Q01	<4.0	<4.0	<10.0	<1.6	<5.4	<0.87	<13.0	<6.1	<4.7
Q02	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q03	<5.0	<5.0	<10.0	<2.0	<6.0	<1.0	<20.0	<7.0	<6.0
Q05	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q06	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q07	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q08	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q09A	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q10	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q11	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q11 (S)	<.01	<.01	--	<5.0	<10.0	<10.0	--	<10.0	<10.0
Q12	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q13	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q14	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q15	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q16B	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q17	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q18A	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q18A (D)	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q20B	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q21	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q21 (D)	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q21 (S)	<.01	<.01	--	<5.0	<10.0	<10.0	--	<10.0	<10.0
Q22	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q24	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q25	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q26	<8.0	<8.0	<20.0	<3.0	<10	<2.0	<30.0	<10.0	<9.0
Q27	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q28	<8.0	<8.0	<20.0	<3.0	<10	<2.0	<30.0	<10.0	<9.0
Confined-aquifer-system samples									
Q09B	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q16A	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q16A (D)	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q18B	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q19A	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7
Q20A	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1	<4.7

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Benzo thia-zole	Benzyl alcohol	Bis (2-chloro-ethoxy) methane	Bis (2-chloro-ethyl) ether	Bis (2-chloro-iso-propyl ether	2,2-Bis (para-chloro-phenyl)-1,1-dichloro-ethane	2,2-Bis (para-chloro-phenyl)-1,1-dichloro-ethene	2,2-Bis (para-chloro-phenyl)-1,1,1-tri-chloroethane
Surficial-aquifer samples								
Q01	<2.11	<0.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q02	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q03	<2.11	<.90	<2.0	<2.0	<6.0	<5.0	<6.0	<10
Q05	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q06	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q07	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q08	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q09A	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q10	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q11	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q11 (S)	--	--	<5.0	<5.0	<5.0	<.01	--	--
Q12	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q13	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q14	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q15	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q16B	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q17	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q18A	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q18A (D)	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q20B	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q21	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q21 (D)	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q21 (S)	--	--	<5.0	<5.0	<5.0	<.01	--	--
Q22	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q24	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q25	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q26	<2.11	<1.0	<3.0	<4.0	<10	<8.0	<10	<20
Q27	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q28	<2.11	<1.0	<3.0	<4.0	<10	<8.0	<10	<20
Confined-aquifer-system samples								
Q09B	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q16A	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q16A (D)	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q18B	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q19A	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2
Q20A	<2.11	<.72	<1.5	<1.9	<5.3	<4.0	<4.7	<9.2

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989-- Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Bis(2-ethyl hexyl) phthalate	Bromomethane	4-Bromophenyl-phenyl ether	Butylbenzyl phthalate	Carbon disulfide	alpha-Chlordane	gamma-Chlordane	4-Chloroaniline	2-Chloronaphthalene
Surficial-aquifer samples									
Q01	<4.8	<5.8	<4.2	<3.4	<0.5	<5.1	<5.1	<7.3	<0.50
Q02	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q03	<6.0	<5.8	<5.0	<4.0	<.5	<6.0	<6.0	<9.0	<.60
Q05	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q06	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q07	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q08	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q09A	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q10	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q11	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q11 (S)	<5.0	<3.0	<5.0	<5.0	--	--	--	--	<5.0
Q12	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q13	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q14	<4.8	<600	<4.2	<3.4	<50	<5.1	<5.1	<7.3	<.50
Q15	5.4	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q16B	7.0	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q17	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q18A	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q18A (D)	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q20B	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q21	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q21 (D)	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q21 (S)	<5.0	<3.0	<5.0	<5.0	--	--	--	--	<5.0
Q22	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q24	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q25	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q26	29	<5.8	<8.0	<7.0	<.5	<10	<10	<10	<1.0
Q27	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q28	5.7	<5.8	<8.0	<7.0	<.5	<10	<10	<10	<1.0
Confined-aquifer-system samples									
Q09B	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q16A	7.9	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q16A (D)	<4.8	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q18B	5.4	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q19A	300	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50
Q20A	8.7	<5.8	<4.2	<3.4	<.5	<5.1	<5.1	<7.3	<.50

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989-Semivolatile organic compounds--Continued*

Well no. (fig. 3)	2-Chlorophenol	4-Chlorophenylmethyl sulfide	4-Chlorophenylmethyl sulfone	4-Chlorophenylmethyl sulfoxide	4-Chlorophenylphenyl ether	Chrysene	Dibenz [a, h] anthracene	Dibenzofuran
Surficial-aquifer samples								
Q01	<0.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q02	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q03	<1.0	<1.26	<4.72	<4.23	<6.0	<3.0	<8.0	<2.0
Q05	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q06	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q07	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q08	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q09A	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q10	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q11	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q11 (S)	<5.0	--	--	--	<5.0	<10.0	<10.0	--
Q12	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q13	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q14	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q15	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q16B	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q17	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q18A	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q18A (D)	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q20B	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q21	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q21 (D)	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q21 (S)	<5.0	--	--	--	<5.0	<10.0	<10.0	--
Q22	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q24	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q25	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q26	<2.0	<1.26	<4.72	<4.23	<10	<5.0	<10	<3.0
Q27	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q28	<2.0	<1.26	<4.72	<4.23	<10	<5.0	<10	<3.0
Confined-aquifer-system samples								
Q09B	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q16A	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q16A (D)	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q18B	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q19A	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7
Q20A	<.99	<1.26	<4.72	<4.23	<5.1	<2.4	<6.5	<1.7

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Di-n-butyl phthalate	Dichlorobenzenes	3,3' Dichlorobenzidine	2, 4-Dichlorophenol	Dieldrin	Diethyl phthalate	Dimethyl disulfide	2, 4-Dimethylphenol
Surficial-aquifer samples								
Q01	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q02	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q03	<4.0	<10.0	<10.0	<3.0	<6.0	<2.0	<1.14	<7.0
Q05	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q06	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q07	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q08	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q09A	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q10	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q11	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q11 (S)	<5.0	--	--	<5.0	<.01	<5.0	--	<5.0
Q12	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q13	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q14	<3.7	<1,000	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q15	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q16B	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q17	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q18A	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q18A (D)	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q20B	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q21	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q21 (D)	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q21 (S)	<5.0	--	--	<5.0	<.01	<5.0	--	<5.0
Q22	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q24	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q25	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q26	<7.0	<10.0	<20.0	<6.0	<10	<4.0	<1.14	<10
Q27	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q28	<7.0	<10.0	<20.0	<6.0	<10	<4.0	<1.14	<10
Confined-aquifer-system samples								
Q09B	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q16A	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q16A (D)	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q18B	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q19A	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8
Q20A	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	<1.14	<5.8

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Dimethyl phthalate	2,4-Dinitrophenol	2,4-Dinitrotoluene	2,6-Dinitrotoluene	Di-n-octyl phthalate	1,2-Diphenylhydrazine	Dithiane	alpha-Endosulfan
Surficial-aquifer samples								
Q01	<1.5	<21.0	<4.5	<0.79	<15.0	<2.0	<1.11	<9.2
Q02	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q03	<2.0	<30.0	<5.0	<.90	<20.0	<2.0	<1.11	<10
Q05	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q06	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q07	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q08	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q09A	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q10	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q11	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q11 (S)	<5.0	<20.0	<5.0	<5.0	<10.0	--	--	--
Q12	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q13	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q14	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q15	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q16B	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q17	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q18A	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q18A (D)	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q20B	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q21	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q21 (D)	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q21 (S)	<5.0	<20.0	<5.0	<5.0	<10.0	--	--	--
Q22	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q24	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q25	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q26	<3.0	<40.0	<9.0	<2.0	<30.0	<4.0	<1.11	<20
Q27	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q28	<3.0	<40.0	<9.0	<2.0	<30.0	<4.0	<1.11	<20
Confined-aquifer-system samples								
Q09B	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q16A	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q16A (D)	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q18B	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q19A	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2
Q20A	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	<1.11	<9.2

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	beta-Endosulfan	Endosulfan sulfate	Endrin	Endrin ketone	Fluoranthene	Heptachlor	Heptachlor epoxide	Hexachlorobenzene	Hexachlorobutadiene
Surficial-aquifer samples									
Q01	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q02	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q03	<10	<10	<10	<10	<4.0	<2.0	<6.0	<2.0	<4.0
Q05	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q06	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q07	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q08	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q09A	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q10	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q11	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q11 (S)	--	--	<.01	--	<5.0	<.01	<.01	<5.0	<5.0
Q12	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q13	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q14	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q15	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q16B	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q17	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q18A	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q18A (D)	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q20B	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q21	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q21 (D)	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q21 (S)	--	--	<.01	--	<5.0	<.01	<.01	<5.0	<5.0
Q22	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q24	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q25	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q26	<20	<20	<20	<20	<7.0	<4.0	<10	<3.0	<7.0
Q27	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q28	<20	<20	<20	<20	<7.0	<4.0	<10	<3.0	<7.0
Confined-aquifer-system samples									
Q09B	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q16A	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q16A (D)	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q18B	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q19A	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Q20A	<9.2	<9.2	<7.6	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Hexa-chloro-cyclo-penta-diene	Hexa-chloro-ethane	Indeno [1,2,3-c,d] pyrene	Iso-phorone	Lindane	Meth-oxy-chlor	Methyl-n-butyl ketone	3-Methyl-4-chloro-phenol
Surficial-aquifer samples								
Q01	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q02	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q03	<10	<2.0	<10	<6.0	<5.0	<6.0	<3.6	<5.0
Q05	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q06	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q07	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q08	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q09A	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q10	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q11	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q11 (S)	<5.0	<5.0	<10.0	<5.0	<.01	<.01	--	<30.0
Q12	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q13	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q14	<8.6	2.6	<8.6	<4.8	<4.0	<5.1	<400	<4.0
Q15	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q16B	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q17	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q18A	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q18A (D)	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q20B	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q21	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q21 (D)	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q21 (S)	<5.0	<5.0	<10.0	<5.0	<.01	<.01	--	<30.0
Q22	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q24	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q25	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q26	<20	<3.0	<20	<10	<8.0	<10	<3.6	<8.0
Q27	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q28	<20	<3.0	<20	<10	<8.0	<10	<3.6	<8.0
Confined-aquifer-system samples								
Q09B	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q16A	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q16A (D)	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q18B	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q19A	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0
Q20A	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	2-Methyl-4,6-di-nitro-phenol	Methyl-iso-butyl ketone	Methyl-ethyl ketone	2-Methyl-naphtha-lene	2-Methyl phenol	4-Methyl-phenol	Naph-tha-lene	2-Nitro-aniline	3-Nitro-aniline
Surficial-aquifer samples									
Q01	<17.0	<3.0	<6.4	<1.7	<3.9	<0.52	<0.5	<4.3	<4.9
Q02	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q03	<20.0	<3.0	<6.4	<2.0	<8.0	<.60	<.5	<5.0	<6.0
Q05	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q06	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q07	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q08	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q09A	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q10	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q11	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q11 (S)	<30.0	--	--	--	--	--	<5.0	--	--
Q12	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q13	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q14	<17.0	<300	<600	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q15	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q16B	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q17	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q18A	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q18A (D)	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q20B	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q21	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q21 (D)	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q21 (S)	<30.0	--	--	--	--	--	<5.0	--	--
Q22	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q24	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q25	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q26	<30.0	<3.0	<6.4	<3.0	<5.0	<1.0	<1	<9.0	<10
Q27	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q28	<30.0	<3.0	<6.4	<3.0	<5.0	<1.0	<1	<9.0	<10
Confined-aquifer-system samples									
Q09B	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q16A	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q16A (D)	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q18B	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q19A	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9
Q20A	<17.0	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	4-Nitro-aniline	2-Nitro-benzene	4-Nitro-phenol	N-Nitroso-di-Nitro-phenol	N-Nitroso-di-N-methyl-amine	N-Nitroso-di-propyl-amine	1,4-phenyl-amine	Oxa-thiane	PCB 1016
Surficial-aquifer samples									
Q01	<5.2	<0.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q02	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q03	<6.0	<.6	<4.0	<10.0	<2.0	<5.0	<4.0	<1.98	<20.0
Q05	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q06	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q07	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q08	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q09A	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q10	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q11	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q11 (S)	--	<5.0	<5.0	<30.0	<5.0	<5.0	<5.0	--	<.1
Q12	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q13	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q14	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q15	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q16B	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q17	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q18A	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q18A (D)	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q20B	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q21	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q21 (D)	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q21 (S)	--	<5.0	<5.0	<30.0	<5.0	<5.0	<5.0	--	--
Q22	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q24	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q25	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q26	<10	<1.0	<7.0	<20.0	<4.0	<9.0	<6.0	<1.98	<40.0
Q27	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q28	<10	<1.0	<7.0	<20.0	<4.0	<9.0	<6.0	<1.98	<40.0
Confined-aquifer-system samples									
Q09B	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q16A	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q16A (D)	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q18B	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q19A	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0
Q20A	<5.2	<.5	<3.7	<12.0	<2.0	<4.4	<3.0	<1.98	<21.0

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989-- Semivolatile organic compounds--Continued*

Well no. (fig. 3)	PCB 1221	PCB 1232	PCB 1242	PCB 1248	PCB 1254	PCB 1260	Penta-chloro-phenol	Phen-anth-rene	Phen-ol
Surficial-aquifer samples									
Q01	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<0.5	<9.2
Q02	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q03	<20.0	<20.0	<40.0	<40.0	<50.0	<50.0	<20.0	<.6	<10
Q05	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q06	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q07	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q08	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q09A	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q10	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q11	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q11 (S)	<.1	<.1	<.1	<.1	<.1	<.1	<30.0	<5.0	<5.0
Q12	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q13	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q14	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q15	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q16B	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q17	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q18A	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q18A (D)	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q20B	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q21	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q21 (D)	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q21 (S)	--	--	--	--	--	--	<30.0	<5.0	<5.0
Q22	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q24	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q25	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q26	<40.0	<40.0	<60.0	<60.0	<80.0	<80.0	<40.0	<1.0	<20
Q27	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q28	<40.0	<40.0	<60.0	<60.0	<80.0	<80.0	<40.0	<1.0	<20
Confined-aquifer-system samples									
Q09B	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q16A	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q16A (D)	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q18B	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q19A	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2
Q20A	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5	<9.2

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	Pyrene	Styrene	Thio-di-glycol	Toxa-phene	1,2,4-Tri-chloro-benzene	2,4,5-Tri-chloro-phenol	2,4,6-Tri-chloro-phenol
Surficial-aquifer samples							
Q01	<2.8	<0.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q02	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q03	<3.0	<.5	<65.9	<50.0	<2.0	<6.0	<5.0
Q05	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q06	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q07	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q08	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q09A	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q10	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q11	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q11 (S)	<5.0	<3.0	--	<1.0	<5.0	--	<20.0
Q12	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q13	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q14	<2.8	<50	<65.9	<36.0	<1.8	<5.2	<4.2
Q15	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q16B	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q17	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q18A	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q18A (D)	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q20B	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q21	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q21 (D)	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q21 (S)	<5.0	<3.0	--	<1.0	<5.0	--	<20.0
Q22	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q24	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q25	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q26	<6.0	<.5	<65.9	<80.0	<4.0	<10	<8.0
Q27	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q28	<6.0	<.5	<65.9	<80.0	<4.0	<10	<8.0
Confined-aquifer-system samples							
Q09B	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q16A	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q16A (D)	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q18B	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q19A	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Q20A	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2

Table 4d. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Well no. (fig. 3)	2-ethyl-1-hexanol[1]	1,2-epoxy-cyclohexene[1]	Tridecane[1]
Surficial-aquifer samples			
Q03	--	--	10
Q07	--	2.0	--
Q14	--	2.0	--
Q24	--	1.0	--
Q28	--	2.0	--
Confined-aquifer-system samples			
Q16A	3.0	--	--
Q18B	3.0	1.0	--
Q19A	3.0	--	--

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[1] Compounds identified during chromatograph analysis of base-neutral acid-extractable compounds. These compounds may not be reported in routine analyses

Table 4e. *Results of chemical analyses of water from selected wells on Graces Quarters, Aberdeen Proving Ground, spring 1989--*
Unknown compounds

[Concentrations in micrograms per liter; all concentrations are approximate. Compound names are codes. Codes are designated by the U.S. Army Toxic and Hazardous Materials Agency to distinguish one unknown compound from another. Compounds coded UNK500 and above probably are semivolatile compounds. --, compound not reported]

Well no. (fig. 3)	UNK511	UNK512	UNK534	UNK541	UNK546	UNK549	UNK550	UNK555	UNK562	UNK599
Surficial-aquifer samples										
Q02	--	--	--	--	--	--	--	--	--	--
Q03	--	--	--	--	--	4.0	--	--	--	--
Q07	--	--	--	--	--	--	--	--	5.0	--
Q09A	--	--	--	--	--	--	--	--	--	--
Q10	--	--	--	--	--	--	--	--	--	3.0
Q11	--	--	--	--	--	--	--	--	--	3.0
Q12	5.0	--	--	--	--	--	--	--	--	--
Q14	--	--	--	1.0	--	--	2.0	5.0	--	--
Q18A	--	--	--	--	--	--	--	--	--	--
Q24	--	4.0	--	--	--	--	--	--	--	--
Q26	--	--	--	--	--	--	--	--	--	80
Q28	--	6.0	--	--	--	--	--	--	--	50
Confined-aquifer-system samples										
Q16A	--	--	4.0	--	--	--	--	--	--	4.0
Q18B	--	--	--	--	1.0	--	--	--	--	--
Q19A	--	--	--	--	--	--	--	--	--	--

Well no. (fig. 3)	UNK614	UNK616	UNK630	UNK637	UNK647	UNK657
Surficial-aquifer samples						
Q02	--	3.0	--	--	--	--
Q03	--	--	--	--	--	--
Q07	--	3.0	--	--	--	--
Q09A	--	--	--	--	8.0	--
Q10	--	2.0	--	--	--	--
Q11	--	3.0	--	--	--	--
Q12	--	--	--	--	--	--
Q14	--	2.0	--	--	--	--
Q18A	1.0	--	--	--	--	--
Q24	9.0	2.0	90	30	--	--
Q26	--	--	--	--	--	--
Q28	--	--	--	--	--	--
Confined-aquifer-system samples						
Q16A	--	--	--	--	--	--
Q18B	--	8.0	--	7.0	--	4.0
Q19A	--	5.0	--	--	--	--

Table 5a. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Physical properties, major constituents, and nutrients*

[μS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; --, missing data; <, less than; D, duplicate sample]

Sampling site (fig. 4)	Date	Specific conductance (μS/cm)	pH (standard units)	Oxygen, dissolved (mg/L)	Oxygen demand, chemical (low level) (mg/L)	Oxygen demand, biochemical, 5-day (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)
Inland samples										
SW04	05-24-89	45	6.02	8.1	35	0.004	2.57	1.83	2.71	1.99
SW06	05-25-89	45	5.97	2.1	26	.002	6.12	1.43	1.86	1.72
SW07	05-25-89	86	6.38	6.4	22	0	10.4	2.92	3.03	<.375
SW07 (D)	05-25-89	86	6.38	6.4	21	0	12.4	3.97	2.99	<.375
SW08	05-25-89	212	5.85	5.5	53	.002	10.9	7.30	19.1	.919
SW09	05-24-89	170	6.18	--	110	.001	29.0	4.66	1.98	4.13
SW10	05-24-89	63	6.54	5.9	71	.002	8.42	3.39	1.11	2.45
SW11	05-24-89	65	4.56	6.5	29	0	4.58	1.81	3.00	<.375
Estuarine samples										
SW01	05-24-89	302	6.61	7.7	15	.001	11.6	7.94	32.6	3.27
SW02	05-24-89	319	6.91	8.5	8	.002	11.1	8.70	39.5	4.00
SW03	05-25-89	368	6.67	7.8	4	.001	10.6	9.08	44.3	3.73
SW05	05-25-89	1,750	6.12	7.5	15	.001	12.0	35.0	280	13.3

Sampling site (fig. 4)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Residue, volatile, dissolved (mg/L)	Residue, total, at 105 °C, suspended (mg/L)	Nitrogen, NO_2+NO_3 (mg/L as N)
Inland samples									
SW04	9	11	<10.0	2.90	<1.23	<1.0	102	30	<0.010
SW06	23	28	<10.0	<2.12	<1.23	<1.0	80	14	.013
SW07	25	30	11.1	<2.12	<1.23	<1.0	82	<2	.016
SW07 (D)	25	30	11.1	<2.12	<1.23	<1.0	86	1	.013
SW08	10	12	22.9	55.0	<1.23	<1.0	230	8	.013
SW09	65	79	14.0	<2.12	<1.23	<1.0	194	10	1.70
SW10	20	24	<10.0	<2.12	<1.23	<1.0	286	88	.013
SW11	0	0	20.8	2.93	<1.23	<1.0	82	41	.250
Estuarine samples									
SW01	29	35	14.9	71.0	<1.23	<1.0	214	21	.990
SW02	33	40	17.1	88.0	<1.23	<1.0	390	142	.980
SW03	33	40	17.1	93.0	<1.23	<1.0	246	42	.960
SW05	10	12	91.0	540	<1.23	1.3	--	26	.560

Table 5b. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Minor constituents*

[Concentrations in micrograms per liter; --, missing data; <, less than; D, duplicate sample]

Sampling site (fig. 4)	Date	Aluminum (as Al)	Antimony (as Sb)	Barium (as Ba)	Beryllium (as Be)	Cadmium (as Cd)	Chromium (as Cr)
Inland samples							
SW04	05-24-89	474	<38	14.4	<5.0	<4.01	<6.02
SW06	05-25-89	662	<38	16.6	<5.0	<4.01	<6.02
SW07	05-25-89	<141	<38	14.1	<5.0	<4.01	<6.02
SW07 (D)	05-25-89	<141	<38	11.8	<5.0	<4.01	<6.02
SW08	05-25-89	478	<38	43.0	<5.0	<4.01	7.75
SW09	05-24-89	656	<38	72.2	<5.0	<4.01	<6.02
SW10	05-24-89	13,100	<38	59.6	<5.0	<4.01	16.1
SW11	05-24-89	727	<38	52.7	<5.0	<4.01	<6.02
Estuarine samples							
SW01	05-24-89	667	<38	40.8	<5.0	12.2	16.5
SW02	05-24-89	2,020	<38	18.2	<5.0	<4.01	9.57
SW03	05-25-89	815	<38	15.6	<5.0	4.02	<6.02
SW05	05-25-89	751	<38	13.5	<5.0	<4.01	<6.02

Sampling site (fig. 4)	Copper (as Cu)	Iron (as Fe)	Manganese (as Mn)	Nickel (as Ni)	Silver (as Ag)	Thallium (as Ti)	Zinc (as Zn)
Inland samples							
SW04	8.80	1,440	54.7	<34.3	<4.60	<81.4	<21.1
SW06	<8.09	1,440	600	<34.3	<4.60	<81.4	<21.1
SW07	16.2	708	131	<34.3	<4.60	<81.4	55.4
SW07 (D)	10.9	1,040	132	<34.3	<4.60	<81.4	64.5
SW08	9.47	3,220	2,400	<34.3	<4.60	<81.4	40.0
SW09	11.2	1,270	73.0	<34.3	<4.60	<81.4	34.4
SW10	30.9	13,300	166	<34.3	<4.60	<81.4	48.6
SW11	12.2	254	198	<34.3	<4.60	<81.4	75.3
Estuarine samples							
SW01	31.2	1,110	59.0	53.1	<4.60	<81.4	65.6
SW02	15.5	4,020	41.3	<34.3	<4.60	<81.4	31.7
SW03	12.2	642	24.6	<34.3	<4.60	<81.4	<21.1
SW05	<8.09	904	211	<34.3	<4.60	<81.4	<21.1

Table 5c. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989-- Volatile organic compounds and total organic halogens*

[Concentrations in micrograms per liter unless specified. mg/L, milligrams per liter; --, missing data; <, less than; D, duplicate sample; S, split sample]

Sampling site (fig. 4)	Date	Carbon, organic, total (mg/L as C)	Phenols, nonspecific, total	Halide, total organic	Benzene	Bromodichloromethane	Bromoform	Carbon tetrachloride	Chlorobenzene
Inland samples									
SW04	05-24-89	10.9	<7.12	20.9	--	--	--	--	--
SW06	05-25-89	11.9	<7.12	15.2	<0.50	<0.59	<2.6	<0.58	<0.50
SW07	05-25-89	8.15	<7.12	86.3	<.50	<.59	<2.6	<.58	<.50
SW07 (D)	05-25-89	8.33	<7.12	30.4	<.50	<.59	<2.6	<.58	<.50
SW08	05-25-89	16.0	10.7	55.1	<.50	<.59	<2.6	<.58	<.50
SW09	05-24-89	20.2	9.43	6.20	<.50	<.59	<2.6	<.58	<.50
SW10	05-24-89	20.8	17.6	25.2	<.50	<.59	<2.6	<.58	<.50
SW11	05-24-89	11.1	<7.12	40.9	<.50	<.59	<2.6	<.58	<.50
Estuarine samples									
SW01	05-24-89	3.69	<7.12	25.2	<.50	<.59	<2.6	<.58	<.50
SW02	05-24-89	3.71	--	18.8	<.50	<.59	<2.6	<.58	<.50
SW03	05-25-89	3.67	<7.12	18.6	<.50	<.59	<2.6	<.58	<.50
SW05	05-25-89	5.31	<7.12	112	<.50	<.59	<2.6	<.58	<.50

Sampling site (fig. 4)	Chlorodibromomethane	Chloroethane	2-Chloroethylvinylether	Chloroform	Chloromethane	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,1-Dichloroethane
Inland samples									
SW04	--	--	--	--	--	<1.7	<1.7	<1.7	--
SW06	<0.67	<1.9	<0.71	<0.50	<3.2	<1.7	<1.7	<1.7	<0.68
SW07	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW07 (D)	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW08	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW09	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW10	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW11	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
Estuarine samples									
SW01	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW02	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW03	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68
SW05	<.67	<1.9	<.71	<.50	<3.2	<1.7	<1.7	<1.7	<.68

Table 5c. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Volatile organic compounds and total organic halogens--Continued*

Sampling site (fig. 4)	1,2-Di-chloro-ethane	1,1-Di-chloro-ethylene	1,2-Di chloro-ethylene	1,2-Di-chloro-propane	*cis-* 1,3-Di-chloro-propene	*trans-* 1,3-Di-chloro-propene	Ethyl-benzene	Fluorene	Methylene chloride
Inland samples									
SW04	--	--	--	--	--	--	--	<3.7	--
SW06	<0.50	<0.50	<0.50	<0.50	<0.58	<0.70	<0.50	<3.7	<2.3
SW07	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW07 (D)	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW08	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW09	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW10	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW11	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
Estuarine samples									
SW01	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW02	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW03	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3
SW05	<.50	<.50	<.50	<.50	<.58	<.70	<.50	<3.7	<2.3

Sampling site (fig. 4)	1,1,2,2 Tetra-chloro-ethane	Tetra-chloro-ethylene	Toluene	1,1,1-Tri-chloro-ethane	1,1,2-Tri-chloro-ethane	Tri-chloro-ethylene	Tri-chloro-fluoro-methane	Vinyl chloride	Xylenes total
Inland samples									
SW04	--	--	--	--	--	--	--	--	--
SW06	<0.51	<1.6	<0.50	<0.50	<1.2	<0.5	<1.4	<2.6	<0.84
SW07	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW07 (D)	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW08	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW09	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW10	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW11	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
Estuarine samples									
SW01	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW02	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW03	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84
SW05	<.51	<1.6	<.50	<.50	<1.2	<.5	<1.4	<2.6	<.84

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds*

[Concentrations in micrograms per liter; <, less than; --, missing data; D, duplicate sample]

Sampling site (fig. 4)	Benzo [a] pyrene	Ace-naphlor	Acetic acid, vinyl ester	Acetone	Acrolein	Acrylo-nitrile	Aldrin	Anthracene	alpha-Benzene hexa-chloriide
Inland samples									
SW04	<1.7	<0.50	--	--	--	--	<4.7	<0.50	<4.0
SW06	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW07	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW07 (D)	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW08	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW09	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW10	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW11	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
Estuarine samples									
SW01	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW02	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW03	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0
SW05	<1.7	<.50	<8.3	<13.0	<100	<100	<4.7	<.50	<4.0

Sampling site (fig. 4)	Benzene-hexa-chloride	Benzene-hexachloride	Benzidine	beta-anthracene	Benzene-[b] fluor-anthene	Benzene-[a] [k] fluor-anthene	Benzo-[g,h,i] Benzo-acid	Benzo-perylene
Inland samples								
SW04	<4.0	<4.0	<10.0	<1.6	<5.4	<0.87	<13.0	<6.1
SW06	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW07	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW07 (D)	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW08	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW09	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW10	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW11	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
Estuarine samples								
SW01	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW02	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW03	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1
SW05	<4.0	<4.0	<10.0	<1.6	<5.4	<.87	<13.0	<6.1

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4)	Benzo [a] pyrene	Benzo-thia-zole	Benzyl alcohol	Bis (2-chloro-ethoxy) methane	Bis (2-chloro-ethyl) ether	Bis (2-chloro-iso-propyl) ether	2, 2-Bis (para-chloro-phenyl)-1,1-dichloro-ethane	2, 2-Bis (para-chloro-phenyl 1,1-dichloro-ethene
Inland samples								
SW04	<4.2	--	<0.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW06	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW07	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW07 (D)	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW08	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW09	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW10	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW11	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
Estuarine samples								
SW01	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW02	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW03	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7
SW05	<4.2	--	<.72	<1.5	<1.9	<5.3	<4.0	<4.7

Sampling site (fig. 4)	2, 2-Bis (para-chloro-phenyl)-1,1,1-tri-chloroethane	Bis (2-ethyl) hexyl) phthalate	Bromo-methane	4-Bromo-phenyl-phenyl ether	Butyl-benzyl phthalate	Carbon disulfide	alpha-Chlordane	gamma-Chlordane
Inland samples								
SW04	<9.2	4.5	--	<4.2	<3.4	--	--	<5.1
SW06	<9.2	7.5	<5.8	<4.2	<3.4	<0.5	--	<5.1
SW07	<9.2	4.7	<5.8	<4.2	<3.4	<.5	--	<5.1
SW07 (D)	<9.2	4.5	<5.8	<4.2	<3.4	<.5	--	<5.1
SW08	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1
SW09	<9.2	4.7	<5.8	<4.2	<3.4	<.5	--	<5.1
SW10	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1
SW11	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1
Estuarine samples								
SW01	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1
SW02	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1
SW03	<9.2	5.9	<5.8	<4.2	<3.4	<.5	--	<5.1
SW05	<9.2	<4.8	<5.8	<4.2	<3.4	<.5	--	<5.1

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4)	4-Chloroaniline	2-Chloro-naphthalene	2-Chloro-phenol	*p*-Chloro-phenyl-methyl-sulfide	*p*-Chloro-phenyl-methyl-sulfone	*p*-Chloro-phenyl-methyl-sulfoxide	4-Chloro-phenyl-phenyl-ether	Chrysene
Inland samples								
SW04	<7.3	<0.50	<0.99	--	--	--	<5.1	<2.4
SW06	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW07	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW07 (D)	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW08	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW09	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW10	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW11	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
Estuarine samples								
SW01	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW02	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW03	<7.3	<.50	<.99	--	--	--	<5.1	<2.4
SW05	<7.3	<.50	<.99	--	--	--	<5.1	<2.4

Sampling site (fig. 4)	Dibenzo [a,h] anthracene	Dibenzo furan	Di-n-butyl phthalate	Di-chloro-benzene	3, 3-Di-chloro-benzidine	2, 4-Dichloro-phenol	Dieldrin	Diethyl phthalate	Di-methyl di sulfide
Inland samples									
SW04	<6.5	<1.7	<3.7	--	<12.0	<2.9	<4.7	<2.0	--
SW06	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW07	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW07 (D)	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW08	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW09	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW10	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW11	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
Estuarine samples									
SW01	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW02	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW03	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--
SW05	<6.5	<1.7	<3.7	<10.0	<12.0	<2.9	<4.7	<2.0	--

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4)	2,4-Dimethylphenol	Dimethyl phthalate	2,4-Dinitrophenol	2,4-Dinitrotoluene	2,6-Dinitrotoluene	Di-n-octyl phthalate	1,2-Diphenylhydrazine	Dithiane	alpha-Endosulfan
Inland samples									
SW04	<5.8	<1.5	<21.0	<4.5	<0.79	<15.0	<2.0	--	<9.2
SW06	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW07	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW07 (D)	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW08	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW09	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW10	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW11	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
Estuarine samples									
SW01	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW02	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW03	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2
SW05	<5.8	<1.5	<21.0	<4.5	<.79	<15.0	<2.0	--	<9.2

Sampling site (fig. 4)	beta-Endosulfan	Endosulfan sulfate	Endrin	Endrin aldehyde	Endrin ketone	Fluoranthene	Heptachlor	Heptaepoxide	Hexachlorobenzene	Hexachlorobutadiene
Inland samples										
SW04	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW06	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW07	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW07 (D)	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW08	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW09	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW10	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW11	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
Estuarine samples										
SW01	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW02	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW03	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4
SW05	<9.2	<9.2	<7.6	<8.0	<8.0	<3.3	<2.0	<5.0	<1.6	<3.4

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4)	Hexachlorocyclopentadiene	Hexachloroethane	Indeno [1, 2, 3-c, d] pyrene	Isophorone	Lindane	Methoxychlor	Methyl-n-butyl ketone	3-Methyl-4-chlorophenol	2-Methyl-4, 6-dinitrophenol
Inland samples									
SW04	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	--	<4.0	<17.0
SW06	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW07	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW07 (D)	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW08	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW09	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW10	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW11	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
Estuarine samples									
SW01	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW02	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW03	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0
SW05	<8.6	<1.5	<8.6	<4.8	<4.0	<5.1	<3.6	<4.0	<17.0

Sampling site (fig. 4)	Methyl-iso-butyl ketone	2-Methyl-ethyl ketone	Methyl-naphthalene	2-Methyl phenol	4-Methyl-phenol	Naphthalene	2-Nitro-aniline	3-Nitro-aniline	4-Nitro-aniline
Inland samples									
SW04	--	--	<1.7	<3.9	<0.52	<0.5	<4.3	<4.9	<5.2
SW06	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW07	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW07 (D)	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW08	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW09	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW10	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW11	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
Estuarine samples									
SW01	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW02	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW03	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2
SW05	<3.0	<6.4	<1.7	<3.9	<.52	<.5	<4.3	<4.9	<5.2

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4)	Nitro-benzene	2-Nitro-phenol	4-Nitro-phenol	N-Nitroso-di-methyl-amine	N-Nitroso-di-N-propyl-amine	N-Nitroso-di -phenyl-amine	Oxa- 1, 4-thiane	PCB 1016
Inland samples								
SW04	<0.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW06	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW07	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW07 (D)	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW08	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW09	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW10	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW11	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
Estuarine samples								
SW01	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW02	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW03	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0
SW05	<.5	<3.7	<12.0	<2.0	<4.4	<3.14	--	<21.0

Sampling site (fig. 4)	PCB 1221	PCB 1232	PCB 1242	PCB 1248	PCB 1254	PCB 1260	Pentachlorophenol	Phenanthrene
Inland samples								
SW04	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<0.5
SW06	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW07	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW07 (D)	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW08	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW09	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW10	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW11	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
Estuarine samples								
SW01	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW02	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW03	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5
SW05	<21.0	<21.0	<30.0	<30.0	<36.0	<36.0	<18.0	<.5

Table 5d. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Maryland, spring 1989--Semivolatile organic compounds--Continued*

Sampling site (fig. 4	Pheno	Pyrene	Styrene	Thiodiglycol	Toxaphene	1, 2, 4-Trichloro-benzene	2, 4, 5-Triichloro-phenol	2, 4, 6-Trichloro-phenol
Inland samples								
SW04	<9.2	<2.8	--	<65.9	<36.0	<1.8	<5.2	<4.2
SW06	<9.2	<2.8	<0.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW07	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW07 (D)	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW08	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW09	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW10	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW11	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
Estuarine samples								
SW01	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW02	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW03	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2
SW05	<9.2	<2.8	<.5	<65.9	<36.0	<1.8	<5.2	<4.2

Table 5e. *Results of chemical analyses of surface water from selected sampling sites on Graces Quarters, Aberdeen Proving Ground, Md., spring 1989--Unknown compounds*

[Concentrations in micrograms per liter; all concentrations are approximate. Compound names are codes designated by the U.S. Army Toxic and Hazardous Materials Agency to distinguish one unknown compound from another. Compounds coded UNK500 and above probably are semivolatile compounds. --, compound not reported]

Sampling site (fig. 4)	UNK595	UNK599	UNK642	UNK644	UNK645	UNK646	UNK650
SW01	--	--	--	--	--	4.0	--
SW04	3.0	2.0	5.0	--	8.0	--	10
SW06	--	--	--	5.0	--	--	--
SW08	--	--	--	--	--	4.0	--