



Lithologic and Ground-Water-Quality Data Collected Using Hoverprobe Drilling Techniques at the West Branch Canal Creek Wetland, Aberdeen Proving Ground, Maryland, April-May 2000



Open-File Report 00-446

In cooperation with the

**U.S. ARMY GARRISON, ABERDEEN PROVING GROUND
ENVIRONMENTAL CONSERVATION AND RESTORATION DIVISION
ABERDEEN PROVING GROUND, MARYLAND**



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By Daniel J. Phelan, Michael P. Senus, and Lisa D. Olsen

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2000

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2000
Aberdeen Proving Ground, Edgewood Area

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

	Multiply	By	To obtain
inch (in.)		2.54	centimeter
inch (in.)		25,400	micrometer
square inch (in ²)		6.4516	square centimeter
foot (ft)		0.3048	meter
square foot (ft ²)		0.0929	square meter
gallon (gal)		3.785	liter
milliliter (mL)		0.03381	ounce, fluid
pound (lb)		0.4536	kilogram
pounds per square inch (lb/in ²)		703.1	kilograms per square meter

Vertical datum: 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.

Other abbreviated units of measure: Water temperature, chemical concentration, and other chemical and physical properties of constituents are given in metric units. Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$^{\circ}\text{F} = 1.8 \times (^{\circ}\text{C}) + 32$$

Chemical concentration in water is expressed in milligrams per liter (mg/L), and in micrograms per liter (µg/L).

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Abstract

This report presents lithologic and ground-water-quality data collected during April and May 2000 in the remote areas of the tidal wetland of West Branch Canal Creek, Aberdeen Proving Ground, Maryland. Contamination of the Canal Creek aquifer with volatile organic compounds has been documented in previous investigations of the area. This study was conducted to investigate areas that were previously inaccessible because of deep mud and shallow water, and to support ongoing investigations of the fate and transport of volatile organic compounds in the Canal Creek aquifer. A unique vibracore drill rig mounted on a hovercraft was used for drilling and ground-water sampling. Continuous cores of the wetland sediment and of the Canal Creek aquifer were collected at five sites. Attempts to sample ground water were made by use of a continuous profiler at 12 sites, without well installation, at a total of 81 depths within the aquifer. Of those 81 attempts, only 34 sampling depths produced enough water to collect samples.

Ground-water samples from two sites had the highest concentrations of volatile organic compounds—with total volatile organic compound concentrations in the upper part of the aquifer ranging from about 15,000 to 50,000 micrograms per liter. Ground-water samples from five sites had much lower total volatile organic compound concentrations (95 to 2,100 micrograms per liter), whereas two sites were essentially not contaminated, with total volatile organic compound concentrations less than or equal to 5 micrograms per liter.

Introduction

In 1990, Aberdeen Proving Ground (APG) was placed on the National Priorities List established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The U.S. Army and the U.S. Environmental Protection Agency (USEPA), Region III, signed an Interagency Agreement for investigation and remediation of the Canal Creek area and other areas at APG.

The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Environmental Conservation and Restoration Division (ECRD), began a study in 1992 to determine the distribution, fate, and transport of chlorinated volatile organic compounds (VOCs) in ground water from a selected area of the wetland along the West Branch Canal Creek, APG, Maryland (fig. 1). The initial study area was downgradient from a ground-water contamination site. Floating docks and walkways were installed by the Army to allow access to that area. In response to questions from regulators regarding the possible extent of contamination plumes, the initial study area was expanded in the spring of 2000 to investigate areas of the wetland beyond the floating docks.

Wetland conditions such as deep mud and shallow water cause extreme logistical difficulties in transporting and operating drilling equipment, and severely limit the size and range of equipment available for safe and efficient site investigations. To perform hydrogeologic investigations in these areas, the USGS co-developed a drilling system with Hovertechnics, Inc., and MPI Drilling, Inc., that incorporates a small vibracore (also known as sonic) drill rig mounted on a hovercraft. The combined craft and drill rig is called the “Hoverprobe 2000” (referred to hereafter as the hoverprobe in this report), with the capability to perform continuous coring and ground-water profiling operations in wetlands and other previously inaccessible areas. The hoverprobe was used to collect the lithologic and ground-water samples described in this report. This system was the first use of the hoverprobe at a hazardous-waste site, or at a site where unexploded ordnance (UXO) is a potential hazard. The successful completion of this project demonstrated that hoverprobe drilling and ground-water-quality profiling could be carried out safely at hazardous-waste sites, and sites with UXO.

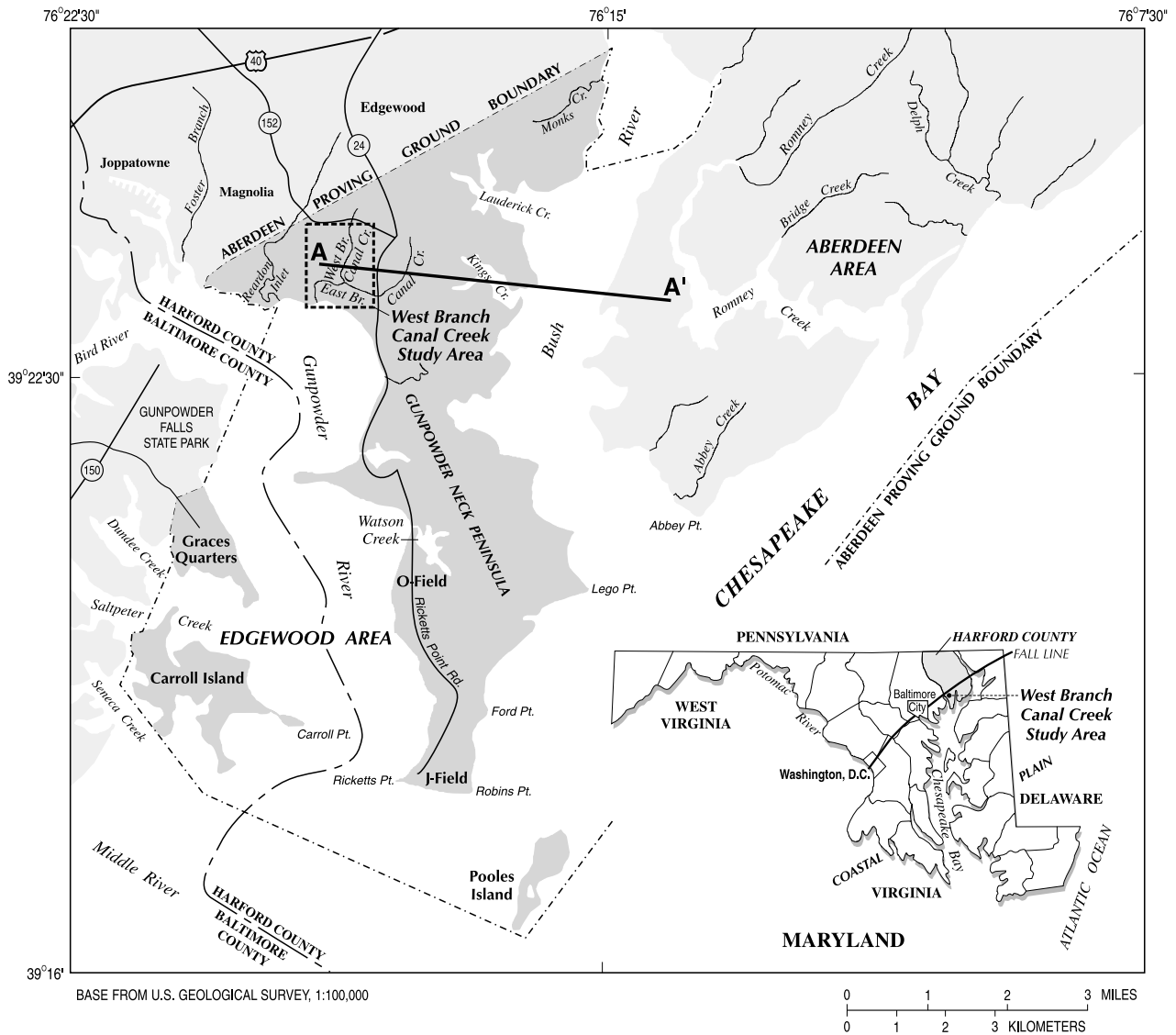


Figure 1. Location of the West Branch Canal Creek study area, Aberdeen Proving Ground, Maryland, and hydrogeologic section A-A' (shown in fig. 3).

Purpose and Scope

The purpose of this report is to present data collected during drilling and ground-water-quality profiling using the USGS hoverprobe during April and May 2000 in the expanded study area of the West Branch Canal Creek wetland. Lithologic data from five sites and organic and inorganic ground-water-quality data from nine sites are presented in the Appendixes at the end of this report.

Site History

Since 1917, APG (fig. 1) has been the primary chemical-warfare research and development center for the U.S. Army. Most of APG's chemical-manufacturing and munitions-filling plants were concentrated in the area of the

West Branch and East Branch Canal Creek. After World War II, large-scale production and filling operations declined sharply, and many of the plants have been demolished or abandoned.

Chlorinated organic solvents, decontaminating agents, and degreasers were common waste products from the manufacturing and filling plants in the Canal Creek area. Waste from many of these activities was discharged into Canal Creek either directly through overland runoff and sewer discharges, or indirectly through the discharge of contaminated ground water into the marsh areas. In the late 1960's, potentially contaminated construction materials from the demolition of some of these manufacturing plants were pushed out into the Canal Creek wetland, creating landfills

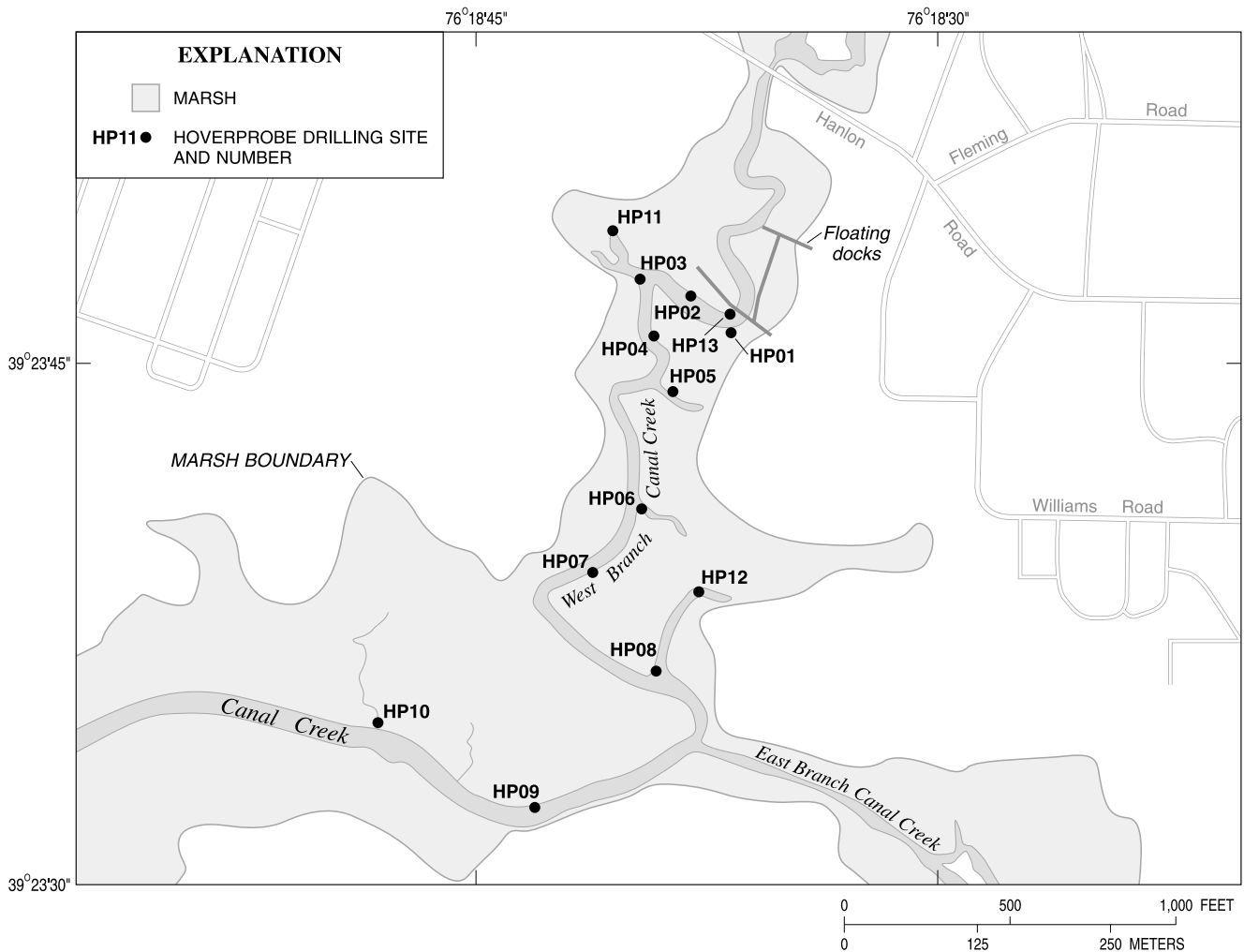


Figure 2. Location of the hoverprobe drilling sites, West Branch Canal Creek, Aberdeen Proving Ground, Maryland.

where there had originally been natural wetland sediments (Lorah and Vroblesky, 1989; Lorah and Clark, 1996).

These various disposal activities resulted in groundwater contamination along the West Branch Canal Creek. No known wastes have discharged to the marsh or creek from the manufacturing plants or sewer systems within the last two decades.

Description of Study Area

Floating docks and walkways were installed in 1994 by the Army to allow access to part of the wetland in the initial West Branch Canal Creek study area (fig. 2). Access to the wetland beyond the dock area is a major logistical problem because of tall, dense grasses (primarily *Phragmites*), and soft mud that typically is more than 8 ft (feet) deep. Surface-water depths can range from 0 to about 5 ft, depending on location, tides, and winds. Small boats can be used in the upper reaches of Canal Creek only at high and medium tides. Low tides could cause most small boats to become stuck in mud for many hours. In addition, unexploded ordnance in

the area (either high-explosive or chemical-round types) must be avoided.

Hydrogeologic Setting

The geology of the Canal Creek area is characterized by thick, wedge-shaped deposits of unconsolidated Coastal Plain sediments that dip southeastward (fig. 3). In the West Branch Canal Creek area, VOCs have been detected in the Canal Creek aquifer. This aquifer ranges from 30 to 70 ft thick in this area (Lorah and Clark, 1996), and is unconfined in the vicinity of the hoverprobe drill sites. The lower confined aquifer, which underlies the approximately 60-ft-thick confining unit, is not known to be contaminated (Lorah and Vroblesky, 1989; Lorah and Clark, 1996). The upper confining unit, the Canal Creek aquifer, the lower confining unit, and the lower confined aquifer are composed of sediments of the Cretaceous Potomac Group (Oliveros and Vroblesky, 1989).

Within the West Branch Canal Creek study area, the Canal Creek aquifer sediments consist of medium- to coarse-

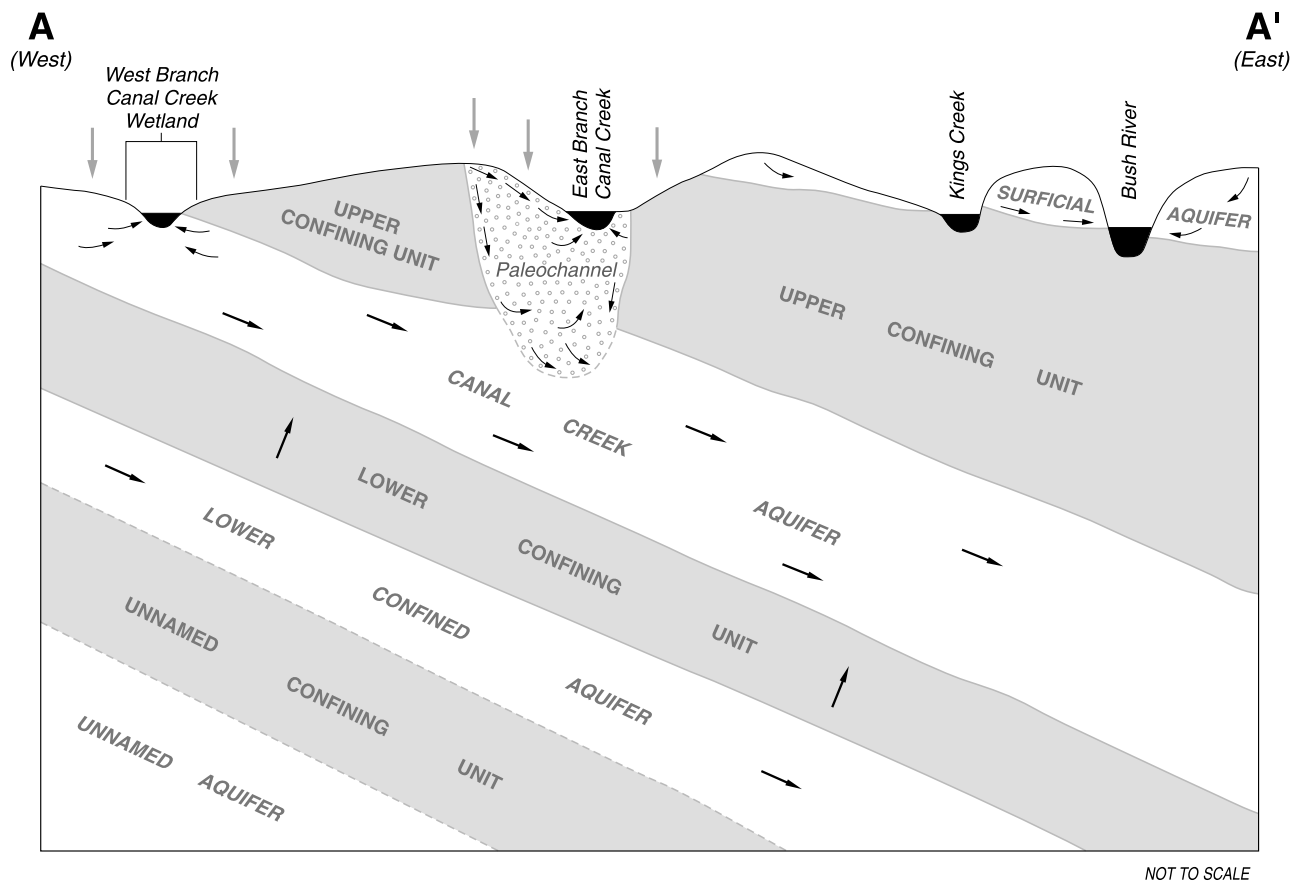


Figure 3. Generalized hydrogeologic section A-A' showing directions of ground-water flow in the Canal Creek area, Aberdeen Proving Ground, Maryland (modified from Lorah and others, 1997, p. 10). [Location of section shown in fig. 1.]

grained sand and gravel, interfingering with thin layers, or lenses, of clay and silt. East of the wetland, the aquifer is overlain by landfill material and the sediments of the upper confining unit. Within the wetland area, measurements from previous studies (Lorah and Clark, 1996; Lorah and others, 1997) showed that the thickness of the wetland sediment ranged from 6 to 12 ft. During this study, the wetland sediments were found to be as thick as 25 ft at HP10, the farthest downstream of the hoverprobe sites (fig. 2).

Shallow ground water on both sides of West Branch Canal Creek generally flows laterally and upward toward the creek channel. Recharge in the form of precipitation occurs upgradient from the creek. Discharge of ground water from the Canal Creek aquifer occurs through the wetland sediments into the creek and surrounding wetland areas (Lorah and Clark, 1996).

Previous Investigations

During 1977–78, the U.S. Army Toxic and Hazardous Materials Agency performed the first survey of the soil, sediment, ground water, and surface water of the Edgewood Area of APG (Nemeth and others, 1983). A study conducted by the USGS during 1985–92 described the hydrogeology of the site, and determined that a large ground-water contaminant plume was present in the Canal Creek aquifer along the West Branch Canal Creek. The study also showed that the contaminated ground water was probably discharging to the creek and its surrounding freshwater wetlands (Lorah and Clark, 1996, fig. 2). Major contaminants included the chlorinated VOCs 1,1,2,2-tetrachloroethane, trichloroethene, and carbon tetrachloride, which are common industrial solvents.

The effects of natural attenuation on VOCs in ground water discharging through the fine-grained marsh sediments were determined by Lorah and others (1997). "Natural attenuation" is a relatively recent term that has been used to refer to all the natural processes that control the fate of contaminants in the environment, including biodegradation, sorption, volatilization, and dispersion, and to recognize that these processes could act to naturally contain or remediate contaminated ground water (Wiedemeier and others, 1998). Biodegradation and sorption were shown to be important mechanisms for natural attenuation of VOCs in the wetland sediments. The relatively thin layers of wetland sediments are critical in reducing contaminant concentrations and the toxicity of ground water before it discharges to the wetland surface and the creek. Hydrogeologic, water-quality, and sediment-quality data collected by the USGS between 1992 and 1996 in the West Branch Canal Creek area are presented in Olsen and others (1997).

Acknowledgments

The authors thank the following people for their important contributions to this investigation. John Wrobel of the U.S. Army Environmental Conservation and Restoration Division, APG, and Allison O'Brien, contractor for APG, provided project and logistical support. William Smithson and other employees of the U.S. Army Center for Health Promotion and Preventive Medicine, Ground Water and Solid Waste Program, Edgewood, Maryland, loaned drilling equipment and supplies for the ordnance-avoidance and drilling phases of the field work, and provided a location for storage of drilling supplies. William Kriner and other employees of the U.S. Army Corps of Engineers, Baltimore District, loaned additional drilling equipment required when drilling techniques had to be modified because of logistical difficulties.

The authors also thank Joel Johnson and William Walters of Human Factors Applications, Inc., Waldorf, Maryland, for performing field work to clear the drill sites of unexploded ordnance. Hugh Scott of MPI Drilling, Inc., Ontario, Canada, trained USGS drillers and field personnel in ground-water-quality profiling procedures with the hoverprobe.

Wayne Newell and Donald Queen of the USGS Geologic Division, Reston, Virginia, allowed the hoverprobe to be used at the site. Donald Queen and Michael Herder performed all hoverprobe drilling. Peter Hughes, USGS, Madison, Wisconsin, loaned the project the 12-ft-long hovercraft that was used for logistical support. David Brower of the USGS, Baltimore, Maryland, trained the project personnel in the safe operation of the support hovercraft.

Methods of Investigation

Drill sites were selected to determine the vertical and horizontal extent of known and suspected ground-water

contamination in the Canal Creek aquifer. Specific site locations were chosen so that the hoverprobe could lie on a relatively flat wetland area while drilling, and so that safe emergency egress from the site was possible in case of accidental injury or contaminant exposure. Because the water is shallow in the freshwater tidal wetland, site access for all field efforts was by an 18-ft johnboat (when possible), a 12-ft hovercraft that was used to ferry personnel and supplies between the shore and drill sites, and the 21.5-ft hoverprobe that was used for drilling and collection of ground-water samples. Before drilling and ground-water sampling could proceed, each site had to be cleared of the potential hazard of UXO and the sediments screened for chemical-warfare materials.

Clearing Sites of Unexploded Ordnance

Safety regulations at APG require each drill site to be cleared of potential UXO. At each site, a two-man UXO team from Human Factors Applications, Inc. of Waldorf, Md., assisted by a two-man USGS team, performed surface magnetometer sweeps covering an area of at least 25 ft by 25 ft. If the site was clear of UXO on the surface, a pilot hole was drilled by hand so that the magnetometer sensors could be lowered into the ground. A 3-in. (inch) polyvinyl chloride (PVC) pipe was hammered into the ground, and mud samples were collected from inside the pipe as it was cleaned out. The magnetometer was lowered inside the pipe as the pipe was advanced in 2-ft increments to a depth of 10 ft. If the sensors did not detect any metal before 10 ft, the site was considered cleared for drilling. The 3-in. PVC pipe was filled with bentonite pellets and left in place to show the drilling location.

Thirteen proposed sites were cleared for drilling, and were labeled HP01 through HP13 (fig. 2), in the order of completion of the pilot holes. Drilling had to be performed within a 1-ft radius of the pilot hole to stay within the effective radius of influence of the magnetometer sweeps. Mud samples were collected from three depths (approximately 3, 6, and 9 ft bsl, or below land surface) at each pilot hole and sent to a U.S. Army laboratory at APG to be screened for chemical-warfare materials.

Description of the Hoverprobe and Drilling Techniques

The USGS hoverprobe used for drilling and ground-water sampling in this study is a unique craft that was developed by USGS in cooperation with Hovertechnics, Inc., of Benton Harbor, Michigan, and MPI Drilling, Inc., of Picton, Ontario. The hoverprobe is the first craft constructed that combines the versatility of a hovercraft with the utility of a drill rig (fig. 4). The hoverprobe is 21.5 ft long and weighs about 4,000 lb (pounds), with a ground-contact area of about 168 ft² (square feet). The pressure on the ground under the craft while at rest totals about 0.17 lb/in² (pounds per square inch), which is only about 10 percent of the pressure exerted on the ground per square inch by a standing person.

Hovercrafts can be flown on land, water, mud, snow, or ice, and are propelled by one or more fans that provide both

lift and thrust. A scoop behind the fan diverts part of the air under the craft to provide the lift. A segmented skirt constructed of rubber-coated fabric surrounds the base of the craft. The skirt traps most of the pressurized air under the craft, allowing it to maintain a constant ground clearance between the craft and the surface. The segmented skirt also allows the craft to conform to various surface textures and conditions, allowing it to fly directly between land, water, ice, snow, or mud. The operator guides the craft by using handlebars and throttle controls similar to a motorcycle or jet ski. The handlebars turn rudders that are located behind the fans, thus steering the craft. No moving parts are located under the craft. The hovercraft can proceed to or from a site even if there is insufficient water to float it.

The drill rig on the hoverprobe is a “Metaprobe” vibracore drill, which is manufactured by MPI Drilling, Inc. Hydraulically driven cams are used to generate high frequency vibrations at the cutting edge of a hollow drill string. A hole and core can be cut, or a monitoring well installed rapidly, with almost no cuttings resulting at the surface. No fluids are used or injected into the ground. The drill can be used to retrieve continuous core up to a maximum depth of about 100 ft from saturated, unconsolidated materials. Drilling can proceed while the craft is on mud, solid ground, or floating on water, and can continue as water levels or tides shift.

The hoverprobe had to be positioned within a 1-ft radius of the magnetometer pilot hole. While the hoverprobe is in hovering mode, the drill hole in the center of the craft must be capped to keep air, water, and mud from blowing up the hole, which prevents workers from locating the pilot hole while moving. To properly position the craft, three PVC guide pipes were pushed vertically into the mud. A center pipe was placed 11.5 ft from the pilot hole, and pipes were placed 4.5 ft to the right and left sides of the pilot hole. The hovercraft was flown between the two side pipes, and the bow was positioned to touch the center guide pipe. This positioning placed the drill hole of the hoverprobe within the area cleared of UXO. The relative placement of the guide pipes, the pilot hole, and the drill hole is shown in figure 5. When the hoverprobe was properly positioned, a 5-in.-diameter PVC surface casing was pushed into the mud to keep the craft aligned over the drill hole as the water level in the creek changed with the tides.

Standard operating procedures (SOPs) (U.S. Army Directorate of Safety, Health, and Environment, 1995, SOP 005, Decontamination) at APG require that drill rigs be decontaminated by steam-cleaning before and after drilling at a contaminated site. The hoverprobe is similar to a large boat because it contains a water-tight hull and bilge pumps. Decontamination (decon) of the rig was done by (1) flying the rig from shore to the floating docks; (2) steam-cleaning the rig while it was in the creek channel; (3) using the bilge pumps and hoses to pump the decon water to a tank on the docks; and (4) using a separate pump to convey the decon water to storage drums on shore for subsequent treatment and disposal.

Sample-Numbering Convention

Sample numbers used in this report are a combination of the magnetometer-sweep site number, and the depth in ft bls from which the sample was obtained. For example, sample HP01-12 is from hoverprobe site 1 at a depth of 12 ft bls, and sample HP13-21 is from site 13 at a depth of 21 ft bls, and so forth. Site HP04 was cleared of UXO, but was not cored or sampled.

Sediment Coring

Continuous sediment cores were collected from five sites: HP01, HP05, HP08, HP10, and HP11 (fig. 2). The vibracore drill rig used in this study (fig. 6) usually recovered 100 percent of the core; however, the amount of compression of the core varied depending on the type of sediments encountered.

The compression of the core was determined by:

- (1) advancing the first 5-ft-long pipe to its maximum depth,
- (2) measuring the length of empty pipe above the core, and
- (3) noting the difference between the two measurements. As each pipe was advanced in 5-ft increments, the depth from the top of the casing to the top of the core was measured, thereby allowing the calculation of how much compression occurred by each 5-ft advancement of the core pipe.

At the first site (HP01), an attempt was made to core continuously through the wetland sediments and the aquifer using schedule 80 PVC pipe. At one point while coring through the gravels of the aquifer, the continuous vibrations of the PVC core pipe liquefied the soft wetland sediments in the pipe. Accurate depth measurements to the top of the core could no longer be made because the tape measure sank gradually through the liquefied sediments. The coring technique was modified as described in the following sections to resolve this problem. The maximum depth of penetration at each site for each type of coring is shown in table 1.

Coring of the Wetland Sediments Wetland sediments at sites HP05, HP08, and HP11 were cored to the top of the aquifer using 3-in.-diameter PVC pipes with clear plastic liners (fig. 6A). The surficial wetland sediments are fine-grained silts and muds, with approximately 60-percent porosity. Coring with the PVC pipe was stopped and the depth recorded when resistance was met at the top of the aquifer. The PVC pipes were then capped and removed from the hoverprobe, then transferred to land to remove the core from the pipes (fig. 6B). Depths to the top of the Canal Creek aquifer (bottom of the wetland sediments) ranged from 10 to 25 ft bls (table 1).

Coring of the Canal Creek Aquifer Sediments The aquifer sediments were cored using 2.5-in.-diameter steel pipes instead of PVC pipe, because the steel pipe can transmit the vibrations better than PVC when drilling through sands and gravels. At sites HP01, HP05, HP08, and HP11, steel drill pipe was lowered into the same holes from which the wetland sediment cores had been retrieved. The bottom of the 2.5-in.-diameter drill pipe was set at the same penetration depth as that of the PVC pipe. The distance from the top of casing to the top of the core was measured to determine the



(A) The hoverprobe drill rig and working area

The drill hole is located in the center, under the mast, and is capped while flying the craft.



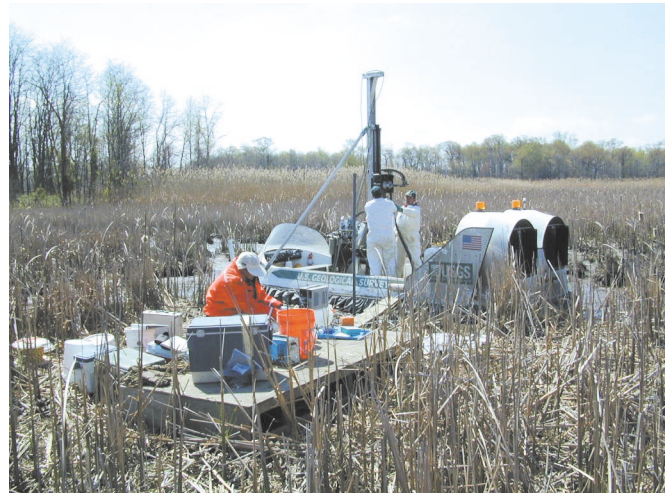
(B) The hoverprobe and support hovercraft at site HP08

Deep soft mud prohibits access and emergency egress by foot or boat at low tide, thus requiring the use of a support hovercraft.



(C) Portable docks at site HP01

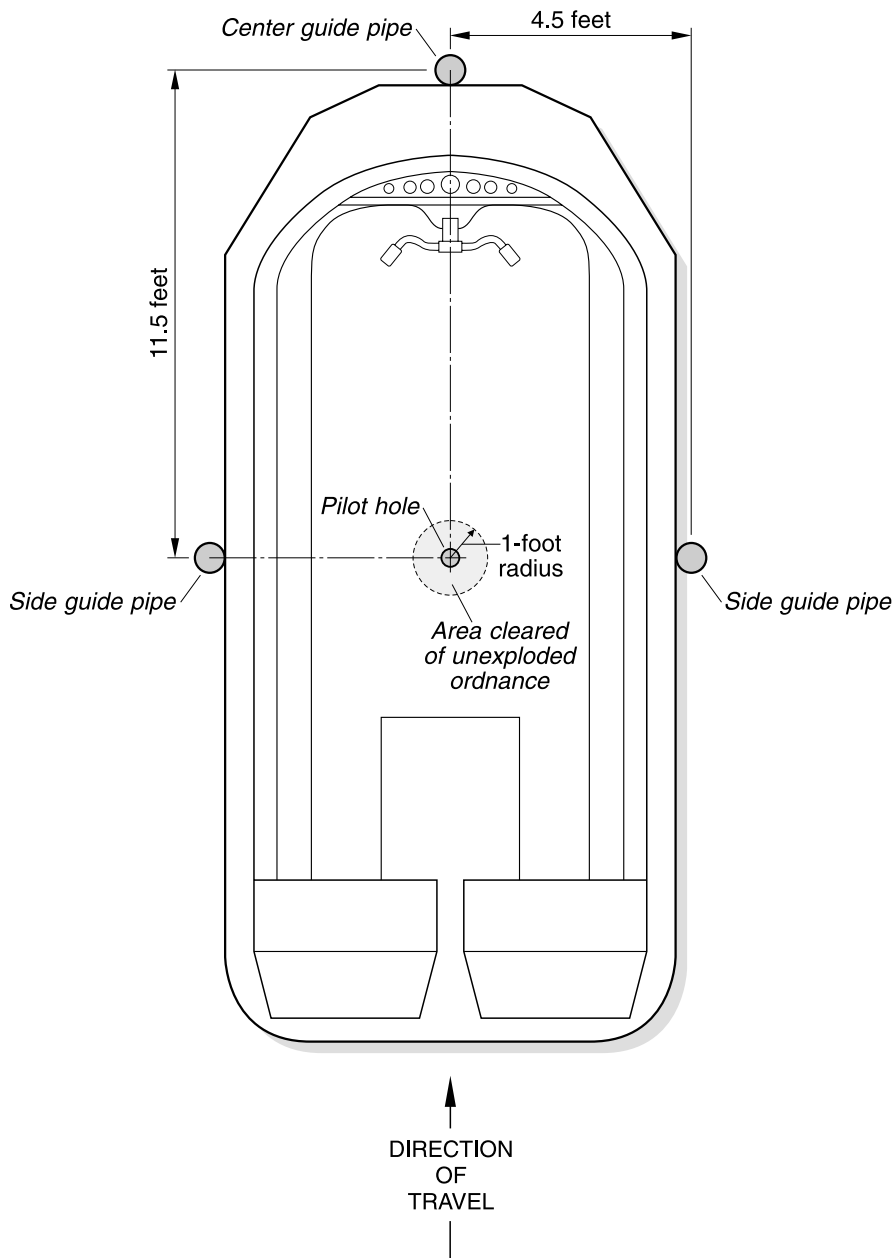
Ground water at this site had concentrations of total volatile organic compounds ranging from 790 to 50,100 micrograms per liter.



(D) Ground-water-quality profiling at site HP05

The peristaltic pump and ground-water sampling equipment were set up on the portable docks. Depending on tides and access at other sites, the sampling equipment was set up on either the portable docks, the support hovercraft, or on the johnboat.

Figure 4. (A) The hoverprobe drill rig and working area, (B) the hoverprobe and support hovercraft at site HP08, (C) portable docks at site HP01, and (D) ground-water-quality profiling at site HP05 on West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April-May 2000. [Photographs by USGS.]



NOTE: Guide pipes were installed prior to moving the hoverprobe onto the site. With the nose of the craft on the center pipe, and centered between the side pipes, the drill hole was within the area cleared of unexploded ordnance.

Figure 5. Technique for positioning of the hoverprobe over the magnetometer-swept pilot hole, Aberdeen Proving Ground, Maryland.

amount of disturbed (waste) sediment that had collected within the casing. Drilling continued from that point, with measurements made to the top of the core each time a pipe was added so that the amount of core compression could be determined. Drilling was stopped either when a 2-ft-thick

clay layer was encountered, or at the point of “refusal,” when the drill bit was stopped by the resistance of the sediments. The maximum depth of penetration at each site is shown in table 1.



(A) Coring with the hoverprobe



(B) Removing the core in sealed tubes



(C) Transferring the core into core boxes



(D) Core boxes with core from the Canal Creek aquifer

Figure 6. (A) Coring with the hoverprobe, (B) removing the core in sealed tubes, (C) transferring the core into core boxes, and (D) core boxes with core from the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, April-May 2000. [Photographs by USGS.]

Table 1. *Maximum core depths using polyvinyl chloride (PVC) and steel core pipe, depths to the top of the Canal Creek aquifer, and refusal depths of the ground-water-quality profiler in the Canal Creek aquifer, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000*

[ft bls, feet below land surface; refusal depth is the depth at which the progression of the drill bit stopped; --, not cored;
Note: site HP04 not sampled]

Site	Depth cored with PVC pipe (ft bls)	Depth to the top of the Canal Creek aquifer (ft bls)	Total depth cored with PVC and steel pipe (ft bls)	Refusal depth of the ground-water-quality profiler (ft bls)
HP01	13.9	12.9	47.4	41
HP02	--	15	--	43
HP03	--	11	--	38
HP05	20.2	19.2	43.4	43.5
HP06	--	19	--	40.5
HP07	--	15	--	47
HP08	17.8	15.4	22.8	^A 17
HP09	--	12	--	20
HP10	(steel pipe only)	22.5	40.3	36
HP11	21.8	10.0	39	^A 30
HP12	--	25	--	38
HP13	--	11.5	--	21.5

^A Depth of last water sample collected (refusal of core pipe was deeper).

Steel drill pipe was used exclusively at site HP10 because (1) the site was much farther from the docks than all of the other sites, making logistical support difficult, (2) about 5 ft of water was present at the site, and (3) a shallow clay lens in the aquifer was anticipated on the basis of the core from site HP08. The clay lens encountered at site HP08 at a depth of 25 ft was not encountered at site HP10 as anticipated.

Drilling requirements at APG require double casing when penetrating a confining unit that is at least 2 ft thick. Because double casing was difficult to use under such challenging site conditions, no 2-ft-thick clays were penetrated. Only one 2-ft-thick clay was encountered during the entire drilling operation (site HP08, at 25–27 ft bls).

When removing the steel core pipe, each 5-ft length was hung from the top of the mast, and the drill rig was used to vibrate the core out of the barrel into clean plastic rain gutters. The core immediately was checked with a photo-ionization detector (PID) for organic vapors. The length of the core then was measured, and the core was placed into

core boxes and labeled (fig. 6C). When the final core pipe was removed from the borehole, coated bentonite pellets were immediately poured down the borehole to seal any part of the hole that had not already collapsed. The 5-in.-diameter PVC surface casing was then removed, allowing the pellets to seal the hole to land surface.

Water-Quality Analyses

Ground-water samples collected for methane and organic constituents were analyzed at an on-site laboratory at West Branch Canal Creek. Methane samples were analyzed using a gas chromatograph with a flame-ionization detector, and VOC samples were analyzed using purge-and-trap gas chromatography with a mass-selective detector. Inorganic samples were sent for analyses to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado. Sulfide concentrations were determined in the field using a CHEMetrics A-1051 photometer kit.

Ground-Water-Quality Profiling

At the five sites where coring was performed, and after the borehole had been sealed, the hoverprobe was moved to the opposite side of the original magnetometer pilot hole. This new location was within the 1-ft radius that had been cleared of UXO to perform the ground-water-quality profiling. Ground-water-quality profiling was performed at 12 sites that had been cleared of UXO.

Ground-water-quality profiling involves collecting ground-water-quality samples at multiple discrete depths to determine vertical changes in water quality, without first drilling a borehole or installing a well. In this study, a 1.7-in.-diameter stainless-steel drive-point screen with a 0.125-in.-diameter Teflon riser tube connected directly to the screen was used (fig. 7). As the drive point was pushed into the sediments, a peristaltic pump was used to continuously pump organic-free deionized water down the tubing to clean the tubing and keep the drive-point screen clear. When the desired sample depth was reached, the pump direction was reversed and ground water was pumped to the surface. Specific conductance, pH, dissolved oxygen, and temperature of the pumped ground water were measured. When the readings stabilized, typically after 15–20 minutes of pumping, water samples were collected. Carryover from the previous sample was minimized by both pumping the deionized water down the tubing, and pumping ground water for 15–20 minutes before collection of samples.

Ground-water samples were collected and analyzed for VOCs, methane, and sulfide. If the dissolved oxygen concentrations exceeded approximately 2 mg/L (milligrams

per liter), sulfide samples were not collected. If sufficient water was available, attempts were made to collect samples for major ion analyses near the top and the bottom of the Canal Creek aquifer.

After a sample was collected, deionized water was pumped down the tubing with a peristaltic pump while the rig vibrated the drive point down to the next desired sampling depth. When that depth was reached, the pumping direction again was reversed for sampling, and the sampling process was repeated. When the sampling profile was finished, the pipe and screen were removed. The sands and gravels of the aquifer would then collapse into the drill hole. Bentonite pellets were then immediately poured down the hole, and the surface casing was removed so that any preferential pathway resulting from drilling into the aquifer was sealed.

Lithologic Data

Continuous sediment cores were collected from five sites: HP01, HP05, HP08, HP10, and HP11 (fig. 2). The maximum core depths and depths to the top of the Canal Creek aquifer are listed in table 1. The lithologic descriptions of the core samples collected from these five sites are presented in Appendix A. Photographs of the sections of core are shown in figure 8.

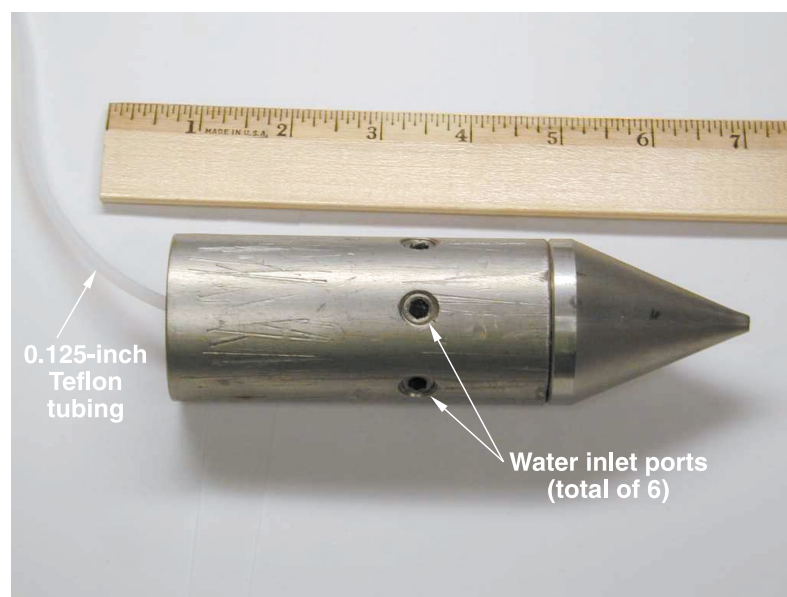
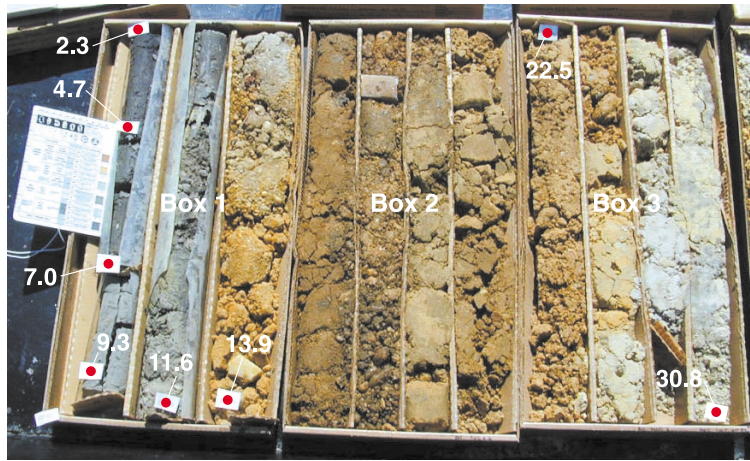


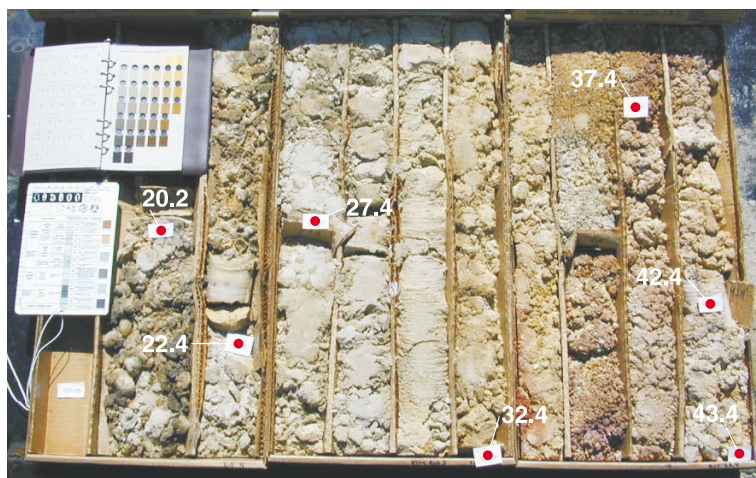
Figure 7. The ground-water-quality profiler and sample tubing. [Photograph by USGS.]



Core from site HP01, boxes 1-3



Core from site HP01, boxes 4-5

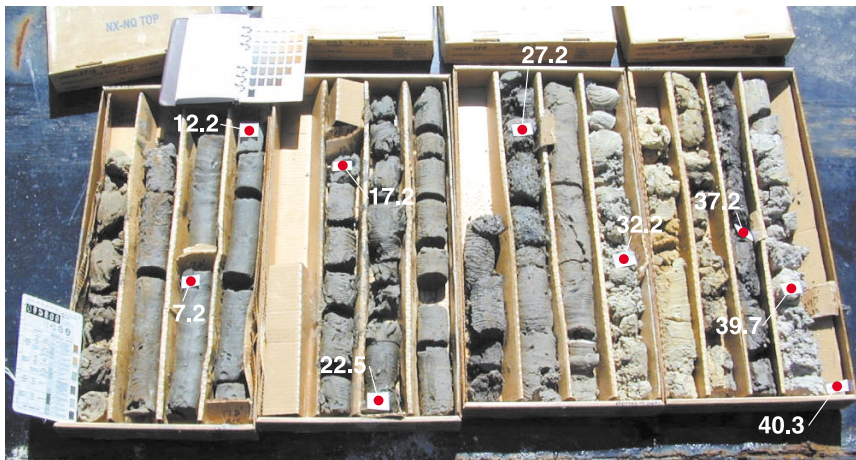


Core from site HP05

Figure 8. The core recovered from the hoverprobe drilling sites, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April-May 2000. (Numbers displayed are known depths in feet below land surface.) [Photographs by USGS.]



Core from site HP08



Core from site HP10



Core from site HP11

Figure 8. The core recovered from the hoverprobe drilling sites, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April-May 2000. (Numbers displayed are known depths in feet below land surface.) [Photographs by USGS.] -- Continued

Cores from the surficial wetland sediments above the Canal Creek aquifer were most affected by compression because of the high porosity of these fine-grained sediments. For example, at site HP10, cores from land surface to 17 ft bbs compressed to a total of 6 ft of core. Cores from the Canal Creek aquifer had less compression than the cores in the wetland sediments; however, compression was still a factor in assigning accurate depths to the core. Depths of samples shown in Appendix A are approximate, based on the interpretation of the amount of core recovered from each interval. Depths to the bottom of the wetland sediment (top of the aquifer) are more accurate because depths were recorded when the low drilling resistance of the wetland sediments noticeably changed to the higher drilling resistances of the sand and gravel of the aquifer.

All soil samples collected during the UXO clearance phase were screened for the presence of chemical-warfare materials, and none were detected in any of the samples. All soil samples collected during UXO clearance and all cores collected with the hoverprobe were screened in the field with a PID with a 10.6-electron-volt lamp for the presence of organic vapors. No detections above background levels were measured with the PID in any of the soil samples or cores from this study.

Ground-Water-Quality Data

Ground-water-quality samples were collected using the ground-water-quality profiler described in the previous “Methods of Investigation” section. Some ground-water samples were analyzed for inorganic constituents to determine general water-quality characteristics of the Canal Creek aquifer, and all ground-water samples were analyzed for VOCs to determine the areal extent and magnitude of suspected ground-water contamination. Quality-assurance samples described in the following section were collected and analyzed to ensure the validity of the data.

Attempts were made to collect ground-water samples from 12 sites at a total of 81 depths in the Canal Creek aquifer. Of those 81 attempts, only 34 sampling depths produced enough water to collect samples. A minimum of 100 mL (milliliters) of ground water was required for purging the sampling lines before a sample could be obtained. Depths where samples were collected typically produced at least 3 liters of water. Field parameters were monitored during pumping. Sites HP06, HP07, and HP10 did not produce any water from the Canal Creek aquifer.

Ground-water-quality profiling was performed initially at site HP01 on April 6–7, 2000, and then again on April 26, 2000. After the VOC concentrations from the first sampling were analyzed, it was determined that total VOCs from HP01-17 exceeded 50,000 µg/L (micrograms per liter) and the site was resampled. The maximum total VOC concentrations from the second sampling exceeded

45,000 µg/L at HP01-15, confirming the results of the first sampling.

Evaluation of Quality-Assurance Data

Quality assurance of water-quality data is an important step in data interpretation. For quality-assurance purposes, one duplicate and one blank sample were submitted to the USGS NWQL for the analysis of major ions. To determine the reproducibility of analyses from the on-site lab at Canal Creek, duplicate samples were collected for all methane samples, and triplicate samples were collected for all VOCs. Reproducibility of duplicate samples can be determined by the relative percent difference (RPD) between samples by the following calculation:

$$\frac{|C_1 - C_2|}{(C_1 + C_2)} \times 100\% = \text{RPD}$$

where:

C_1 is the concentration in the first sample, and
 C_2 is the concentration in the duplicate sample.

Three types of blanks were collected to evaluate the possibility of contamination bias in the sample data: source-water blanks, equipment blanks, and field blanks. The source-water blanks were VOC vials filled in the field with the same organic-free deionized water that was used to flush the tubing between samples. Equipment blanks, which consisted of organic-free deionized water drawn through the drive-point screen, sample tubing, and peristaltic pump tubing prior to sampling, were collected to determine the potential for contamination bias associated with the sampling equipment.

Field blanks were collected to evaluate the effectiveness of the *in situ* decontamination procedures that were performed on the profiling equipment between sampling depths. *In situ* decontamination consisted of carefully pumping organic-free deionized water down the 0.125-in.-diameter Teflon tubing to clear the tubing and the drive point of potentially contaminated ground water while advancing the drive point to the next sampling depth. The volume of water used to decontaminate the tubing was minimized to avoid introducing undesirable amounts of organic-free deionized water at the next sampling depth. Field blanks consisted of the water that was left in the tubing after this rinsing step, but before the aquifer water reached the pump. These field blanks were therefore not expected to be completely free of ground water from the previous sample. The additional rinsing of the drive point and tubing for at least 15–20 minutes during the purging steps would have considerably reduced the potential for contamination from the previous sampling depth to bias the concentrations in the new sample. Field blanks were collected from 13 randomly selected sampling depths. Each field blank is identified in Appendix B as being collected just before or after a specific sample.

Quality Assurance of Major Ion Data One duplicate and one blank ground-water sample were sent for analyses to the NWQL. Of the 11 parameters analyzed in the duplicate samples, 10 had detectable concentrations in each sample, and 1 parameter had no detection in either sample. Of the 10 analytes detected, the average RPD was 0.7 percent, with a maximum of 2.8 percent and a minimum of 0 percent. The blank sample had no concentrations above the reporting limits (Appendix B).

Quality Assurance of Methane Data Duplicate methane samples from 33 of 34 sample depths were analyzed. Seven pairs of duplicate samples had concentrations that exceeded the minimum reporting limits in both samples. Of these seven pairs of duplicates, the average RPD was 2.1 percent, with a maximum of 5 percent, and a minimum of 0.2 percent. The remaining 26 pairs of duplicate samples had both values that were below reporting limits. No duplicate pairs had a value above the reporting limit in one sample and a value below the reporting limit in the corresponding duplicate sample. Because of the small differences between duplicates, and because differences in methane concentrations are more likely to result from losses rather than gains, only the higher of the two methane values is presented in Appendix C.

Quality Assurance of Volatile Organic Compound Data VOC samples were collected in triplicate because VOCs usually exhibit a larger degree of variability than other constituents, and the wide range of VOC concentrations in some samples necessitated analyzing replicate samples using a variety of dilution factors. When the results for one or more constituents were outside the calibrated range of the instrument, dilutions were required to achieve results that were within the calibrated range. When different dilutions were run, only the data that were within the calibrated range of the instrument were included in this report (Appendix D). As a result, for some constituents with low concentrations, the published result is from a sample that was not diluted. For other constituents with high concentrations, the published result is based on dilution ratios ranging from 1:5 to 1:200 (ratio of sample water to total water volume analyzed). Although these methods achieve the most accurate values for each constituent, fewer replicate analyses can be used to calculate the RPD because a sample value from one dilution might be out of the calibrated range of the

instrument, while the duplicate sample with a different dilution would have a value within the calibrated range of the instrument. Calculating RPDs from those two samples would not be valid.

Only two sets of VOC replicate samples had complete analyses with all data reported from the same dilution. Samples for HP08-17 were run at no dilution, whereas samples for HP13-12 were run at a dilution of 1:50. The RPDs for VOC concentrations measured above the reporting limit in duplicate pairs are listed at the bottom of this page.

The ground-water-quality profiler is a screening tool designed to measure changes in water quality with depth. Because the profiler cannot be removed and completely decontaminated between sample depths, some carryover of VOCs between samples at contaminated sites is possible. More thorough decontamination of the tubing between sampling depths was not possible without introducing an undesirable amount of a cleaning solvent into the ground. The effectiveness of the additional rinsing of the profiling equipment during purging could not be measured directly because any VOCs detected in field samples collected after purging may have originated solely from the ground water being sampled, and would not necessarily be the result of carryover from the previous sample.

Nearly all field blanks (the deionized water used to rinse the sample tubing between samples) had detections of some VOCs, but concentrations were generally less than 10 percent of those in the previous sample. Field blanks were then collected, and ground water was then pumped through the tubing for about 15–20 minutes before collecting the sample. This additional purging step was assumed to have decreased the amount of carryover from the previous sampling depth to negligible amounts.

The assumption described in the previous paragraph was tested by analyzing the data from the field blank collected between HP13-16 and HP13-21. These were the only sampling sites for which the concentrations in the deeper sample were much lower than concentrations in the shallower sample. In samples from HP13-16, total VOC concentrations were approximately 46,800 µg/L. Total VOCs in the field blank that was collected after the tubing was rinsed were approximately 3,900 µg/L, which represents a 92-percent decrease from the previous sample.

Sample name	Number of analytes detected in both samples	Dilution factor	Minimum relative percent difference (percent)	Maximum relative percent difference (percent)	Average relative percent difference (percent)
HP08-17	9	Undiluted	0.0	9.3	3.1
HP13-12	7	1:50	.3	33.9	15.4

At site HP13-21, ground water was pumped through the tubing for 26 minutes after collection of the field blank, and before collecting samples. The highest total VOCs in the triplicate samples from HP13-21 were 450 µg/L, a decrease of 88 percent from the previous field blank. If the total VOCs in samples from site HP13-21 were assumed to be 0 µg/L instead of 450 µg/L, and all of the 450 µg/L resulted from carryover from the previous sample, then the carryover of VOCs from the previous sample would be about 1 percent. If the actual concentration for total VOCs in samples from HP13-21 was closer to 450 µg/L than to 0 µg/L, however, the total carryover would be less than 1 percent from the previous sample. In summary, if there was carryover from the previous sample in this case, it was in the range of 1 percent or less. Carryover from any sample other than site HP13-21 was negligible because at no other site did total VOCs decline by more than 96 percent from the previous sample.

Inorganic Water-Quality Data

Ground-water samples were collected for analyses of major ions from 9 sites, and a total of 24 depths. These samples were used to define the general ground-water geochemistry, locations of potential contamination sources, and areas of possible brackish-water intrusion caused by tidal fluctuations. The inorganic ground-water-quality data and associated field parameters are presented in Appendix B.

Redox Parameters

Dissolved oxygen, sulfide, and methane concentrations were measured to determine which areas of the aquifer were under anaerobic or aerobic conditions. Because the carbon atoms in highly chlorinated VOCs have a relatively high oxidation state, they are microbially degraded most easily through reduction reactions under anaerobic conditions (Lorah and others, 1997). These redox parameters, along with specific conductance and pH, are presented in Appendix C.

Organic Water-Quality Data

Ground-water samples were collected for analyses of VOCs from 9 sites and a total of 34 depths. These data are presented in Appendix D. For a given analysis, only the value based on the dilution that resulted in a value within the calibrated range of the instrument is shown. VOCs with low concentrations are usually generated from undiluted samples, and the highest VOC concentrations are generated from samples diluted up to 200 times. Quality-assurance samples such as source-water blanks, equipment blanks, and field blanks are included at the end of Appendix D.

Concentrations of all organic compounds for which detections were measured are shown in Appendix D. The chlorinated ethanes are listed first, with heavier compounds preceding the lighter ones, so that 1,1,2-tetrachloroethane appears first, followed by 1,1,1,2-tetrachloroethane, 1,1,2-trichloroethane, and so on, ending with 1,1-dichloroethane. The chlorinated ethenes are listed next, starting with tetrachloroethene and ending with 1,1-dichloroethene, and are followed by the chlorinated methanes, starting with carbon tetrachloride and ending with methylene chloride. The remaining VOCs of lesser interest are listed after the groups of chlorinated solvents.

Total concentrations of VOCs that exceeded the minimum reporting limit for each site and depth are listed in Appendix D so that comparisons between each site can be made. Ground-water samples from sites HP01 and HP13 had the highest concentrations of VOCs, with total VOC concentrations from most depths ranging from about 15,000 to 50,000 µg/L. Ground-water samples from sites HP02, HP05, HP08, HP09, and HP12 had much lower concentrations of VOCs. Sites HP03 and HP11 were essentially uncontaminated sites, with total VOCs less than or equal to 5 µg/L.

The 36 compounds that were analyzed for, but had concentrations below the reporting limit of 0.5 µg/L, are listed in table 2. These compounds are not listed in Appendix D.

Unknown VOCs that were detected in samples were tentatively identified based on a computerized process that compares the mass spectra for the unknown peak to the National Institute of Standards and Technology (NIST) mass spectral library (NIST, 1998). For compounds that had a match quality of 40 percent or higher against a compound in the NIST library, or that could be identified based on retention time, concentrations were estimated by mathematically comparing the response of the unknown peak to the responses of VOCs with similar chemical structures in the same sample. Tentatively identified compounds (TICs) in the ground-water samples and their estimated concentrations are listed in table 3. These estimated concentrations should only be considered as an indication of the possible presence of these compounds.

Table 2. *Organic compounds that were analyzed for, but not detected at a reporting limit of 0.5 micrograms per liter for ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000*

Bromobenzene	2-Chlorotoluene	<i>n</i> -Propylbenzene
Bromochloromethane	1,3-Dichlorobenzene	Styrene
Bromoform	Dichlorodifluoromethane	Toluene
<i>n</i> -Butylbenzene	1,2-Dichloropropane	1,2,3-Trichlorobenzene
<i>sec</i> -Butylbenzene	1,3-Dichloropropane	1,2,4-Trichlorobenzene
<i>tert</i> -Butylbenzene	2,2-Dichloropropane	Trichlorofluoromethane
Chloroethane	<i>cis</i> -1,3-Dichloropropene	1,2,3-Trichloropropane
4-Chlorotoluene	<i>trans</i> -1,3-Dichloropropene	1,2,4-Trimethylbenzene
Dibromochloromethane	Ethyl benzene	1,3,5-Trimethylbenzene
Dibromomethane	Isopropylbenzene	Vinyl chloride
1,2-Dibromo-3-chloropropane	<i>p</i> -Isopropyltoluene	<i>m,p</i> -Xylenes
1,2-Dibromoethane	Naphthalene	<i>o</i> -Xylene

Table 3. *Tentatively identified compounds and their estimated concentrations for ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000*

[In sample names the last 2 digits are the sample depth in feet below land surface; replicate number identifies which of the three volatile organic compounds sample vials was analyzed; TIC, tentatively identified compound; µg/L, micrograms per liter; <, less than]

Sample name	Replicate number	Date sampled	Tentative identity of compound	Retention time of TIC peak (seconds)	Quality of match (percent)	Estimated concentration (µg/L)
HP01-12	1	04/06/2000	carbon disulfide	11.4	74	280
HP01-12	1	04/06/2000	hexachloroethane	31.4	91	2,500
HP01-12	3	04/06/2000	hexachloroethane	31.4	94	2,200
HP01-12	1	04/06/2000	pentachloroethane	28.1	99	1,000
HP01-17	1	04/07/2000	hexachloroethane	31.4	91	10,000
HP01-17	3	04/07/2000	hexachloroethane	31.3	59	8,500
HP01-17	1	04/07/2000	pentachloroethane	28.1	91	1,200
HP01-17	3	04/07/2000	pentachloroethane	28.0	64	1,200
HP01-27	1	04/07/2000	hexachloroethane	31.4	91	120
HP01-27	3	04/07/2000	pentachloroethane	28.0	72	40
HP01-37	1	04/07/2000	hexachloroethane	31.4	91	120
HP01-37	3	04/07/2000	hexachloroethane	31.3	64	340
HP01-37	3	04/07/2000	pentachloroethane	28.0	64	190
HP01-42	1	04/07/2000	hexachloroethane	31.4	94	620
HP01-42	1	04/07/2000	pentachloroethane	28.1	92	190
HP05-35	3	04/12/2000	hexachloroethane	31.3	53	10
HP05-35	3	04/12/2000	pentachloroethane	28.0	50	4
HP01-12	2	04/26/2000	hexachloroethane	31.3	80	520
HP01-12	2	04/26/2000	pentachloroethane	28.0	78	350
HP01-18	2	04/26/2000	hexachloroethane	31.4	91	2,600
HP01-18	2	04/26/2000	pentachloroethane	28.1	<40	410
HP01-27	3	04/26/2000	hexachloroethane	31.4	86	40
HP13-12	1	05/11/2000	hexachloroethane	31.4	<40	1,000
HP13-12	1	05/11/2000	pentachloroethane	28.1	<40	300
HP13-16	3	05/11/2000	hexachloroethane	31.4	<40	420
HP13-16	3	05/11/2000	pentachloroethane	28.1	<40	70
HP13-21	3	05/11/2000	hexachloroethane	31.4	<40	2
HP13-21	3	05/11/2000	pentachloroethane	28.1	<40	1

Summary

This report presents lithologic data from five sites, and ground-water-quality data from nine sites collected from April through May 2000 during drilling in the tidal wetland of the West Branch Canal Creek, Aberdeen Proving Ground, Maryland. This work was performed by the U.S. Geological Survey in cooperation with the Environmental Conservation and Restoration Division of Aberdeen Proving Ground. This study was conducted to investigate areas that were previously inaccessible because of deep mud and shallow water, and to support ongoing investigations concerning the fate and transport of organic contaminants in the Canal Creek aquifer. A hoverprobe, which is a drill rig that incorporates a small vibrocore (sonic) drill rig mounted on a hovercraft, was used for coring and ground-water sampling. This was the first use of the hoverprobe at a hazardous-waste site, or at a site where unexploded ordnance is a potential hazard. The successful completion of this project demonstrated that the hoverprobe drilling and ground-water-quality profiling could be carried out safely at hazardous-waste sites, and sites with unexploded ordnance.

Ground-water sampling attempts using a continuous profiler were made at 12 sites, without well installation, at a total of 81 depths within the aquifer. Of those 81 attempts, only 34 sampling depths from 9 sites produced enough water to collect samples. Ground-water samples were collected for analyses of major ions from 24 depths, and for analyses of volatile organic compounds and redox parameters from 34 depths. Lithologic data from the five sites, and organic and inorganic ground-water-quality data from the nine sites are presented.

Ground-water samples from sites HP01 and HP13 had the highest concentrations of volatile organic compounds, with total volatile organic compounds concentrations from most depths ranging from about 15,000 to 50,000 micrograms per liter. Ground-water samples from sites HP02, HP05, HP08, HP09, and HP12 had much lower concentrations of volatile organic compounds than sites HP01 and HP13. Sites HP03 and HP11 were essentially uncontaminated, with total volatile organic compounds in the Canal Creek aquifer less than or equal to 5 micrograms per liter.

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APPENDIXES A THROUGH D FOLLOW

**Appendix A. *Lithologic descriptions of core collected with the hoverprobe,
West Branch Canal Creek, Aberdeen Proving Ground, Maryland***

[Depth refers to the bottom of the specified interval in feet below land surface (depths are approximate based on interpretation of the amount of core recovered from each interval); ft, feet; letter symbols and typical descriptions from the Unified Soil Classification System (Casagrande, 1948); Alphanumeric codes enclosed in brackets at selected horizons refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990): for example, (2.5Y3/1)]

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)	
Code	Typical Descriptions
CH	Inorganic clays of high plasticity, fat clays
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays
GC	Clayey gravels, gravel-sand-clay mixtures
GM	Silty gravels, gravel-sand-silt mixtures
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
GW	Well-graded gravels, gravel-sand mixtures, little or no fines
ML	Inorganic silts and very fine sands, silty or clayey fine sands or clayey silts with slight plasticity
OH	Organic clays of medium to high plasticity, organic silts
OL	Organic silts and organic silty clays of low plasticity
PT	Peat, humus, swamp soils with high organic contents
SM	Silty sands, sand-silt mixtures
SP	Poorly graded sands, gravelly sands, little or no fines
SW	Well-graded sands, gravelly sands, little or no fines

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP01 (Land-surface elevation is 0.6 ft below sea level.)			
USCS Code	Length of core recovered (feet)	Description	
<i>Land surface</i>			
OL	1.5	Organic silts with high organic content; dark grayish brown (2.5Y4/2)	
2.3			
OL	1.5	Organic silts with high organic content; very dark gray (7.5YR3/0)	
4.7			
OL	1.5	Organic silts with high organic content; black (7.5YR2/0)	
7.0			
OH	1.5	Organic clays and silts of medium plasticity; very dark gray (5Y3/1)	
9.3			
OL	1.0	Organic silts and organic silty clays of low plasticity; very dark gray (5Y3/1)	
	SM	0.5	Silty sands, sand-silt mixtures; gray (5Y5/1)
	GP	1.0	Poorly graded gravels (0.19-0.75 inches) with some sand; very dark gray (5Y3/1) to mostly light gray (5Y6/1)
11.6			
	GP	1.0	Poorly graded gravels (0.19-0.75 inches) with some sand; light gray (5Y6/1) and reddish yellow (7.5YR6/8)
	SW	1.0	Well-graded sands with some gravel up to 2.00 inches; reddish yellow and strong brown (7.5YR5/8)
13.9			
	SW	2.0	Well-graded sands, no fines, some gravel (0.19-0.75 inches); strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
	GP	0.5	Poorly graded gravel; strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
	SW	0.5	Well-graded sand; strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
	GP	1.0	Poorly graded gravel (0.19-0.75 inches); strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
	SW	2.0	Well-graded sands, no fines, some gravel (0.19-0.75 inches); strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
	SW	2.0	Well-graded sands, no fines, little gravel (up to 0.75 inches); strong brown (7.5YR5/6) and dark brown (7.5YR3/3)
22.5			
	SW	1.0	Well-graded sands with gravel, no fines; yellowish brown (10YR5/4)
	SW	1.5	Well-graded sands with gravel (0.19-2.00 inches), no fines; strong brown (7.5YR5/6)

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP01 (Continued)		
USCS Code	Length of core recovered (feet)	Description
SW	1.0	Well-graded sands, no gravel or fines; yellow (10YR7/8) and (10YR7/6)
SW	1.0	Well-graded sands, no gravel or fines; light gray (10YR7/2) and very pale brown (10YR8/3)
SW	1.0	Well-graded sands, no gravel or fines; white (10YR8/1) and light gray (10YR7/2)
SW	2.0	Well-graded sands, no gravel or fines; yellow (10YR8/6), gray (10YR6/1), and very pale brown (10YR8/3)
SW	0.5	Well-graded sands, no gravel or fines; marbled white-pale brown (10YR8/2) and light gray (10YR6/1)
SW	0.5	Well-graded sands with gravel but no fines; marbled yellow (10YR7/8) and yellowish brown (10YR5/6)
GP	1.0	Poorly graded gravels (0.19-0.75 inches), gravel-sand mix, no fines; marbled yellow (10YR8/6) and pale brown (10YR6/3)
SW	0.5	Well-graded sands, no gravel or fines; marbled white-pale brown (10YR8/2) and light gray (10YR6/1)
SW	2.0	Well-graded sands, no gravel or fines; marbled white-pale brown (10YR8/2) and gray (10YR5/1)
GP	1.0	Poorly graded gravels (0.19-2.00 inches); yellowish brown (10YR5/4) and very pale brown (10YR7/3)
GP	0.5	Poorly graded gravels (0.19-2.00 inches); some sand; yellowish red (10YR5/8) and red (10R4/6)
SP	1.0	Poorly graded sands, gravelly sands, no fines; brownish yellow (10YR6/6)
GP	1.0	Poorly graded gravels, gravel-sand mixture, no fines; red (10R5/6)
GP	1.0	Poorly graded gravels (0.19-2.00 inches); very pale brown (10YR7/3)
GP	2.0	Poorly graded gravels (0.19-2.00 inches); red-brown (10R4/6)
GP	1.5	Poorly graded gravels (0.19-2.00 inches); yellowish-brown (10YR5/4)
CL	3.0	Inorganic clay of low plasticity; light gray (10YR7/1)
CL	0.5	Inorganic clay of low plasticity; white (5Y8/1)

Depth below land surface (feet)

30.8

39.1

47.4

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP05 (Land-surface elevation is 0.1 ft below sea level.)			
	USCS Code	Length of core recovered (feet)	Description
Land surface	PT	10.5	Peat, humus, swamp soils with high organic contents; dark gray (5Y4/1) and transitions to dark olive gray (5Y3/2)
20.2	SW	1.0	Well-graded sands with gravel (0.19-1.0 inch quartz) but no fines; white (5Y8/2) to pale olive (5Y6/3) to dark gray (5Y4/1) mixture
	SW	1.0	Well-graded sands, no gravel or fines; white (5Y8/2), pale olive (5Y6/3), dark gray (5Y4/1), yellow (10YR7/8) patch-work mixture, and spots of red (2.5YR5/8)
22.4	SM	0.5	Silty sand, sand-silt mixture; fading of white (5Y8/2), pale olive (5Y6/3), dark gray (5Y4/1), and yellow (10YR7/8)
	SW	0.5	Well-graded sand with some fines; mostly white (5Y8/2) with some light yellowish brown (2.5YR6/3)
	SW	1.0	Well-graded sands; white (5Y8/2) and grayish brown (2.5Y5/2)
	SW	3.5	Well-graded sands; very pale brown (10YR8/3) and pale brown (10YR6/3)
27.4	SW & SP	1.5	Well-graded sands with gravel (0.19-0.75 inches), poorly graded sands; very pale brown (10YR6/3) and pale brown (10YR6/3)
	SP	2.0	Poorly graded sands with gravel (0.19-0.75 inches); very pale brown (10YR8/4) and brown (10YR5/3)
32.4	SW	1.0	Well-graded sands, gravel but no fines; very pale brown (10YR8/3) and yellow (10YR7/6)
	GP	1.0	Poorly graded gravels (0.19-0.75 inches), gravel-sand mix (0.08-0.19 inches); very pale brown (10YR8/3), yellow (10YR7/6), and some red (10R4/8)
	GW	1.0	Well-graded gravels (0.19-0.75 inches); brown (7.5YR5/4) with a band of dark red (10R3/6)
	GW	1.0	Well-graded gravel (0.19-0.75 inches); dark red (2.5YR3/6) and yellowish red (5YR5/8)
37.4	GW	1.0	Well-graded gravel (0.19-0.75 inches); dark red (2.5YR3/6) and yellowish red (5YR5/8)
	GW	1.0	Well-graded gravel to very coarse gravel (0.75-2.9 inches); reddish brown (5YR5/4)
	GW	1.0	Well-graded gravel; white (5YR8/1) and pinkish white (5YR8/2)
42.4	GC	0.25	Band of clayey gravel; white (5YR8/1) and pinkish white (5YR8/2)
43.4	GW	0.75	Well-graded gravel to very coarse gravel (0.75-2.9 inches); white (5YR8/1) and pinkish white (5YR8/2)

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP08 (Land-surface elevation is 1.3 ft above sea level.)		
USCS Code	Length of core recovered (feet)	Description
<i>Land surface</i>		
PT	5.0	Peat, humus, swamp soils with high organic content; dark gray (5Y4/1)
PT	3.0	Peat, humus, swamp soils with high organic content; dark gray (5Y4/1) and transitions to dark olive gray (5Y3/2)
PT	4.5	Peat, humus, swamp soils with high organic content; dark olive gray (5Y3/2) to olive gray (5Y4/2)
SP	3.0	Poorly graded medium sands (0.02-0.08 inches), little or no fines; olive gray to gray (5Y4/2)
SP to GP	1.0	Poorly graded gravels (5Y3/1) to mostly light gray (5Y6/1)
GP	1.0	Poorly graded gravels (0.19-0.75 inches) with some sand; light gray (5Y6/1) and reddish yellow (7.5YR6/8)
ML to CH	1.0	Inorganic silts and very fine sands, rock flour; light brown-yellow with gray (2.5Y6/4) then to inorganic clay of high plasticity, fat clay; pale yellow (2.5Y7/3)
CL	2.0	Inorganic clays of low plasticity; light gray to pale yellow (2.5Y7/2) to dirty white (5Y8/1) and some red marbling, then to light brown (7.5R6/3)
<i>22.8</i>		

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP10 (Land-surface elevation is 0.1 ft above sea level.)			
USCS Code	Length of core recovered (feet)	Description	
<i>Land surface</i>			
OL	1.75	Organic silts and silty clays; very dark grayish brown (10YR3/1) and specks of strong brown (7.5YR5/6) staining	
OH	2.0	Organic clays of medium plasticity; dark gray (5Y4/1)	
	7.2		
	12.2		
OH	4.0	Organic clays of medium to high plasticity; olive gray (5Y4/2)	
	17.2		
OH	2.75	Organic clays of medium to high plasticity; olive gray (5Y4/2)	
OL	1.0	Organic silts and some sand of very low plasticity; very dark gray (2.5Y3/0)	
SM	0.5	Silty sands, sand-silt mixture; dark gray (2.5Y4/0)	
GM	0.5	Silty gravels, gravel-sand-silt mixture; gray (2.5Y5/0) and dark gray (2.5Y4/0)	
SW	3.0	Well-graded sands, some gravel, little or no fines; light gray (2.5Y6/0) and gray (2.5Y5/0) with yellowish red (5YR5/8) staining	
	27.2		
SW	2.0	Well-graded sands with gravel; white (5Y8/1) to light olive gray (5Y6/2)	
SM	1.0	Silty sands, sand-silt mixture; pale yellow (5Y7/3), yellow (5Y7/6), and pale yellow (5Y8/4)	
ML	1.0	Inorganic silts and very fine sands; marbled pale yellow (5Y7/3), yellow (5Y7/6), pale yellow (5Y8/4), and gray (5Y5/1)	
	32.2		
GM	2.0	Silty gravels, gravel-sand-silt mixture; marbled pale yellow (5Y7/3), yellow (5Y7/6), pale yellow (5Y8/4), and gray (5Y5/1)	
	37.2		
CL	2.25	Inorganic clay of low plasticity, slightly gravel clays-sandy/silty clays; very dark gray (5Y3/1), some reddish brown (5YR5/4), and pale yellow (5Y7/3) streaks	
	39.7		
GM	1.75	Silty-sandy gravels; light gray (5Y7/1) and gray (5Y5/1)	
	40.3		

Appendix A. *Lithologic descriptions of core collected with the hoverprobe, West Branch Canal Creek, Aberdeen Proving Ground, Maryland -- Continued*

SITE HP11 (Land-surface elevation is 0.2 ft above sea level.)			
	USCS Code	Length of core recovered (feet)	Description
Land surface	Z PT Z	5.0	Peat, humus, swamp soils with high organic content; dark gray (5Y4/1) and transitions to dark olive gray (5Y3/2)
7.2	OL	1.5	Organic silts and clay of low plasticity; very dark gray (5Y3/1) with some red staining (10R4/8)
	SM	1.0	Silty sands with organics; very dark gray (5Y3/1) and olive (5Y5/2)
	OL	1.5	Organic silts and sands; light gray (5Y7/1) and gray (5Y5/1)
	SP	0.5	Poorly graded sands with some gravel; light gray (5Y7/1) and gray (5Y5/1)
12.0	SW	1.0	Well-graded sands and gravel; light gray (5Y7/1) to gray (5Y6/1)
16.8	SW	0.5	Well-graded sands and 1.5 inches gravel; light gray (5Y7/1) to white (5Y8/1)
	SW	1.0	Well-graded sand, no gravel; light gray (5Y7/2) to yellow (5Y8/6)
	SW	0.5	Well-graded sand, no gravel; strong brown (7.5YR5/8)
	SW	2.0	Well-graded sand, no gravel; strong brown (7.5YR5/8) to a marbled yellow (10R7/6) and very pale brown (10YR7/3)
22.3	SP	1.0	Poorly graded sands with gravel up to 0.75 inches; reddish yellow (7.5YR6/8)
	SW	2.0	Well-graded sands, little or no fines or gravels; white (10R8/2)
	SW	1.0	Well-graded sands, little or no fines or gravels; very pale brown (10YR8/3)
28.0	Z GP Z	2.0	Poorly graded gravel; white (10YR8/2)
	Z GP Z	2.0	Poorly graded gravel with gravel-sand mixture; very pale brown (10YR7/4)
33.0	SW	1.0	Well-graded sand, no gravel; yellow (10YR7/6)
	Z GW Z	2.5	Well-graded gravels (0.75-1.00 inch), some sand; yellow (10YR7/6) and very pale brown (10YR7/3)
38.0	CL	1.0	Inorganic clay of low plasticity; dark gray (10YR4/1)
39.0	CL	0.5	Inorganic clay of low plasticity; gray (10YR6/1) to light gray (10YR7/1) and light yellowish brown (10YR6/4)

APPENDIX B FOLLOWS

Appendix B. Inorganic ground-water-quality data and field parameters from ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter; mg/L , milligrams per liter; $^{\circ}\text{C}$, degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; E, estimated; <, less than; DUP, duplicate sample; --, data not available]

Sample name	Date collected	Time collected	Elevation of land surface datum (feet above sea level)	Depth of sample below land surface (feet)	Specific conductance, field ($\mu\text{S}/\text{cm}$)	Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	pH (standard units)	Oxygen, dissolved (mg/L)	Temperature, water ($^{\circ}\text{C}$) ¹	Calcium, dissolved (mg/L as Ca)
HP01-12	04/06/2000	1700	0.6	12	1,240	1,250	4.6	2.8	24.9	23
HP01-27	04/26/2000	1600	.6	27	414	422	4.6	2.9	14.9	14
HP01-37	04/07/2000	0945	.6	37	572	565	3.7	3.2	17.8	14
HP02-24	04/25/2000	1530	.8	24	756	771	4.7	2.8	10.2	9.7
HP02-33	04/26/2000	0815	.8	33	989	979	4.6	1.9	8.5	9.6
HP02-38	04/26/2000	0910	.8	38	1,370	1,400	4.7	2.1	11.6	5.1
HP02-43	04/26/2000	1040	.8	43	1,890	1,920	4.7	1.7	12.9	6.6
HP03-12	05/10/2000	1050	1.2	12	193	196	4.9	4.2	24.0	6.0
HP03-17	05/10/2000	1145	1.2	17	187	192	4.7	4.8	23.2	6.1
HP03-22	05/10/2000	1225	1.2	22	187	191	4.8	4.6	24.1	5.9
HP03-27	05/10/2000	1310	1.2	27	195	199	4.7	4.3	25.8	6.2
HP03-32	05/10/2000	1400	1.2	32	193	188	4.7	4.6	25.9	6.2
HP03-37	05/10/2000	1440	1.2	37	187	193	4.7	5.2	26.2	5.8
HP05-35	04/12/2000	1105	-.1	32	565	560	3.8	3.4	16.4	16
HP08-17	04/13/2000	1650	1.3	17	2,190	2,110	6.4	1.8	12.9	11
HP09-20	05/08/2000	1400	-0.2	20	4,820	4,920	6.1	2.4	28.5	29
HP11-15	04/18/2000	1130	.2	15	207	218	4.7	5.6	8.6	6.7
HP11-30	04/19/2000	1100	.2	30	207	210	4.6	5.3	12.6	6.4
HP11-30DUP	04/19/2000	1100	.2	30	207	209	4.6	5.3	12.6	6.3
HP12-27	05/09/2000	0905	1.0	27	1,790	1,820	5.7	1.4	21.2	10
HP12-31	05/09/2000	0945	1.0	31	1,990	2,070	4.2	1.7	22.9	10
HP12-36	05/09/2000	1050	1.0	36	2,880	3,030	4.2	2.1	25.1	9.9
HP13-12	04/27/2000	0940	.3	12	881	865	4.7	1.4	11.2	24
HP13-16	04/27/2000	1035	.3	16	697	707	4.3	1.9	11.7	16
HP13-21	04/27/2000	1410	.3	21	104	106	4.8	1.9	10.9	2.9
Source-water blank	05/12/2000	1200	--	--	--	E 2	--	--	--	<.20

¹. The temperature shown is the actual sample temperature rather than the ambient ground-water temperature. Because of the small diameter tubing used, and low flow rates during sampling, sample temperatures were affected by air temperature and sunlight.

Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO ₄)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO ₂)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Sample name
20	166	5.5	170	270	0.17	<0.010	16	5,200	2,200	HP01-12
8.1	43	2.7	61	73	.16	.088	10	44	558	HP01-27
8.0	52	3.1	85	96	<.10	.11	12	1,600	2,070	HP01-37
7.6	115	2.1	91	150	.10	.089	10	38	485	HP02-24
6.0	158	2.1	100	200	.16	.096	11	14	590	HP02-33
2.9	242	1.5	100	320	<.10	.11	8.8	46	316	HP02-38
3.8	332	2.4	44	540	<.10	.093	7.5	170	385	HP02-43
7.0	13	1.8	32	27	<.10	.058	7.1	1,400	100	HP03-12
6.8	13	1.4	31	28	<.10	.044	6.9	27	174	HP03-17
6.7	13	1.2	32	27	<.10	.053	6.6	20	64	HP03-22
7.1	14	1.3	33	29	<.10	.047	6.4	96	71	HP03-27
7.1	13	1.1	32	27	<.10	.024	6.3	14	72	HP03-32
6.6	13	1.3	32	26	<.10	.051	6.1	E 6.5	59	HP03-37
9.9	46	3.5	100	93	<5.0	.090	14	12	629	HP05-35
9.6	336	5.0	100	560	<5.0	.16	21	84,500	1,210	HP08-17
38	810	9.2	270	1,400	<.10	<.01	6.9	177,000	1,750	HP09-20
8.0	15	1.4	36	33	<.10	.030	7.3	46	90	HP11-15
7.7	15	1.3	35	29	<.10	.028	6.0	23	68	HP11-30
7.7	15	1.3	36	30	<.10	.025	6.0	21	67	HP11-30DUP
9.1	298	5.8	120	470	<.10	<.010	16	23,400	526	HP12-27
5.5	385	2.3	110	560	<.10	<.010	16	54	703	HP12-31
5.1	550	2.1	140	820	<.10	.14	21	170	881	HP12-36
15	100	3.6	170	150	<.10	.11	15	13,500	1,550	HP13-12
9.2	93	2.2	120	120	.12	.11	13	72	608	HP13-16
1.7	11	.84	23	8.4	<.10	.019	10	48	204	HP13-21
<.014	<.090	<.24	<.31	<.29	<.10	<.010	<.090	<10	<2.2	Source- water blank

APPENDIX C FOLLOWS

Appendix C. Field and redox parameters from ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000

[$\mu\text{S/cm}$, microsiemens per centimeter; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter; <, less than; --, no data collected;

Note: Sulfide samples generally not collected when dissolved oxygen was above 2 mg/L ; in sample names, the last 2 digits are depth in feet below land surface]

	Sample name	Date collected	FIELD PARAMETERS			REDOX PARAMETERS	
			Specific conductance, field ($\mu\text{S/cm}$)	pH (standard units)	Oxygen, dissolved (mg/L)	Methane ($\mu\text{g/L}$)	Sulfide (mg/L)
First HP01 sample set	HP01-12	04/06/2000	1,240	4.6	2.8	1,180	0.01
	HP01-17	04/07/2000	873	4.0	1.7	<45.6	0.01
	HP01-27	04/07/2000	413	4.6	3.9	<45.1	0.01
	HP01-37	04/07/2000	572	3.7	3.2	<46.4	<0.01
	HP01-42	04/07/2000	629	3.9	3.0	<45.3	0.01
Second HP01 sample set	HP01-12	04/26/2000	841	5.6	--	6,090	--
	HP01-15	04/26/2000	900	4.0	1.3	67.0	0.08
	HP01-18	04/26/2000	530	4.7	3.9	<45.2	--
	HP01-27	04/26/2000	414	4.6	2.9	<45.9	--
	HP02-24	04/25/2000	756	4.7	2.8	<44.2	<0.01
	HP02-30	04/25/2000	978	4.7	3.4	<47.1	--
	HP02-33	04/26/2000	989	4.6	1.9	<48.8	<0.01
	HP02-38	04/26/2000	1,370	4.7	2.1	<47.2	--
	HP02-43	04/26/2000	1,890	4.7	1.7	<42.8	<0.01
	HP03-12	05/10/2000	193	4.9	4.2	<35.9	--
	HP03-17	05/10/2000	187	4.7	4.8	<44.6	--
	HP03-22	05/10/2000	187	4.8	4.6	<45.2	--
	HP03-27	05/10/2000	195	4.7	4.3	<43.6	--
HP03-32	05/10/2000	193	4.7	4.6	<46.3	--	
HP03-37	05/10/2000	187	4.7	5.2	<48.7	--	
HP05-22	04/12/2000	792	4.0	1.6	224	<0.01	
HP05-35	04/12/2000	565	3.8	3.4	<44.1	0.01	
HP08-17	04/13/2000	2,190	6.4	1.8	524	<0.01	
HP09-20	05/08/2000	4,820	6.1	2.4	397	0.08	
HP11-15	04/18/2000	207	4.7	5.6	<13.5	--	
HP11-20	04/19/2000	204	4.7	5.0	<48.8	--	
HP11-25	04/19/2000	164	4.7	--	<43.6	--	
HP11-30	04/19/2000	207	4.7	5.3	<48.0	--	

Appendix C. Field and redox parameters from ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000—Continued

Sample name	Date collected	FIELD PARAMETERS			REDOX PARAMETERS	
		Specific conductance, field ($\mu\text{S}/\text{cm}$)	pH (standard units)	Oxygen, dissolved (mg/L)	Methane ($\mu\text{g}/\text{L}$)	Sulfide (mg/L)
HP12-27	05/09/2000	1,790	5.7	1.4	101	0.01
HP12-31	05/09/2000	1,990	4.2	1.7	<41.3	<0.01
HP12-36	05/09/2000	2,880	4.2	2.1	<41.3	<0.01
HP13-12	04/27/2000	881	4.7	1.4	133	0.03
HP13-16	04/27/2000	697	4.3	1.9	<48.0	<0.01
HP13-21	04/27/2000	104	4.8	1.9	<36.2	0.01

APPENDIX D FOLLOWS

Appendix D. Organic compounds detected in ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000

[All units are in micrograms per liter; min, minimum; max, maximum; <, less than; VOCs volatile organic compounds; the last 2 digits in the sample names are depth in feet below land surface; dilution factors indicate the ratio of the total volume analyzed to the volume of sample water; for example “200” indicates that 1/200 of the total volume analyzed was sample water and 199/200 was blank water and “1” indicates an undiluted sample. Total VOC concentrations in this table do not include tentatively identified compounds (table 3, page 18). An **E** indicates estimated concentration; a **V** indicates detections probably affected by carryover from previous sample; quality-assurance sample data are presented chronologically; all numbers rounded to 3 significant figures]

Sample name	Date collected	Time collected	Dilution factor min / max	1,1,2,2-Tetrachloroethane	1,1,1,2-Tetrachloroethane	1,1,2-Trichloroethane	1,1,1-Trichloroethane	1,2-Dichloroethane
HP01-12	04/06/2000	1200	1 / 200	144	189	42.7	1.6	15.6
HP01-17	04/07/2000	0810	1 / 200	145	146	22.8	<.5	8.4
HP01-27	04/07/2000	0845	1 / 200	33.2	2.9	<.5	<.5	3.2
HP01-37	04/07/2000	0945	1 / 200	54.3	21.6	21.0	<.5	30.1
HP01-42	04/07/2000	1115	1 / 200	57.6	37.8	25.1	<.5	25.6
HP01-12	04/26/2000	1415	20 / 200	71.5	29.1	19.6	<10	10.8
HP01-15	04/26/2000	1445	66 / 200	<33	<33	<33	<33	<33
HP01-18	04/26/2000	1540	5 / 100	21.5	1.6	<2.5	<2.5	<2.5
HP01-27	04/26/2000	1600	1 / 100	30.8	<.5	<.5	<.5	2.7
HP02-24	04/25/2000	1530	1 / 1	23.9	<.5	<.5	<.5	<.5
HP02-30	04/25/2000	1620	1 / 1	17.4	<.5	<.5	<.5	<.5
HP02-33	04/26/2000	0815	1 / 5	44.2	<.5	<.5	<.5	1.7
HP02-38	04/26/2000	0910	1 / 50	<.5	<.5	<.5	<.5	<.5
HP02-43	04/26/2000	1040	1 / 5	11.6	<.5	<.5	<.5	<.5
HP03-12	05/10/2000	1050	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-17	05/10/2000	1145	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-22	05/10/2000	1225	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-27	05/10/2000	1310	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-32	05/10/2000	1400	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-37	05/10/2000	1440	1 / 1	<.5	<.5	<.5	<.5	<.5
HP05-22	04/12/2000	1000	1 / 5	87.6	<.5	<.5	<.5	<.5
HP05-35	04/12/2000	1105	1 / 5	37.7	<.5	<.5	<.5	1.6
HP08-17	04/13/2000	1650	1 / 1	<.5	<.5	<.5	<.5	<.5
HP09-20	05/08/2000	1400	1 / 5	<.5	<.5	<.5	<.5	<.5
HP11-15	04/18/2000	1130	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP11-20	04/19/2000	0930	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP11-25	04/19/2000	1030	1 / 1	<.5	<.5	<.5	<.5	<.5
HP11-30	04/19/2000	1100	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP12-27	05/09/2000	0905	1 / 1	29.4	<.5	<.5	<.5	<.5
HP12-31	05/09/2000	0945	1 / 1	91.8	<.5	<.5	<.5	<.5
HP12-36	05/09/2000	1050	1 / 1	95.7	<.5	<.5	<.5	<.5
HP13-12	04/26/2000	0940	50 / 100	29.4	<25	<25	<25	<25
HP13-16	04/27/2000	1035	1 / 50	E 170	E 121	E 14	<.5	<.5
HP13-21	04/27/2000	1410	1 / 2	<.5	<.5	<.5	<.5	<.5

1,1-Dichloroethane	Tetra-chloroethene	Tri-chloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Carbon tetra-chloride	Chloroform	Sample name
13.2	6,090	185	235	39.1	18.0	10,300	21,500	HP01-12
<.5	5,070	190	<.5	<.5	<.5	29,000	15,300	HP01-17
<.5	255	58.8	2.9	<.5	<.5	1,460	204	HP01-27
<.5	495	59.8	<.5	<.5	<.5	4,630	23,100	HP01-37
10.0	531	76.8	<.5	<.5	3.7	2,350	12,300	HP01-42
<10	768	142	303	<10	<10	4,770	17,500	HP01-12
<33	6,590	<33	<33	<33	<33	25,300	13,700	HP01-15
<2.5	1,990	74.5	<2.5	<2.5	<2.5	17,100	1,220	HP01-18
<.5	145	55.8	2.0	<.5	<.5	448	92.9	HP01-27
<.5	0.6	62.4	<.5	<.5	<.5	13.3	74.6	HP02-24
<.5	<.5	50.0	<.5	<.5	<.5	14.8	115	HP02-30
<.5	8.6	208	5.5	<.5	<.5	49.3	243	HP02-33
<.5	<.5	<.5	<.5	<.5	<.5	<.5	193	HP02-38
<.5	<.5	11.9	<.5	<.5	<.5	34.6	219	HP02-43
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-12
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-17
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-22
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-27
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-32
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP03-37
<.5	49.6	36.9	<.5	<.5	<.5	370	262	HP05-22
<.5	39.9	20.8	<.5	<.5	<.5	806	1,600	HP05-35
<.5	4.1	17.6	121	56.7	<.5	26.7	4.8	HP08-17
<.5	<.5	23.0	19.2	31.1	<.5	<.5	<.5	HP09-20
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-15
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-20
<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	HP11-25
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-30
<.5	76.2	79.0	8.8	6.5	<.5	<.5	<.5	HP12-27
<.5	72.7	89.3	<.5	<.5	<.5	93.7	102	HP12-31
<.5	73.2	93.6	6.3	<.5	<.5	102	153	HP12-36
<25	6,500	353	<25	<25	<25	23,800	19,900	HP13-12
<.5	4,340	273	<.5	<.5	<.5	30,900	11,000	HP13-16
<.5	V 126	V 9.8	<.5	<.5	<.5	V 279	V 28.3	HP13-21

Appendix D. Organic compounds detected in ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000—Continued

Sample name	Date collected	Time collected	Dilution factor min / max	Methylene chloride	Chloro-methane	Bromo-dichloro-methane	Bromo-methane	Hexa-chloro-butadiene
HP01-12	04/06/2000	1200	1 / 200	242	63.4	57.3	<0.5	21.1
HP01-17	04/07/2000	0810	1 / 200	31.6	48.3	37.5	<.5	122
HP01-27	04/07/2000	0845	1 / 200	<.5	10.0	<.5	<.5	<.5
HP01-37	04/07/2000	0945	1 / 200	159	6.3	32.8	<.5	<.5
HP01-42	04/07/2000	1115	1 / 200	218	27.9	54.6	<.5	3.6
HP01-12	04/26/2000	1415	20 / 200	385	<10	11.5	<10	<10
HP01-15	04/26/2000	1445	66 / 200	<33	<33	<33	<33	<33
HP01-18	04/26/2000	1540	5 / 100	<2.5	27.9	<2.5	<2.5	<2.5
HP01-27	04/26/2000	1600	1 / 100	<.5	7.9	<.5	5.3	<.5
HP02-24	04/25/2000	1530	1 / 1	<.5	<.5	<.5	<.5	<.5
HP02-30	04/25/2000	1620	1 / 1	<.5	<.5	<.5	<.5	<.5
HP02-33	04/26/2000	0815	1 / 5	<.5	<.5	2.7	3.4	<.5
HP02-38	04/26/2000	0910	1 / 50	<.5	<.5	<.5	<.5	<.5
HP02-43	04/26/2000	1040	1 / 5	<.5	0.9	2.7	1.4	<.5
HP03-12	05/10/2000	1050	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-17	05/10/2000	1145	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-22	05/10/2000	1225	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-27	05/10/2000	1310	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-32	05/10/2000	1400	1 / 1	<.5	<.5	<.5	<.5	<.5
HP03-37	05/10/2000	1440	1 / 1	<.5	<.5	<.5	<.5	<.5
HP05-22	04/12/2000	1000	1 / 5	<.5	10.7	1.8	38.2	<.5
HP05-35	04/12/2000	1105	1 / 5	22.2	6.1	<.5	<.5	<.5
HP08-17	04/13/2000	1650	1 / 1	<.5	<.5	<.5	<.5	<.5
HP09-20	05/08/2000	1400	1 / 5	<.5	<.5	<.5	0.8	<.5
HP11-15	04/18/2000	1130	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP11-20	04/19/2000	0930	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP11-25	04/19/2000	1030	1 / 1	<.5	<.5	<.5	<.5	<.5
HP11-30	04/19/2000	1100	5 / 5	<2.5	<2.5	<2.5	<2.5	<2.5
HP12-27	05/09/2000	0905	1 / 1	<.5	<.5	<.5	<.5	<.5
HP12-31	05/09/2000	0945	1 / 1	<.5	<.5	<.5	<.5	<.5
HP12-36	05/09/2000	1050	1 / 1	<.5	<.5	<.5	<.5	<.5
HP13-12	04/26/2000	0940	50 / 100	<25	<25	70.3	40.3	<25
HP13-16	04/27/2000	1035	1 / 50	<.5	26.0	31.1	23.2	<.5
HP13-21	04/27/2000	1410	1 / 2	<.5	<.5	<.5	V 1.4	<.5

1,4-Dichloro-benzene	1,2-Dichloro-benzene	Chloro-benzene	Benzene	1,1-Dichloro-propene	Total VOCs	Sample name
<0.5	<0.5	<0.5	<0.5	2.3	39,200	HP01-12
<.5	<.5	<.5	<.5	<.5	50,100	HP01-17
<.5	<.5	<.5	<.5	<.5	2,030	HP01-27
<.5	<.5	<.5	<.5	<.5	28,600	HP01-37
<.5	<.5	<.5	<.5	<.5	15,700	HP01-42
<10	<10	<10	<10	<10	24,000	HP01-12
<33	<33	<33	<33	<33	45,600	HP01-15
<2.5	<2.5	<2.5	<2.5	<2.5	20,400	HP01-18
<.5	<.5	<.5	<.5	<.5	790	HP01-27
<.5	<.5	<.5	<.5	<.5	175	HP02-24
<.5	<.5	<.5	<.5	<.5	197	HP02-30
<.5	<.5	<.5	<.5	<.5	566	HP02-33
<.5	<.5	<.5	<.5	<.5	193	HP02-38
<.5	<.5	<.5	<.5	<.5	282	HP02-43
<.5	<.5	<.5	<.5	<.5	<.5	HP03-12
<.5	<.5	<.5	<.5	<.5	<.5	HP03-17
<.5	<.5	<.5	<.5	<.5	<.5	HP03-22
<.5	<.5	<.5	<.5	<.5	<.5	HP03-27
0.5	<.5	<.5	<.5	<.5	<.5	HP03-32
<.5	<.5	<.5	<.5	<.5	<.5	HP03-37
<.5	<.5	<.5	1.7	<.5	857	HP05-22
<.5	<.5	<.5	<.5	<.5	2,100	HP05-35
0.7	0.9	10.3	17.8	<.5	261	HP08-17
<.5	<.5	3.1	18.0	<.5	95	HP09-20
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-15
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-20
<.5	<.5	<.5	<.5	<.5	<.5	HP11-25
<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	HP11-30
<.5	<.5	<.5	4.1	<.5	204	HP12-27
<.5	<.5	<.5	<.5	<.5	450	HP12-31
<.5	<.5	<.5	5.3	<.5	523	HP12-36
<25	<25	<25	<25	<25	50,700	HP13-12
<.5	<.5	<.5	<.5	<.5	46,900	HP13-16
<.5	<.5	<.5	<.5	<.5	V 445	HP13-21

Appendix D. Organic compounds detected in ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000—Continued

Sample name	Date collected	Time collected	Dilution factor min / max	1,1,1,2-Tetra-chloro-ethane	1,1,2,2-Tetra-chloro-ethane	1,1,2-Tri-chloro-ethane	1,1,1-Tri-chloro-ethane
QUALITY-ASSURANCE SAMPLE DATA							
Field blank before HP01-12	04/06/2000	1500	1 / 1	<0.5	<0.5	<0.5	<0.5
Field blank before HP01-17	04/07/2000	0800	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP01-37	04/07/2000	0945	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP05-35	04/12/2000	1005	1 / 1	<.5	3.6	<.5	<.5
Field blank after HP05-35	04/12/2000	1130	1 / 1	<.5	2.6	<.5	<.5
Equipment blank before HP11-15	04/18/2000	1015	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP11-25	04/19/2000	0950	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP11-30	04/19/2000	1045	1 / 1	<.5	<.5	<.5	<.5
Source-water blank	04/26/2000	0740	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP02-38	04/26/2000	0900	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP02-43	04/26/2000	0930	1 / 1	<.5	<.5	<.5	<.5
Equipment blank before HP01-12	04/26/2000	1400	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP01-18	04/26/2000	1505	1 / 1	<.5	0.8	<.5	<.5
Field blank before HP13-16	04/27/2000	1035	1 / 1	2.4	<.5	<.5	<.5
Field blank before HP13-21	04/27/2000	1325	1 / 1	<.5	<.5	<.5	<.5
Equipment blank before HP09-20	05/08/2000	1110	1 / 1	<.5	<.5	<.5	<.5
Equipment blank before HP03-12	05/10/2000	0955	1 / 1	<.5	<.5	<.5	<.5
Field blank before HP07	05/11/2000	1410	1 / 1	<.5	<.5	<.5	<.5

1,2-Dichloroethane	1,1-Dichloroethane	Tetra-chloroethene	Tri-chloroethene	<i>cis</i> -1,2-Dichloroethene	<i>trans</i> -1,2-Dichloroethene	Sample name
<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	Field blank before HP01-12
<.5	<.5	280	13.9	4.9	<.5	Field blank before HP01-17
<.5	<.5	207	15.9	<.5	<.5	Field blank before HP01-37
<.5	<.5	23.9	5.4	<.5	<.5	Field blank before HP05-35
<.5	<.5	14.1	<.5	<.5	<.5	Field blank after HP05-35
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP11-15
<.5	<.5	2.2	<.5	<.5	<.5	Field blank before HP11-25
<.5	<.5	0.8	<.5	<.5	<.5	Field blank before HP11-30
<.5	<.5	<.5	<.5	<.5	<.5	Source-water blank
<.5	<.5	<.5	12.5	<.5	<.5	Field blank before HP02-38
<.5	<.5	<.5	42.6	<.5	<.5	Field blank before HP02-43
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP01-12
<.5	<.5	283	12.4	<.5	<.5	Field blank before HP01-18
<.5	<.5	3,080	43.4	<.5	<.5	Field blank before HP13-16
<.5	<.5	364	12.3	<.5	<.5	Field blank before HP13-21
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP09-20
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP03-12
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP07

Appendix D. Organic compounds detected in ground-water samples, West Branch Canal Creek, Aberdeen Proving Ground, Maryland, April–May 2000—Continued

Sample name	1,1-Dichloroethene	Carbon tetra-chloride	Chloroform	Methylene chloride	Chloro-methane	Bromo-dichloro-methane	Bromo-methane
QUALITY-ASSURANCE SAMPLE DATA							
Field blank before HP01-12	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Field blank before HP01-17	<.5	1,400	318	<.5	8.0	<.5	<.5
Field blank before HP01-37	<.5	998	162	<.5	<.5	<.5	<.5
Field blank before HP05-35	<.5	151	33.8	<.5	<.5	<.5	<.5
Field blank after HP05-35	<.5	102	68.8	<.5	<.5	<.5	<.5
Equipment blank before HP11-15	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Field blank before HP11-25	<.5	9.4	1.6	<.5	<.5	<.5	<.5
Field blank before HP11-30	<.5	5.2	<.5	<.5	<.5	<.5	<.5
Source-water blank	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Field blank before HP02-38	<.5	<.5	2.8	<.5	<.5	<.5	<.5
Field blank before HP02-43	<.5	6.2	40.0	<.5	<.5	<.5	<.5
Equipment blank before HP01-12	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Field blank before HP01-18	<.5	1,990	379	<.5	<.5	<.5	<.5
Field blank before HP13-16	<.5	22,100	1,710	<.5	23.6	<.5	<.5
Field blank before HP13-21	<.5	3,370	141	<.5	5.0	<.5	<.5
Equipment blank before HP09-20	<.5	<.5	<.5	<.5	3.6	<.5	4.5
Equipment blank before HP03-12	<.5	<.5	<.5	<.5	<.5	<.5	3.2
Field blank before HP07	<.5	<.5	<.5	<.5	<.5	<.5	3.2

Hexa-chloro-butadiene	1,4-Dichloro-benzene	1,2-Dichloro-benzene	Chloro-benzene	Benzene	1,1-Dichloro-propene	Sample name
<0.5	<0.5	<0.5	<0.5	<.5	<.5	Field blank before HP01-12
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP01-17
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP01-37
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP05-35
<.5	<.5	<.5	<.5	<.5	<.5	Field blank after HP05-35
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP11-15
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP11-25
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP11-30
<.5	<.5	<.5	<.5	<.5	<.5	Source-water blank
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP02-38
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP02-43
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP01-12
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP01-18
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP13-16
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP13-21
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP09-20
<.5	<.5	<.5	<.5	<.5	<.5	Equipment blank before HP03-12
<.5	<.5	<.5	<.5	<.5	<.5	Field blank before HP07