CONTAMINATION OF GROUND WATER, SURFACE WATER, AND SOIL, AND EVALUATION OF SELECTED GROUND-WATER PUMPING ALTERNATIVES IN THE CANAL CREEK AREA OF ABERDEEN PROVING GROUND, MARYLAND

By Michelle M. Lorah and Jeffrey S. Clark

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch (in.)	25,400	micrometer
inch per year (in/yr)	0.02540	meter per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
foot squared per day (ft^2/d)	0.09290	meter squared per day
mile (mi)	1.609	kilometer
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	3,785.0	cubic meters per day
pound, avoirdupois (lb)	0.4536	kilogram
ton	907.2	kilogram

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.

Other abbreviated units of measure: Water temperature, specific conductance, 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:

$$^\circ F = 1.8\,(^\circ C) + 32$$

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, formerly used by the U.S. Geological Survey.

Chemical concentration in water is expressed in milligrams per liter (mg/L), parts per million (ppm) (which is virtually the same as milligrams per liter), micrograms per liter (µg/L), milliequivalents per liter (meq/L), or micromoles per liter (µmol/L).

Chemical concentration in soil is expressed as microgram per gram of dry soil (µg/g) or gram per kilogram of dry soil (g/kg). Microgram per gram (µg/g) is the same as milligram per kilogram (mg/kg).

Molecular weight and other mass expressions are expressed in grams (g), and density is given in gram per cubic centimeter (g/cm^3). Other abbreviations used include milliliter (mL) for volume measurements and micrometer (µm), which equals 1×10^{-6} meter, for length.

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MISCELLANEOUS ABBREVIATIONS:

APG	Aberdeen Proving Ground
BNA's	Base/neutral- and acid-extractable organic compounds
CC2	Clothing impregnite material: N,N'-dichloro-*bis*-(2,4,6-trichlorophenyl)urea
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CN	A tear gas: chloroacetophenone
CNB	CN (chloracetophenone) mixed with benzene and carbon tetrachloride
CNS	CN (chloracetophenone) mixed with chloroform and chloropicrin
DANC	Decontaminating Agent Non-corrossive
DDT	An insecticide: 2,2-*bis*(*para*-chlorophenyl)-1,1-dichloroethane
DM	Adamsite, an arsenic-containing military agent
DNAPL	Dense non-aqueous-phase liquid
FS	A smoke mixture
GB	An organophosphorus nerve agent
GC	Gas chromatography
GC-FID	Gas chromatography-flame ionization detector
GC/MS	Gas chromatography/mass spectrometry
GIS	Geographic Information System
HC	Military designation for smoke mixtures that contain hexachloroethane
HGA	Hydrogeologic assessment
MCL	Primary maximum contaminant level
MCLG	Maximum contaminant level goal
PAH	Polycyclic aromatic hydrocarbons
PCB's	Polychlorinated biphenyls
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RDX	Cyclotrimethylenetrinitramine, an explosives compound
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RMSE	Root mean square error
SMCL	Secondary maximum contaminant level
SW	An intermediate compound in manufacturing of organophosphorus nerve agents
SWMU's	Solid-Waste Management Units
TCPU	A byproduct of the manufacturing process of the clothing impregnite material CC2: N,N'-*bis*-(2,4,6-trichlorophenyl)urea
TIOC's	Tentatively identified organic compounds
TOC	Total organic carbon
TOH	Total organic halogen
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound
VX	An organophosphorus nerve agent
WW1	World War I
WW2	World War II
WP	White phosphorus

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By Michelle M. Lorah *and* Jeffrey S. Clark

ABSTRACT

An investigation begun by the U.S. Geological Survey in 1985 has defined the extent of contamination and the types of contaminants in ground water, surface water, and soil in the Canal Creek area of Aberdeen Proving Ground (APG), Maryland. The Canal Creek area has been used since 1917 for manufacturing of military-related chemicals, for filling of chemical munitions, and for various support activities such as fabrication and cleaning of military equipment and metal plating. A total of 33 historical sites are identified as possible significant contaminant sources.

Ground-water contamination is widespread in two aquifers that are composed of unconsolidated Coastal Plain sediments: the Canal Creek aquifer and the overlying surficial aquifer. No contamination was detected in the lower confined aquifer, which is separated from the Canal Creek aquifer by a thick clay unit. One large contaminant plume, referred to as the "western plume," extends parallel to West Branch Canal Creek; another plume, referred to as the "eastern plume," extends eastward from East Branch Canal Creek. Other smaller areas of contamination also were found in the study area.

Thirteen inorganic constituents were found in concentrations that exceed drinking-water regulations established by the U.S. Environmental Protection Agency (USEPA)--chloride, iron, fluoride, manganese, aluminum, antimony, arsenic, beryllium, cadmium, lead, mercury, nickel, and thallium. In addition, zinc and copper are present in ground water in elevated concentrations compared to background concentrations in the study area.

Several chlorinated volatile organic compounds--1,1,2,2-tetrachloroethane, trichloroethylene, chloroform, 1,2-*trans*-dichloroethylene, and carbon tetrachloride--are the most prevalent ground-water contaminants. Maximum concentrations of these five compounds ranged from 650 to 5,800 micrograms per liter during one sampling period. Additional volatile organic compounds that were quantitatively or tentatively identified in the ground water include benzene, chlorinated benzenes, pentachloroethane, and unknown compounds.

Semivolatile organic compounds are not as widely distributed in the ground water as volatile organic compounds are. Nitrobenzene, 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, and two mustard-degradation products (dithiane and 1,4-oxathiane) are present in the ground water at three or fewer sites. Other semivolatile contaminants that were tentatively identified in some ground-water samples include hexachloroethane, 1,2-dibromoethene, tribromoethene, naphthalene compounds, various compounds related to petroleum fuels, and unknown compounds.

Two processes that have affected the distribution, movement, and fate of the volatile organic contaminants are the sinking of dense non-aqueous-phase liquids (DNAPL's) into the aquifers and microbial degradation. DNAPL's that were released at or near the land surface from solvent spills or waste-disposal sites could have easily migrated downward into the aquifers where the near-surface clay layer is absent or thin. The apparent persistence of the volatile organic compounds in the ground water for decades could be partly accounted for by the continuous dissolution of residual DNAPL's in the aquifers. Microbial degradation products, including 1,2-*trans*-dichlo-

roethylene and vinyl chloride, are widespread only in anaerobic regions of the Canal Creek aquifer in the eastern contaminant plume. The ground water is anaerobic in the eastern contaminant plume where a thick confining unit overlies the Canal Creek aquifer; dissolved oxygen is transported into this deep, confined region of the aquifer at a lower rate than it is consumed by biogeochemical reactions.

Ten inorganic constituents were found in surface-water samples that were collected from Canal Creek, Kings Creek, and the Bush River in concentrations that exceed the acute or chronic toxicity criteria recommended by USEPA for freshwater aquatic life. The 10 inorganic contaminants are beryllium, cadmium, copper, cyanide, iron, lead, mercury, silver, thallium, and zinc. A probable source of these inorganic contaminants is the remobilization of metals that accumulated in bottom sediments from discharge of untreated industrial wastewaters and from discharge of treated sanitary and chemical wastes from a wastewater-treatment plant.

The same volatile organic compounds that were major ground-water contaminants were detected in surface-water samples, and discharge of contaminated shallow ground water is probably the major source of these surface-water contaminants. Dissolution of DNAPL's that could still be present in stream bottom sediments is another likely source of the volatile organic compounds in the surface water. Phthalate esters, which are common laboratory contaminants, were the only organic compounds detected in the surface-water samples in concentrations that exceed either acute or chronic toxicity criteria for freshwater aquatic life.

Soil samples had relatively high concentrations of some trace elements, including lead, zinc, and arsenic, at sites where the same constituents were found in elevated concentrations in the shallow ground water. Thus, leaching of constituents from the soils is apparently a pathway for contamination of the shallow ground water. Polycyclic aromatic hydrocarbons, which are ubiquitous contaminants in soils throughout the world from combustion sources, were the most common organic contaminants detected in the soil samples. In addition, a polychlorinated biphenyl (PCB) compound was detected in one soil sample; relatively low concentrations of a biodegradation product of the insecticide DDT were detected in three soil samples; and a number of fatty acids and fuel-related hydrocarbons were tentatively identified.

Ground-water flow in the study area was simulated by use of a modular, three-dimensional, finite-difference ground-water-flow model. The model consists of three layers representing the surficial, Canal Creek, and lower confined aquifers. The model was calibrated to steady-state water levels measured in 23 surficial aquifer wells, 55 Canal Creek aquifer wells, and 25 lower confined aquifer wells. The final calibrated root mean square error between measured and simulated water levels in all 103 wells was 2.0 ft. Because complete records of historical pumpage could not be found, the model was not calibrated to stressed conditions. The model is a simplification of a complex flow system. Results of the model are limited by assumptions made about the flow system during model setup and calibration.

The ground-water-flow model was used in conjunction with a particle-tracker postprocessor computer program to evaluate the development of contaminant plumes and the hydrologic effects of three pumpage scenarios in the Canal Creek area. The development of the contaminant plumes was simulated by use of an estimated value for pumpage in the 1940's to 1960's and suspected source areas for contaminants. A no-pumpage simulation shows that particles originating in the eastern contaminant plume move to the south toward the Gunpowder River, and particles originating in the western plume move to the west and south toward Canal Creek and the Gunpowder River.

Remedial pumpage was simulated by use of estimates of full (2.0 million gallons per day), half (1 million gallons per day), and quarter (0.5 million gallons per day) pumping capacity of existing water-supply wells. At quarter capacity, some of the particles in the eastern plume are captured by the wells. At half capacity, all of the particles in the eastern plume and some of the particles in the western plume are captured by the wells. At full capacity, all of the particles in both plumes are captured by the wells. Estimated advective traveltime for some particles in the full-capacity simulation is more than 60 years; however, transport and reaction processes affecting the nonconservative contaminants would probably increase the traveltime.

Pumpage from Harford County production wells screened in the lower confined aquifer was simulated to assess the possible effect of this pumpage on contaminant movement in the Canal Creek area. Simulations show that the capture areas for the county wells will not be affected by contamination in the Canal Creek aquifer and that pumping the wells will not affect contaminant movement.

INTRODUCTION

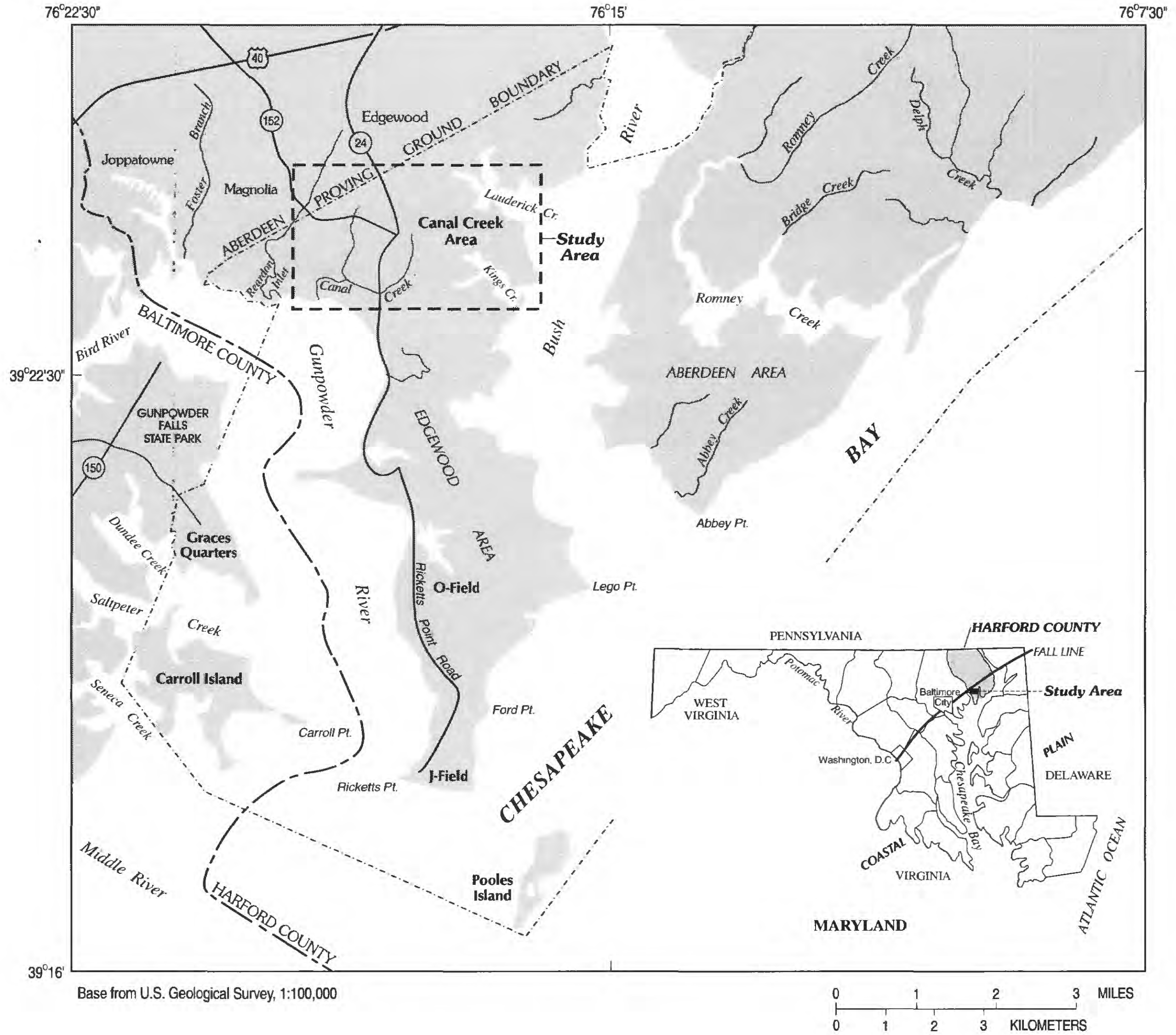
The Canal Creek area of Aberdeen Proving Ground (APG), Md. (fig. 1), has been used to develop, test, and manufacture military-related chemicals since World War I. The Canal Creek area, located in the upper part of the peninsula that forms the Edgewood area of APG in Harford County (fig. 1), encompasses most of APG's former manufacturing facilities. The chemicals produced at these facilities included chlorine, phosgene, chlorpicrin, mustard, white phosphorous, pyrotechnics, tear gas, and clothing-impregnating material. Other relevant activities included loading and testing of chemical-warfare agents, landfilling of domestic waste, land disposal of production wastes, and the use of degreasing solvents on military equipment. Evidence that former activities in the Canal Creek area may have had a deleterious effect on the environment became apparent in 1977 when white phosphorous was found in the bottom sediments of Canal Creek (Nemeth and others, 1983). In 1984, volatile organic compounds were detected in six standby water-supply wells (wells 23E-I and 23K, fig. 2), causing the Maryland State Health Department to recommend that the wells be abandoned. However, the extent of contamination was unknown.

Although the ground water in the Canal Creek area is not currently (1992) used for water supply, the six standby wells were once a valuable water resource. The water-supply system, which was constructed in the early 1940's, had a capacity of approximately 1.5 Mgal/d and was used routinely and extensively before 1968 to supply water for manufacturing activities at APG (Nemeth, 1989). From 1968 through 1984, the wells were maintained as a standby system and were used only for brief periods during droughts when the water supply that was obtained from the reservoir (outside the army base boundaries) needed to be supplemented. Ground water in the Canal Creek area could be needed in the future as a water resource for APG and the state of Maryland if current water supplies decrease and demands increase. Ground-water contamination in the Canal Creek area is also of concern because some domestic water-supply wells are nearby and because Harford County recently installed wells near the northwestern boundary of the study area for possible use as a future municipal source of drinking water. In addition, discharge of contaminated ground water to surface-water bodies could have adverse effects on human, terrestrial-wildlife, and aquatic-wildlife populations. Surface-water bodies in or adjacent to the Canal Creek area include the West and East Branches of Canal Creek, the Gunpowder River, Lauderick Creek, Kings Creek, and the Bush River, all of which ultimately drain to the Chesapeake Bay (figs. 1 and 2).

The nature and extent of ground-water, surface-water, and soil contamination in the Canal Creek area needed to be characterized to assess the effects on ground-water resources in the area, to ensure the safety of public drinking-water supplies, to evaluate the potential threat to the surface-water system, and to evaluate possible remedial actions. In August 1985, the U.S. Army Environmental Management Office of Aberdeen Proving Ground contracted the U.S. Geological Survey (USGS) to conduct a comprehensive investigation of contamination in the Canal Creek area.

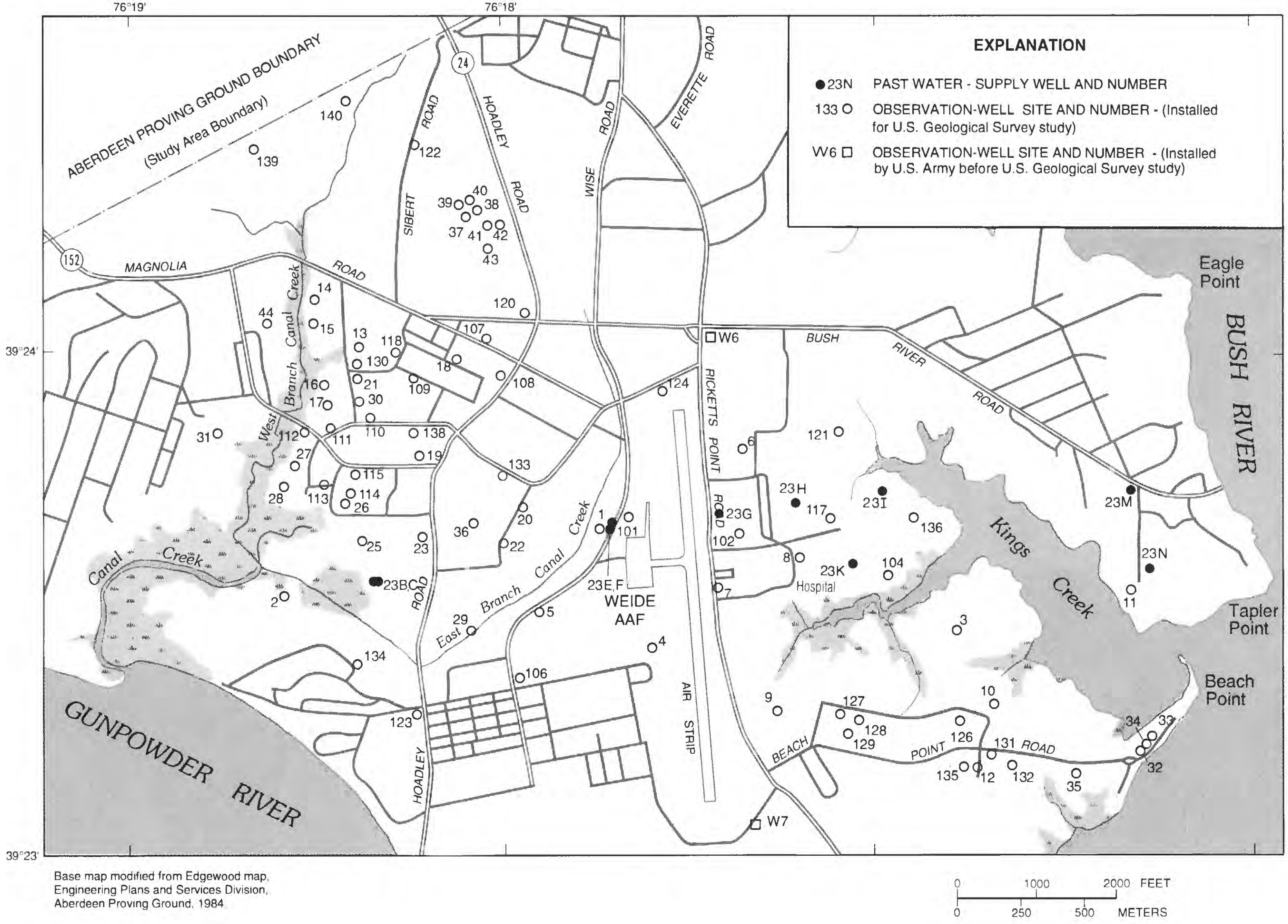
In September 1986, a year after the study began, the U.S. Environmental Protection Agency issued a Resource Conservation and Recovery Act (RCRA) permit (MD3-21-002-1355) to the U.S. Department of Army, Aberdeen Proving Ground, to address Solid-Waste Management Units (SWMU's) in the Edgewood and Aberdeen areas. Solid-waste management units are sites that contain hazardous wastes and thus have a potential to be a source of contaminant release to the environment. The primary objective of the RCRA corrective action program is to remediate releases of hazardous constituents from SWMU's at hazardous waste-treatment, storage, or disposal facilities. In the RCRA permit for the Edgewood area of APG, the Canal Creek area is identified as one of six specific areas that contain SWMU's.

The RCRA permit required that a hydrogeologic assessment (HGA) be done at each of the specific areas that contain SWMU's. The term HGA was later changed to RFI, or RCRA Facility Investigation, although the basic objectives of an HGA remained the same. In February 1990, the Edgewood area of APG was placed on the National Priorities List established under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (U.S. Environmental Protection Agency, 1985). The U.S. Army and U.S. Environmental Protection Agency Region III then negotiated and signed an Interagency Agreement for investigation and remediation of the area in accordance with CERCLA response obligations, RCRA corrective-action obligations, and applicable Federal and state laws and regulations. Listing of the study area on the



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

Figure 1. Location of the Canal Creek study area.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984

Figure 2. Locations of observation-well sites and past water-supply wells in the Canal Creek area.

National Priorities List and signing of the Interagency Agreement did not change the objectives or any other aspect of the USGS study begun in 1985 in the Canal Creek area.

The purpose of an RFI is to provide a framework for characterization of all contaminant releases and movement from SWMU's. The RFI requirements include establishing a monitoring-well network capable of determining the rates and direction of ground-water flow, concentrations of various chemical constituents and indicators in the subsoil and ground water, and the spatial distribution of these constituents and indicators. Development of predictive systems that can be used to generate information for selecting remedial measures also is required.

The objectives of the comprehensive study begun by the USGS in 1985 in the Canal Creek area coincided with the general RFI requirements. The objectives of this study were to (1) define the hydrogeologic framework of the Canal Creek area, (2) determine the nature, distribution, and--as nearly as feasible--the sources of ground-water contamination, (3) describe the movement and behavior of the contaminants, and (4) evaluate the hydrologic and hydrochemical effects of selected remedial activities. Field work was divided into two phases of observation-well installation and sample collection. During the course of the study, the U.S. Army decided that pumping the contaminated ground water from the subsurface, followed by treatment at the surface, was the most feasible type of remedial action for this large an area. Thus, the ground-water-flow model developed for this study was used to evaluate different pumpage scenarios.

An RFI is intended to address the nature and extent of contaminant releases to various environmental media in addition to ground water. Therefore, in 1988, a surface-water component was added to the scope of the USGS study. Soil contamination also was investigated by means of collection and analysis of shallow soil samples in selected areas. The primary objective of the study, however, remained characterization of the hydrogeology and ground-water quality of the Canal Creek area.

Purpose and Scope

The purpose of this report is to (1) characterize ground-water, surface-water, and soil contamination in the Canal Creek area, including the distribution and probable sources of contaminants in all three media and the probable fate of ground-water contaminants, and (2) evaluate selected ground-water pumping alternatives that could be used in remedial actions.

Various aspects of the study were described previously in three interim USGS reports. Two of the interim reports present and evaluate the hydrogeologic data collected during the first and second phases of the study (Oliveros and Gernhardt, 1989; Oliveros and Vroblesky, 1989); the third report presents the ground-water chemical data collected during the first phase of the study (1986-87) and gives an initial evaluation of the inorganic and organic ground-water chemistry in the Canal Creek area on the basis of these data (Lorah and Vroblesky, 1989).

This report presents a description and assessment of all ground-water, surface-water, and soil data collected during 1987-89. All data collected throughout the study (1985-89) are used to assess the distribution, probable sources, and probable fate of the contaminants, and to evaluate the potential effects of selected pumping alternatives that could be used in remedial actions.

The observation-well network that was established in the Canal Creek area includes 87 wells installed during the first phase of the study, 65 wells installed during the second phase for additional definition of the extent and sources of contamination, and two wells installed by the U.S. Army before this study was begun (fig. 2). The wells were installed in clusters (fig. 2) of one to six wells that were screened at different depths. One of the U.S Army wells (W7) was used only for water-level measurements.

To determine the nature and distribution of ground-water contaminants, samples were collected four times between November 1986 and October 1989--once during the first phase of the study and three times during the second phase of the study. The 87 first-phase wells were sampled once before the second-phase wells were drilled. The next ground-water sampling effort included the 65 second-phase wells, 58 of the first-phase wells, and the U.S Army well W6 (fig. 2). Two additional sets of ground-water samples were collected in the spring and fall of 1989 from 80 and 73 selected wells, respectively, to assist in evaluating seasonal effects and to confirm the presence of contamination detected in previous sampling efforts.

Surface-water samples were collected at 31 sites in September 1988 and at 30 sites in June 1989 to characterize the type and distribution of surface-water contaminants and to assess the potential for offsite transport of contaminants through surface water. Shallow soil samples (0 to 2 ft) were collected at 46 sites in September 1989.

Historical data on manufacturing locations and other possible contaminant-release sites were used in conjunction with the ground-water chemical data and the hydrologic data to identify probable sources of contaminants. The probable fate of ground-water contaminants was evaluated by use of information on the physicochemical properties of the contaminants, possible degradation reactions, and the directions and rate of ground-water movement.

A multilayer finite-difference ground-water-flow model was used to represent the hydrologic system and to simulate the potential effects of selected ground-water pumping alternatives. Two of the pumping alternatives consider the effects of possible onsite remedial actions. A third scenario considers the effect of pumpage from offsite production wells in Harford County. Additionally, a particle tracker postprocessor program was used in conjunction with model output to simulate advective ground-water flow within the hydrologic system at various times.

Previous and Concurrent Investigations

No comprehensive ground-water studies were conducted in the Canal Creek area of APG before the USGS began its investigation in 1985. Only a few ground-water analyses had been reported for 14 shallow wells installed in the Canal Creek area (Nemeth and others, 1983) and for the six standby water-supply wells (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988). Otherwise, previous environmental studies focused on surface-water and bottom-sediment sampling and on wastewater disposal. Several studies were also concurrent with the USGS study described in this report.

During 1977-78, the U.S. Army Toxic and Hazardous Materials Agency did a survey of the soil, sediment, ground water, and surface water of the Edgewood area of APG (Nemeth and others, 1983). Water samples collected from 14 wells in the Canal Creek area were analyzed for a hydrolysis product of mustard (thiodiglycol), cholinesterase inhibitors, arsenic, and white phosphorus. Five or fewer ground-water samples were also analyzed for trace metals, other selected inorganic constituents, base-neutral-extractable organic compounds, and volatile organic compounds.

Although no inorganic or organic constituents of concern were detected in the 14 ground-water samples, Nemeth and others (1983) stated that the possibility of contamination could not be eliminated because of the limited number of wells sampled. Several other deficiencies in this initial survey were later recognized, including inadequate siting of wells, failure to sample deeper ground water, and failure to recognize volatile organic compounds as major possible contaminants in the Canal Creek area (Nemeth, 1989, p. 214).

The major compound of concern that was detected in this initial survey of the Canal Creek area was white phosphorus, which was found in surface water and bottom sediment of the upstream reaches of Canal Creek (Nemeth and others, 1983). The compound most frequently detected in bottom sediment in the Canal Creek area was N,N'-*bis*-(2,4,6-trichlorophenyl)urea, abbreviated TCPU. TCPU is produced during the manufacturing process of the clothing impregnite material, CC2. Wastes from impregnite manufacturing and clothing-impregnating operations were discharged to Canal Creek during World War II. TCPU was found in bottom sediment in Canal Creek, the Gunpowder River, Kings Creek, and the Bush River (Nemeth and others, 1983; Nemeth, 1989, p. 239). All other organic compounds detected in bottom sediment during the environmental survey were either naturally occuring compounds or compounds such as fuel-related hydrocarbons that could not be directly related to activities at APG (Nemeth and others, 1983).

In December 1983 and March 1984, the Maryland State Health Department collected water samples from the six standby water-supply wells, 23E-I and 23K (fig. 2) (Lorah and Vroblesky, 1989, p. 19). Volatile organic compounds were measured in water from all the wells, although only low concentrations were detected in ground water collected from the deepest well, 23E. The highest concentrations were observed at well 23F (fig. 2) during both sampling periods. The major contaminant was 1,1,2,2-tetrachloroethane, for which the maximum concentration was 2,300 μg/L. Other volatile organic compounds that were detected in water from one or more of the standby wells included carbon tetrachloride, tetrachloroethylene, chloroform, trichloroethylene, 1,2-*trans*-dichloroethylene, 1,1,2-trichloroethane, 1,2-dichloroethane, vinyl chloride, benzene, chlorobenzene, and xylenes.

Since 1966, a water-quality-monitoring program has been operating in the Edgewood area and mainly involves the collection of surface-water and effluent samples from Canal Creek and Kings Creek (Nemeth and others, 1983). As part of this monitoring program, the U.S. Army Environmental Hygiene Agency did an assessment of surface-water quality in the Edgewood area in 1977. Water-column, bottom-sediment, and fish and clam samples were collected from three sites along Canal Creek, four sites along Kings Creek, four sites in the Gunpowder River, and four sites in the Bush River (U.S. Army Environmental Hygiene Agency, 1977). Samples were also collected from several creeks that are outside the study area. When these samples were collected in 1977, most of the wastewater generated by manufacturing plants, research laboratories, and other buildings in the Edgewood area was discharged untreated to adjacent streams or rivers.

The 1977 study concluded that nutrient overloading had the largest effect on surface-water quality in the Edgewood area. Elevated concentrations of some trace metals and pesticides also were detected in Canal Creek and Kings Creek. In Canal Creek, lead and zinc concentrations were above background concentrations in the surface-water and bottom-sediment samples; in Kings Creek, silver, zinc, and mercury concentrations were above background concentrations in the water column. Analyses for volatile organic compounds were not done.

From August 1984 through May 1985, the U.S. Army Environmental Hygiene Agency (1985) conducted another water-quality and biological study of the surface-water system in the Canal Creek area. By this time, the wastewater-treatment system had been upgraded to eliminate all discharges of untreated wastes to the adjacent streams. Surface-water, bottom-sediment, and fish samples were collected from a total of six sites along Canal Creek and Kings Creek. Nutrient concentrations were low in the water column, in contrast to results from the 1977 study. Unlike the 1977 study, volatile organic compounds were determined in all surface-water samples collected in Canal Creek. Results showed the presence of carbon tetrachloride, 1,1,2,2-tetrachloroethane, tetrachloroethylene, trichloroethylene, chloroform, 1,2-dichloroethane, and methylene chloride in the water samples (U.S. Army Environmental Hygiene Agency, 1985). The agency concluded that the concentrations of volatile organic compounds were within safe limits for aquatic and human health; however, the presence of these volatile compounds in the surface water indicated an active, nearby source of the compounds, such as discharge of contaminated ground water to the creek (U.S. Army Environmental Hygiene Agency, 1985).

Elevated cyanide, copper, lead, zinc, and beryllium concentrations also were detected in surface-water samples (U.S. Army Environmental Hygiene Agency, 1985). Pesticides and polychlorinated biphenyls (PCB's) were detected in bottom-sediment samples from Canal Creek but not in water samples. The compound TCPU also was detected in bottom-sediment samples from both Canal Creek and Kings Creek. Various metals were found in the bottom-sediment samples, and the high concentrations indicated that Canal Creek had received more metal waste in the past than Kings Creek had (U.S. Army Environmental Hygiene Agency, 1985). Bottom-sediment samples collected in 1986 confirmed the presence of elevated concentrations of arsenic, chromium, and lead in Canal Creek and Kings Creek and the presence of elevated concentrations of PCB's in Canal Creek (Lancellotti, 1987). Analyses of fish muscle tissues showed that mercury, selenium, zinc, pesticides, and PCB's were present in fish from Canal Creek and Kings Creek, but concentrations were below criteria established by the U.S. Enviromental Protection Agency for human consumption (U.S. Army Environmental Hygiene Agency, 1985).

Nemeth (1989) summarizes other studies that have addressed different aspects of wastewater disposal at APG. These studies include evaluations of (1) the plumbing and sewer systems of various buildings to determine which facilities could discharge liquid radioactive waste, (2) the effect of wastewater discharges on the Gunpowder and Bush Rivers, (3) the APG water-supply system and the generation and handling of industrial, solid, and domestic wastes, (4) the operation of the sewage-treatment plant, and (5) the priority pollutants in wastewater generated in the Edgewood area.

Many of the studies that addressed the wastewater and sewer systems included some short-term monitoring of wastewater discharges to surface water. Under the current National Pollutant Discharge Elimination System permit, APG is required to monitor wastewater discharges for flow rate, biochemical oxygen demand, total suspended solids, fecal coliform, dissolved oxygen, total phosphorus, and total residual chlorine. Several studies have also addressed the drinking-water supply systems in the Edgewood area (Nemeth, 1989).

The USGS study that began in 1985 has produced reports that describe the hydrogeology of the Canal Creek area (Oliveros and Vroblesky, 1989), the inorganic and organic ground-water quality in the area based on data collected from November 1986 through April 1987 (Lorah and Vroblesky, 1989), and the hydrogeologic data collected from April 1986 through March 1988 in the study area (Oliveros and Gernhardt, 1989). In addition, Vroblesky and Lorah (1991) describe a new technique to locate areas where ground water that is contaminated with volatile organic compounds discharges to surface water. This research involved the collection of bottom-sediment gas bubbles from a total of 15 sites along Canal Creek during October 1988-89. Analysis of the gas bubbles showed that concentrations of volatile organic contaminants were substantially higher in areas where the same compounds occur in adjacent ground water that discharges to the creek. The analysis of the volatile organic content of the bubbles was also useful in identifying an area of previously unknown ground-water contamination.

Several studies were done concurrently with the USGS study. Nemeth (1989) did the RCRA Facility Assessment (RFA) of the Edgewood area of APG. The RFA presents information on historical activities in the area that have or may have resulted in the release of hazardous materials to the environment. The report discusses the history of facilities that generated wastes, identifies chemicals that have been introduced into the environment, describes past waste-disposal methods, summarizes the environmental chemistry and fate of selected military-related chemicals, summarizes previous environmental studies, and describes SWMU's and other sites that could be potential sources of contamination.

In addition to the information gathered for the RFA, a historical records search and site survey was done for 34 buildings in the Edgewood area, 28 of which are in the Canal Creek study area (EAI Corporation, 1989a and 1989b). The primary purpose of the records search was to identify potential contaminants in each building that could pose a hazard during demolition of the buildings. Visual inspections of the sites and interviews with past and present employees also were done. Seventeen of the buildings were determined to be potentially contaminated because they were used to store, manufacture, or process chemical-warfare agents or other types of contaminants. Some buildings posed a safety hazard because of their deteriorating condition (EAI Corporation, 1989a,b).

A preliminary baseline risk assessment (Durda and others, 1991) was done from October 1989 through January 1991 for eight priority areas at APG, one of which was the Canal Creek area. The risk assessments provide information on potential adverse effects on humans and wildlife from chemical contamination at these sites. The assessments, which are considered preliminary because of data limitations, are most useful for identifying the chemicals of concern, exposure pathways, and populations of greatest potential concern for each area (Durda and others, 1991). For the Canal Creek area, Durda and others (1991) conclude that (1) additional data are needed for full evaluation of potential human health risks, (2) acute and chronic toxicity from contaminants in Canal Creek probably has affected the composition and structure of the resident aquatic communities, and (3) terrestrial wildlife feeding in Canal Creek seem to be at risk from dietary exposure to heavy metals.

Acknowledgments

We wish to thank the following people and agencies for their important contributions to this study. Cynthia L. Couch and John Wrobel of the Environmental Management Division, Aberdeen Proving Ground, coordinated many aspects of the project. The U.S. Army Corps of Engineers installed the observation wells, and the U.S. Army Technical Escort Unit at Aberdeen Proving Ground provided special safety monitoring at some drilling locations. We are also grateful for the valuable information on past operations and waste disposal in the Canal Creek area provided by Gary Nemeth of the U.S. Army Environmental Hygiene Agency, Waste Disposal Engineering Division, Aberdeen Proving Ground.

DESCRIPTION OF STUDY AREA

Geographic Setting and Land Use

APG is in Harford County on the western shore of the upper Chesapeake Bay in northeastern Maryland (fig. 1). APG consists of two peninsulas that are separated by the Bush River--the Aberdeen area and the Edgewood area. The Canal Creek study area is located in the upper part of the Edgewood area (fig. 1). The study area lies in the Atlantic Coastal Plain Physiographic Province, where the topography is characterized by low hills, shallow valleys, and plains. Within the Canal Creek area, altitudes range from sea level to approximately 60 ft above sea level.

The climate is temperate and moderately humid. Because of the proximity of APG to the Chesapeake Bay and the Atlantic Ocean, winters are milder and humidity is higher than further inland. Climatological data for 1949-64 reveals that the average annual precipitation ranges from 39 to 45 in. (Durda and others, 1991, p. 2-7). Based on the records for 1949-64, the mean daily temperature is 33.8 °F in the winter and 75.2 °F in the summer. Mean annual temperature is about 54 °F. Predominant wind direction is from northwest to north-northwest in the winter and from south to south-southwest in the summer. Average wind speed ranges from about 6 to 7 mi/h; wind speeds generally are higher in the winter and spring (Durda and others, 1991, p. 2-7).

Canal Creek, which is the creek from which the study area name was derived, drains a land surface of more than 3,000 acres, including much of the study area (fig. 2). The East and West Branches of Canal Creek flow southward from their confluence into the Gunpowder River, an estuary at the southwestern edge of the study area; Lauderick Creek and Kings Creek drain to another estuary, the Bush River, on the eastern boundary. Kings Creek drains approximately 800 acres of land surface, much of which is included in the present study area. The creeks and estuaries in the study area are influenced by tides, and the change in surface-water level with the tide ranges from about 0.5 to 1.5 ft depending on the specific location.

Most of the land in the Canal Creek study area is developed, containing buildings, paved areas, and grassy landscaped areas. Since 1917, most manufacturing operations at APG were conducted in the Canal Creek area. Currently (1992), the area is a research and development center. Existing buildings include laboratories, munitions filling plants, offices, and vacant buildings that were manufacturing plants in the past. Several residential areas for military personnel and their families, recreational areas, and military training areas are also present. The Bush River is a popular recreational area for fishing and boating, and the mouth of Canal Creek at the Gunpowder River also is a fishing area.

Marshes that are classified as estuarine, emergent, irregularly flooded wetlands (Durda and others, 1991, p. 7-66) surround the West Branch Canal Creek, a small area along the East Branch of Canal Creek, and the entire reach of Canal Creek below the confluence of the two branches (fig. 2). Small wetland areas are also adjacent to Kings Creek. Wetland areas were more extensive in the past; however, landfilling of sanitary and production wastes eliminated many marsh areas, especially along the East Branch Canal Creek. Most of the land adjacent to the East Branch Canal Creek is mowed regularly, whereas the land immediately surrounding the West Branch consists of tall marsh vegetation including *Phragmites*, grasses, sedges, cattails, arrowhead, and pickerelweed (Durda and others, 1991, p. 2-4). Forested areas are present mainly near the northern boundary of the study area.

Most of the terrestrial wildlife present in the study area is characteristic of disturbed and developed land and includes woodchuck, eastern chipmunk, house mouse, gray squirrel, pigeon, mourning dove, mockingbird, and house sparrow (Durda and others, 1991, p. 7-66). Deer are common in the forested areas. Wading birds, ducks, shorebirds, frogs, and muskrat can be seen in the wetland areas, and the creeks and estuaries support a variety of freshwater and estuarine aquatic life. The endangered peregrine falcon and bald eagle also are found in the APG area.

Hydrogeology

Hydrogeologic Framework

The regional geology is characterized by thick, wedge-shaped deposits of unconsolidated Coastal Plain sediments that rest unconformably on the older crystalline rocks of the Piedmont Physiographic Province (Owens, 1969, p. 77). The Coastal Plain sediments dip southeastward, increasing to a thickness of approximately 400 ft in the study area. The unconsolidated sediments include the Potomac Group of Cretaceous age overlain by the Talbot Formation of Pleistocene age. Both units are fluvial in origin and consist of beds of clay, silt, sand, and gravel. In some locations, the Talbot Formation has been eroded by Holocene streams, and the underlying Potomac Group has been exposed.

The hydrogeology of the Canal Creek area of APG has been described in previous reports (Oliveros and Vroblesky, 1989; Oliveros and Gernhardt, 1989). Additional hydrogeologic data that were collected after publication of these reports are given in Appendixes A1 through A6 (at the end of this report). The data in the Appendix include additional lithologic logs (Appendix A1); chemical, physical, and mineralogic data from core samples of aquifer and confining units (Appendix A2 through A5; and synoptic water-level measurements (Appendix A6).

The generalized hydrogeologic section in figure 3 shows the aquifers and confining units delineated in the study area. The surficial aquifer sediments are primarily composed of the Talbot Formation. The upper confining unit, the Canal Creek aquifer, the lower confining unit, and the lower confined aquifer are composed of Potomac Group sediments. The sediments follow the regional trend, dipping and thickening southeastward. Because of their fluvial origin, the aquifers and confining units have variable thicknesses over relatively short distances and commonly contain individual beds that are not laterally continuous. Hydrogeologic section A-A', which extends west to east across the study area (fig. 4), illustrates some of the complexity of these fluvial deposits (fig. 5).

The Canal Creek aquifer (figs. 3 and 5), which was the major aquifer investigated during the present study, has a thickness of 30 to 70 ft in the study area. The Canal Creek aquifer is unconfined or semiconfined in areas where the upper confining unit is absent. The upper confining unit is absent in two areas that extend approximately parallel to the present courses of the East and West Branches of Canal Creek (fig. 6). Near the West Branch Canal Creek, the upper confining unit and Canal Creek aquifer crop out (fig. 5). Near the East Branch Canal Creek, a Pleistocene paleochannel deposit has replaced the upper confining unit, and the Canal Creek and surficial aquifers are in direct hydraulic connection (fig. 5). The Canal Creek aquifer is confined east and south of the paleochannel where the aquifer dips approximately 50 ft/mi (Oliveros and Vroblesky, 1989, p. 30-31) under the thickening upper confining unit (figs. 5 and 6). The upper confining unit is

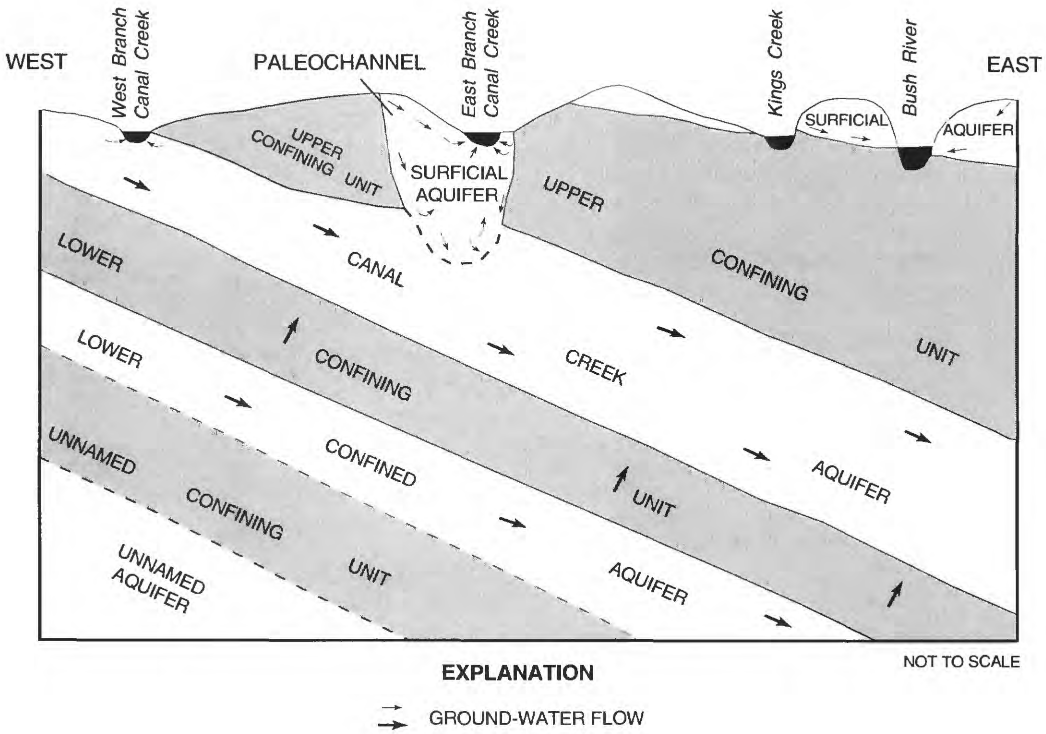


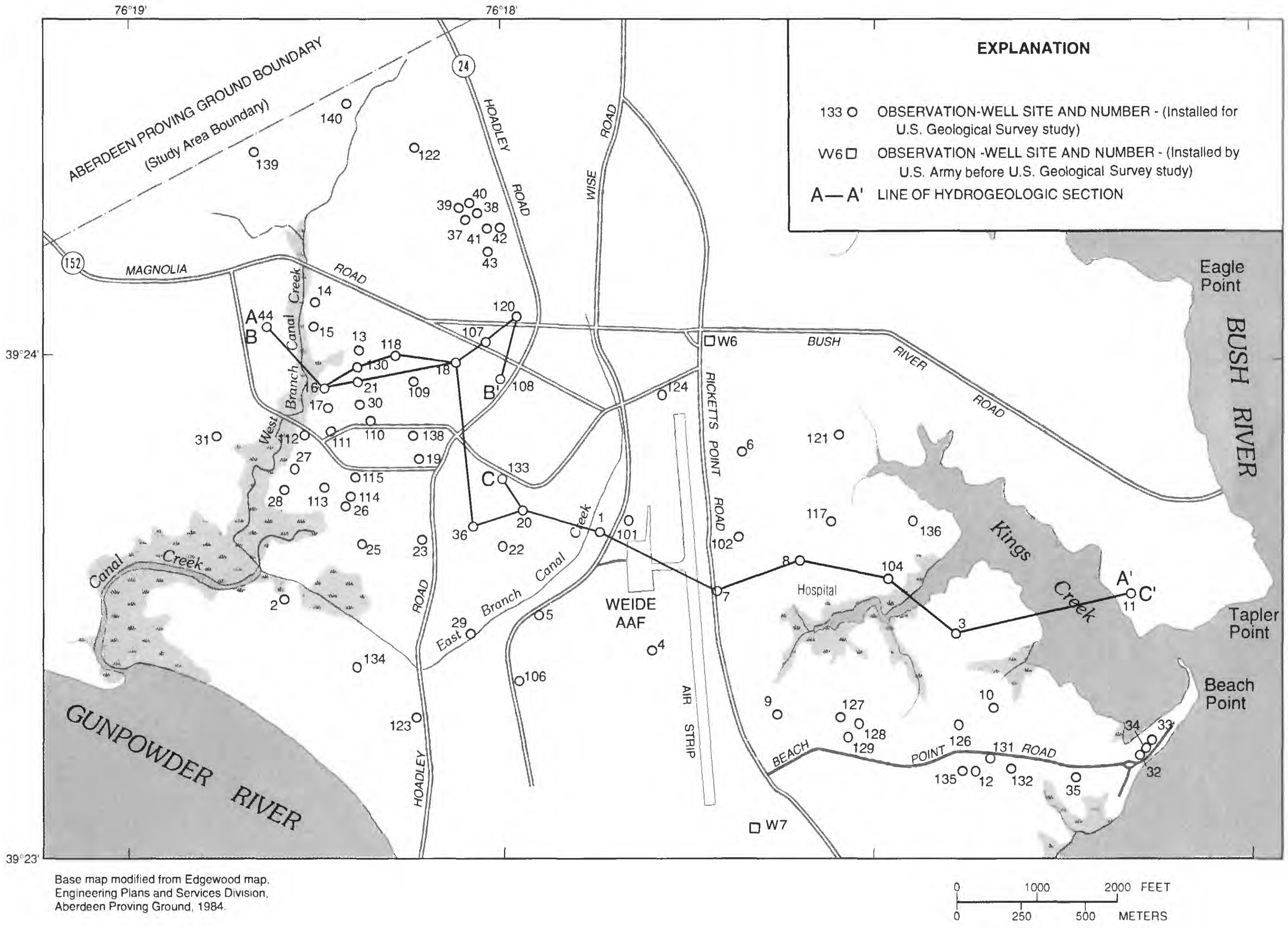
Figure 3. Generalized hydrogeologic section and conceptualization of directions of ground-water flow in the Canal Creek area, Aberdeen Proving Ground, Maryland. (Modified from Oliveros and Vroblesky, 1989, p. 24.)

more than 100 ft thick in the extreme southeastern part of the study area (fig. 6).

The surficial aquifer, which overlies the Canal Creek aquifer, becomes discontinuous and pinches out east and northeast of the paleochannel. Isolated parts of the surficial aquifer are present south of Kings Creek (fig. 3) and at Beach Point (fig. 2). The lithology of the surficial aquifer is highly variable because a large part of the study area has been disturbed by excavation and landfilling.

The lower confining unit and lower confined aquifer underlie the Canal Creek aquifer (fig. 3). The lower confining unit (fig. 3) has a distinct upper contact with the Canal Creek aquifer and a gradational contact with the underlying lower confined aquifer. The lower confining unit ranges in thickness from 35 to 65 ft. The lower confined aquifer (fig. 3) consists of fine- to medium-grained sand (Appendix A2) interbedded with clay. Although individual sand layers are laterally discontinuous, the lower confined aquifer as a whole seems to be continuous over the entire study area.

The aquifer sediments consist primarily of medium- to coarse-grained quartz sand and gravel that contain a small percentage of dark, heavy mineral grains (Appendix A2 and Appendix A4). Sequences of fine-grained sand and silt that contain an abundance of muscovite and lignite fragments are interbedded in the aquifer sediments in some areas (Oliveros and Vroblesky, 1989, p. 14). Orange to yellow iron staining is common in sand and gravel throughout the Canal Creek and surficial aquifers, and some sand layers show multicolored bands of purple, red, orange, yellow, and white. Iron mineralization is commonly found as small nodules and as ferruginous zones of cemented sand and gravel. Hematite, an iron-bearing heavy mineral, was the most abundant mineral besides quartz in aquifer sediment samples; another iron-containing mineral, geothite, was present in minor amounts in sediment samples (Appendix A4).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 4. Locations of hydrogeologic sections.

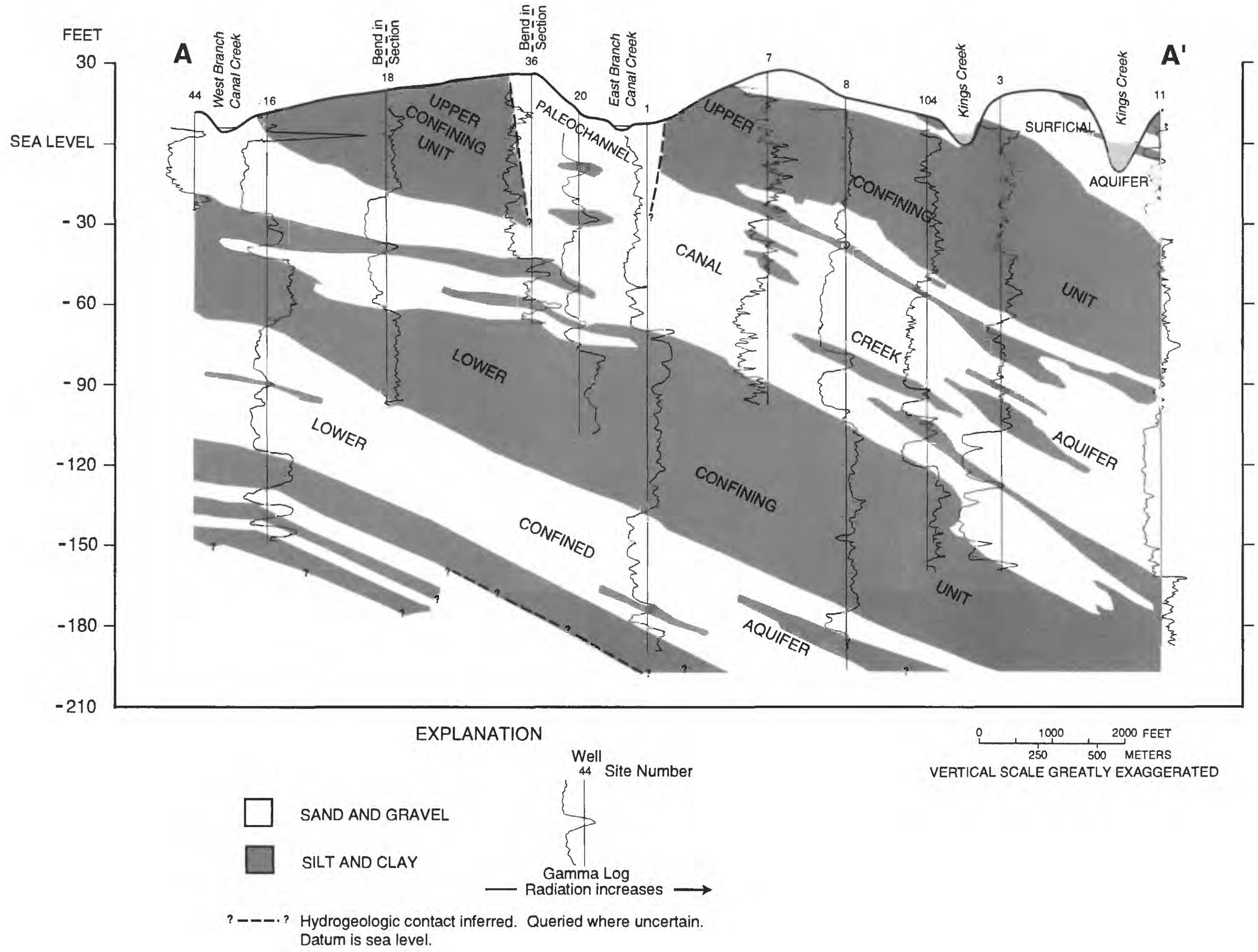
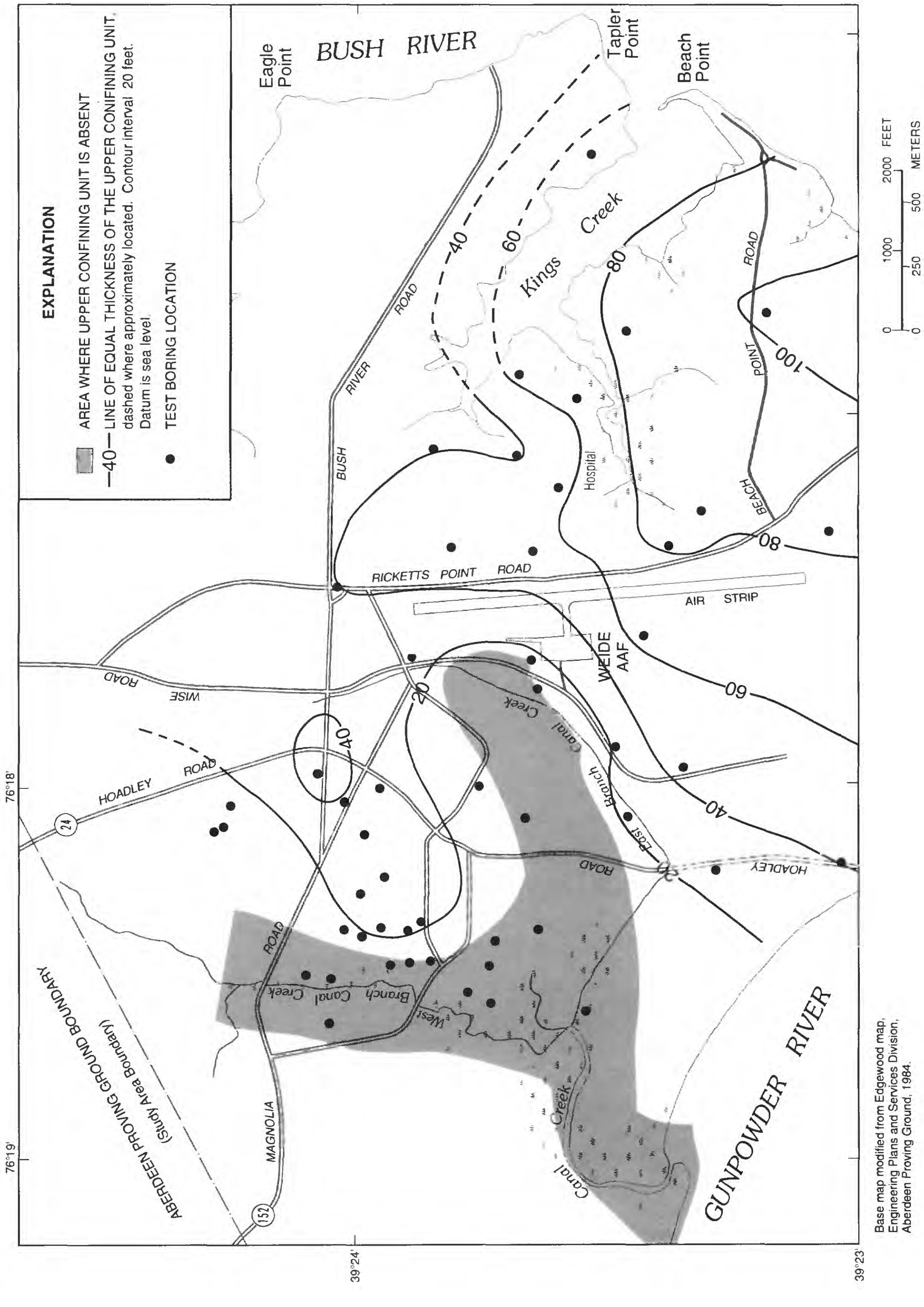


Figure 5. Hydrogeologic section A-A'. (From Oliveros and Vroblesky, 1989, fig. 7.)



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 6. Thickness of the upper confining unit.

The sediments of the upper and lower confining units contain a lower percentage of quartz and a higher percentage of the clay minerals kaolinite and illite than the respective percentage concentrations in the aquifer sediments (Appendix A4). The low plasticity indexes of the confining unit sediments (Appendix A3) are characteristic of kaolinite clays (Brady, 1978, p. 106-107). Major constituents that are commonly present in clay minerals and feldspars, such as aluminum, potassium, and magnesium, are found in higher concentrations in confining unit sediments than in aquifer sediments (Appendix A5). Concentrations of minor inorganic constituents and trace metals, such as manganese, barium, cobalt, chromium, nickel, and zinc, also are high in the confining unit sediments (Appendix A5). Clays commonly contain high concentrations of trace metals because of substitution reactions, ion exchange, or sorption (Blatt and others, 1980, p. 269).

Ground-Water Flow

The Canal Creek aquifer contains two separate flow systems: an unconfined local flow system and a confined regional flow system (Oliveros and Vroblesky, 1989, p. 35). The local flow system is present where the upper confining unit is absent near the West Branch Canal Creek and in the paleochannel near the East Branch Canal Creek (fig. 6). Ground water in the local flow system of the Canal Creek aquifer discharges vertically upward to the surficial aquifer or directly to the creeks, whereas ground water in the regional flow system moves southeast and downdip in the deep, confined part of the Canal Creek aquifer (fig. 3).

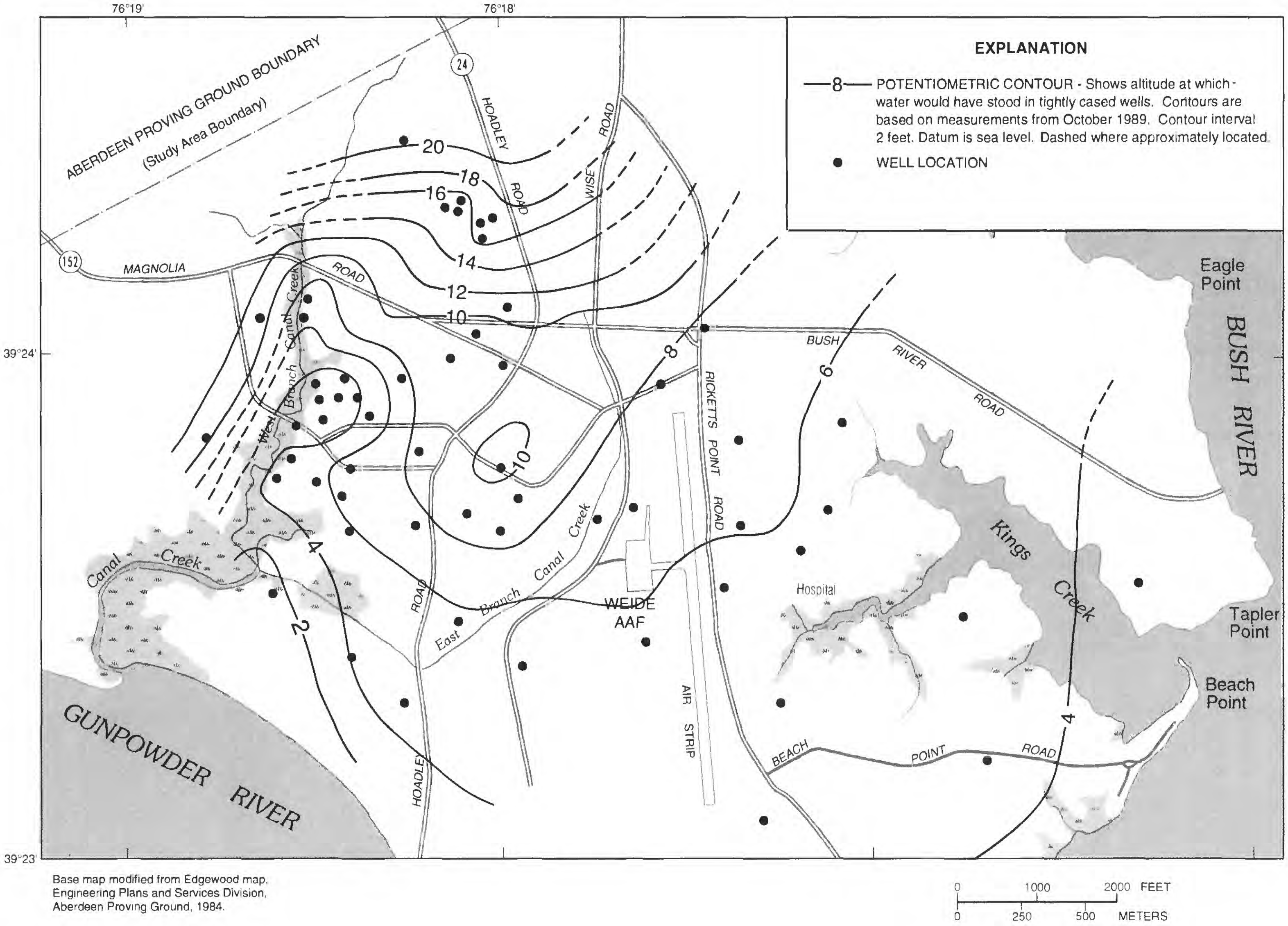
In the outcrop area of the Canal Creek aquifer (fig. 3), the distribution of hydraulic head in the aquifer indicates that ground-water flow is strongly affected by the presence of the West Branch Canal Creek (fig. 7). The upper part of the Canal Creek aquifer at sites near the West Branch Canal Creek has been hydrologically defined as part of the surficial aquifer because it behaves as a water-table aquifer (Oliveros and Vroblesky, 1989, p. 11). Near the West Branch Canal Creek, head distributions in this water-table aquifer (fig. 8) are very similar to the heads measured in wells screened in the lower part of the Canal Creek aquifer (fig. 7). Large bends in the head contours around the West Branch Canal Creek indicate that ground water in the lower part (fig. 7) and the upper part (fig. 8) of the Canal Creek aquifer flows toward and discharges to the West Branch Canal Creek. Some ground water also flows toward the East Branch Canal Creek near the confluence of the creek branches (figs. 7 and 8).

Ground-water flow in the Canal Creek aquifer near the West Branch Canal Creek is also affected by drainage into a network of leaky sewers and storm drains (Oliveros and Vroblesky, 1989). The potentiometric surface of the Canal Creek aquifer bends upgradient near a building called the pilot plant (fig. 7), indicating convergent ground-water flow where ground water is discharging into leaky sewerlines. In addition, excavation of the sewerlines around this plant in the mid-1980's disturbed the aquifer sediments and probably increased their horizontal hydraulic conductivity.

Near the East Branch Canal Creek, the Canal Creek aquifer is in direct hydrologic contact with the surficial aquifer, and a transition between the local and regional flow systems causes the ground-water flow to diverge (figs. 3 and 7). A slight bend in the potentiometric surface of the Canal Creek aquifer indicates an upward component of flow discharging to the surficial aquifer in the paleochannel; however, a large horizontal component of flow into the deep confined system subdues the response of the Canal Creek aquifer to the presence of the East Branch Canal Creek (figs. 3 and 7). Eastward of the East Branch Canal Creek, ground water in the Canal Creek aquifer moves mainly to the southeast in the confined regional system and discharges offsite (figs. 3 and 7).

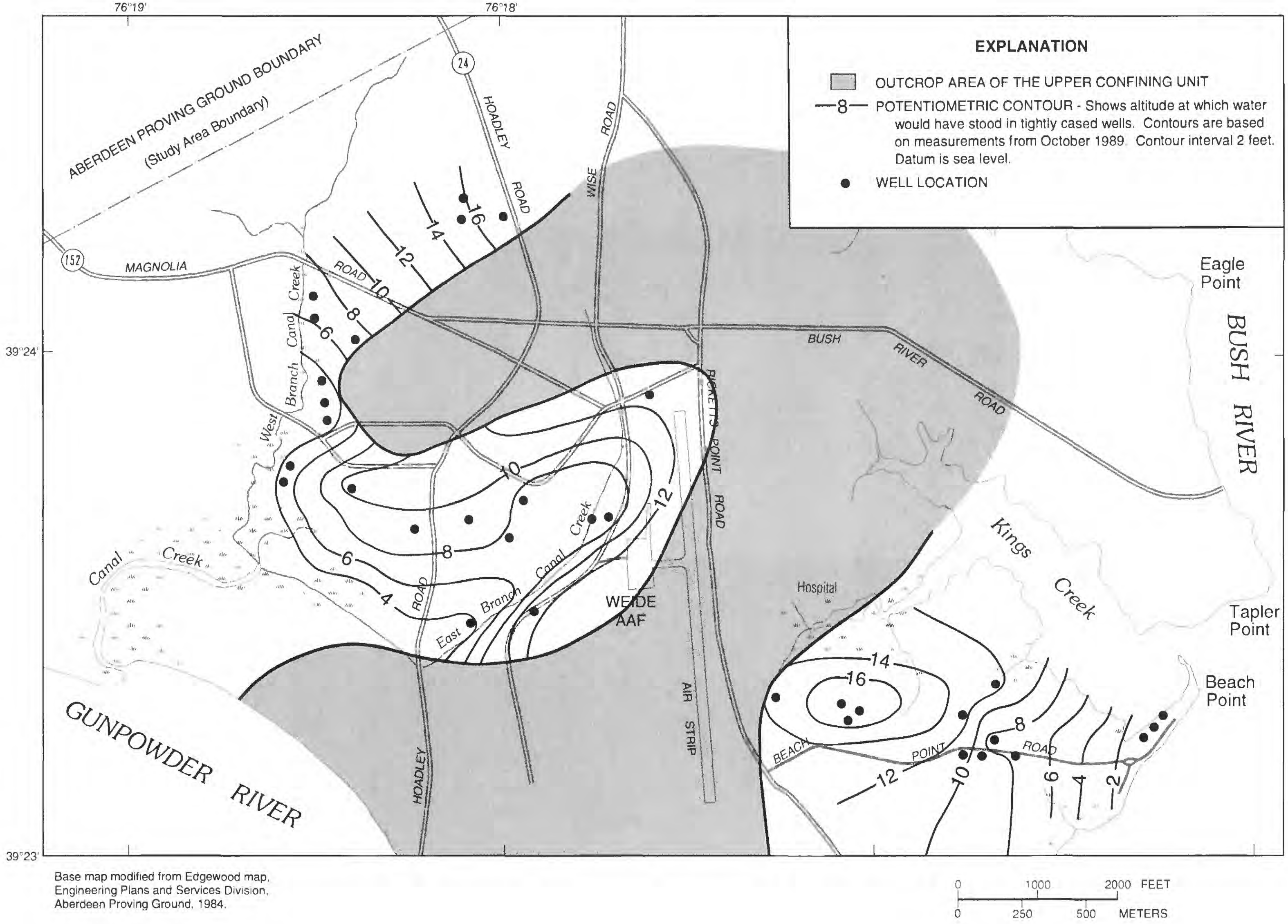
The Canal Creek aquifer receives recharge from three sources: (1) downward flow from the surficial aquifer, (2) upward flow from the lower confined aquifer, and (3) precipitation infiltrating to the aquifer in the outcrop area. Recharge from the surficial aquifer, which occurs where the vertical head gradient is downward, is shown in figure 9 as the unshaded zone. In the areas designated as recharge areas, the Canal Creek aquifer is highly susceptible to contaminants released at the surface. The zone of insignificant recharge or discharge in figure 9 delineates where the upper confining unit is thick enough to generally inhibit upward or downward ground-water flow.

The surficial aquifer receives recharge from direct infiltration of precipitation or surface water and from upward flow from the Canal Creek aquifer in some areas. Direct infiltration can occur over most of the surface area of the aquifer. The surficial aquifer discharges to surface water, to leaky sewers and storm drains, and to the Canal Creek aquifer. Much of the downward discharge from the surficial-aquifer to the Canal Creek aquifer probably returns as recharge to the surficial aquifer at topographic



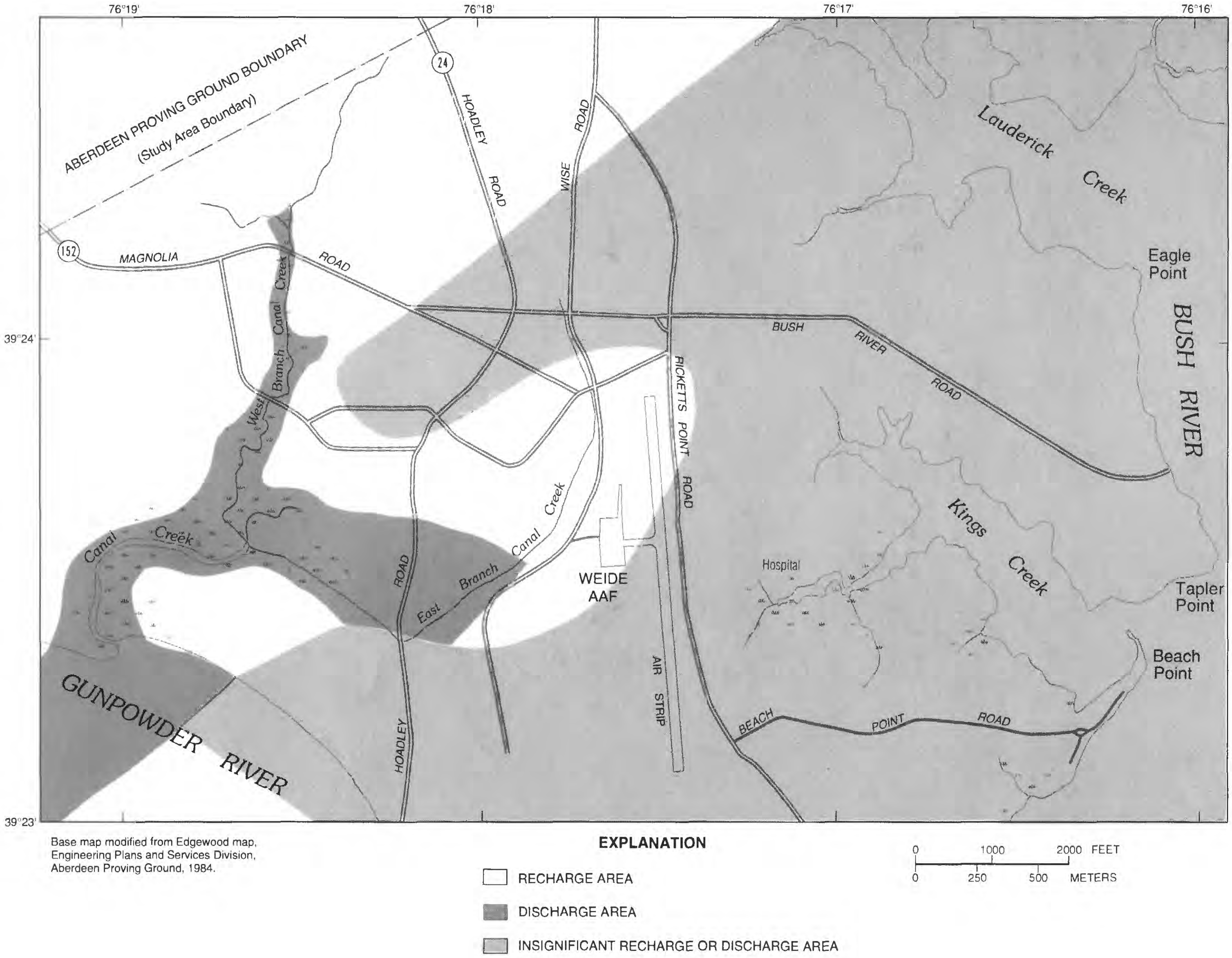
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 7. Distribution of hydraulic head in the Canal Creek aquifer, October 1989.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 8. Distribution of hydraulic head in the surficial aquifer, October 1989.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 9. Approximate locations of recharge and discharge areas for the Canal Creek aquifer.

lows; however, some may enter the regional flow system of the Canal Creek aquifer and move to the southeast to discharge offsite.

Water-level fluctuations in the Canal Creek area are caused mainly by rainfall and tidal effects. The maximum seasonal fluctuation in water levels observed in the Canal Creek aquifer was 2 to 3 ft (Oliveros and Vroblesky, 1989, p. 37). Seasonal changes in water levels in the Canal Creek aquifer are greatest in the unconfined parts of the aquifer. The hydrograph for well 44A (fig. 10), which is screened in the unconfined Canal Creek aquifer near the West Branch Canal Creek (figs. 2 and 6), generally shows a rise in water level during the winter and spring, when rainfall and effective recharge are greatest; a decline in water level generally occurs in the late summer to fall, when effective recharge is less (fig. 10).

Seasonal water-level fluctuations are greatest (as high as 5.5 ft) in the hydrologically isolated parts of the surficial aquifer east of the East Branch Canal Creek (Oliveros and Vroblesky, 1989, p. 25). Seasonal fluctuations in the water level of the lower confined aquifer (fig. 11) generally are less than those in the Canal Creek (fig. 10) or surficial aquifers. Overall, ground-water-flow directions in the three aquifers did not differ significantly throughout the study area as a result of seasonal fluctuations.

Currently (1992), pumpage stress does not affect ground-water flow within the study area. However, a large amount of water was pumped from the Canal Creek aquifer during and after World War II and was used for manufacturing activities. Six of the wells that were pumped, 23E-I and 23K (fig. 2), were considered a part of the water-supply system for the Canal Creek area until 1984 (Nemeth, 1989, p. 9). Wells 23F, 23G, and 23H were used to the greatest extent. A pump was installed in well 23N, but the well was probably never pumped for water supply. Wells 23B and 23C may have been operated periodically in the 1950's and 1960's but then were abandoned.

Well 23M, also identified as HA Ed 24, does not have a pump and has been used as an observation well by the USGS since 1949. The hydrograph for well HA Ed 24 shows a decline in water level of about 20 ft between 1950 and 1968 (fig. 12). Before 1968, the ground-water-flow system was probably dominated by the cone of depression that formed around the pumped wells. After about 1968, the water-supply wells (wells 23E-I and 23K) were not used routinely but were considered standby wells until 1984, when organic contaminants were detected in the water.

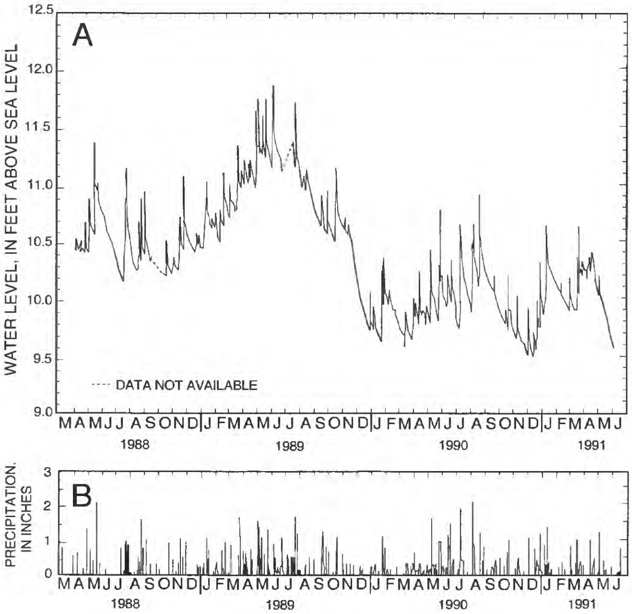


Figure 10. Observed water levels in the Canal Creek aquifer at well 44A and precipitation in the Aberdeen area, Maryland, March 1988 through June 1991.

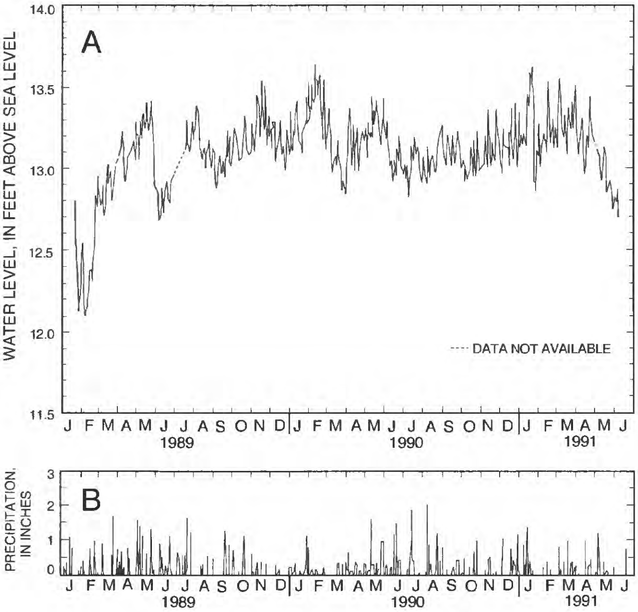


Figure 11. Observed water levels in the lower confined aquifer at well 139A and precipitation in the Aberdeen area, Maryland, January 1989 through June 1991.

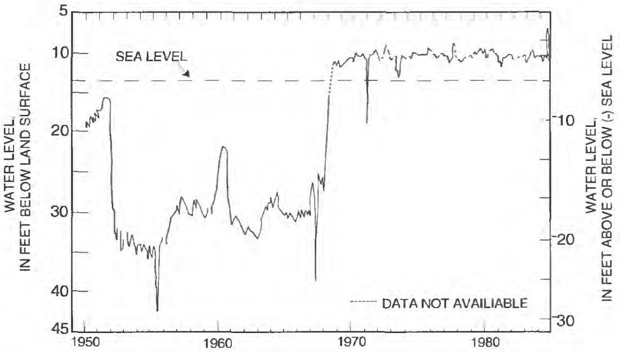


Figure 12. Observed water levels in the Canal Creek aquifer at well 23M (HA ED 24), Aberdeen Proving Ground, Maryland, 1950-85.

Site History and Waste Characterization

Since 1917, APG has been the primary chemical-warfare research and development center for the United States. Activities at APG have included laboratory research, field testing, and pilot-scale manufacturing of chemical materials. The Canal Creek area was also the location of plants for production-scale chemical manufacturing and for chemical munitions filling. Manufacturing and filling plants were concentrated in the area between the West and East Branches of Canal Creek (fig. 13). A summary of selected historical activities that took place at the locations marked in figure 13 is given in table 1.

Figure 13 and table 1 give only a partial reconstruction of the site history. Only those plants and related activities that are believed to have had the greatest effect on the environment are included. Many buildings were used for a number of different operations throughout their history, and historical records are incomplete. All historical information given in this report was derived from the RFA (Nemeth, 1989).

Most of the buildings in the Canal Creek area that were used for chemical manufacturing, munitions filling, or other related activities are considered to be SWMU's because they are historical waste-accumulation sites. Specific areas associated with the past manufacturing and filling buildings, such as sumps, storage tanks, ventilation systems, and waste-water discharge points, also are considered to be SWMU's. Nemeth (1989) identifies specific parts of buildings that are classified as SWMU's. In this report, the entire plant area is considered as a possible waste-release site, and individual SWMU's generally are not identified. Waste-disposal and waste-burning sites also are classified as SWMU's and include the salvage yard, smoke burning sites, sand pit, mustard plant waste pit, phossy water ponds, laboratory waste disposal pits (fig. 13; table 1), and landfill areas along the West and East Branches of Canal Creek.

Manufacturing, Filling, and Support Activities

Major production-scale activities that took place in the Canal Creek area include manufacturing of chlorine, mustard, chloroacetophenone (CN), and impregnite material (CC2); impregnating of protective clothing; and filling of munitions with chemical agents and with incendiary, smoke, or pyrotechnic materials (fig. 13 and table 1). Experimental and pilot production of chemicals, smoke materials, and pyrotechnic materials also took place in several buildings in the Canal Creek area. Other support activities that could have released wastes to the environment include operation of machine shops, garages, and the airfield. Manufacturing and filling plants were most active during World Wars I and II (WW1 and WW2).

Chlorine was used as a raw material for producing nearly all the chemical agents used in WW1 and WW2, and chlorine itself was used as an agent during WW1. Separate chlorine plants were built for each war. The WW2 plant was leased by the Diamond Alkali Company [1] to manufacture chlorine for commercial use after WW2.

Mustard, a blistering agent, was manufactured during WW1 and WW2 in several buildings near the junction of the East and West Branches of Canal Creek. The term "mustard" in historical records usually refers to sulfur mustard unless otherwise noted. Mustard also was produced at least once after WW2, between 1949 and 1950.

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[1] The use of trade, product, industry, or firm names in this report is for identification purposes and does not constitute endorsement by the U. S. Geological Survey nor impute responsibility for any present or potential effects on the natural resources.

The chemical agent CN, a tear gas, was manufactured intermittently beginning shortly after WW1 and continuing through WW2. CN was the principal tear gas agent produced in the United States before 1960. CN was sometimes mixed with other chemicals, including benzene and carbon tetrachloride (to make CNB) and chloroform and chloropicrin (to make CNS). During the 1920's and 1930's, the first CN plant was operated in the mustard plant area (fig. 13). A second CN plant was placed in operation in 1941 in building 58. During CN manufacturing in building 58, the bottom of the sewerline that received the acidic wastewater from the plant dissolved; it is not known when this problem was discovered or corrected.

Impregnite, when applied to clothing, provides protection by reacting with chemical agents to prevent hazardous amounts of the agents from reaching the skin. The material N,N'-dichloro-*bis*(2,4,6-trichlorophenyl)urea, abbreviated as CC2, has been the U.S. military standard impregnite since 1924. CC2 was manufactured in building 103 during about 1933-42 and in the building 87 complex, commonly known as the pilot plant, during 1942 (fig. 13).

Although a water-suspension process has been the preferred method of applying CC2 to clothing since the end of WW2, an organic-solvent process was mainly used before WW2. Experimental work with the impregnating process began in building 103 in 1930, but the first production-size clothing-impregnating unit was not installed until 1934 (table 1). Clothing-impregnating operations in building 103, which took place through 1967, were mostly pilot-scale or experimental work. The largest clothing-impregnating plant in the Canal Creek area was operated in building 73 during 1942. The solvent recovery system for this plant failed, releasing large quantities of solvent through the sewerline to the East Branch Canal Creek. In addition, two mobile units were used to conduct field tests of the impregnating processes at Beach Point during WW2 (fig. 13).

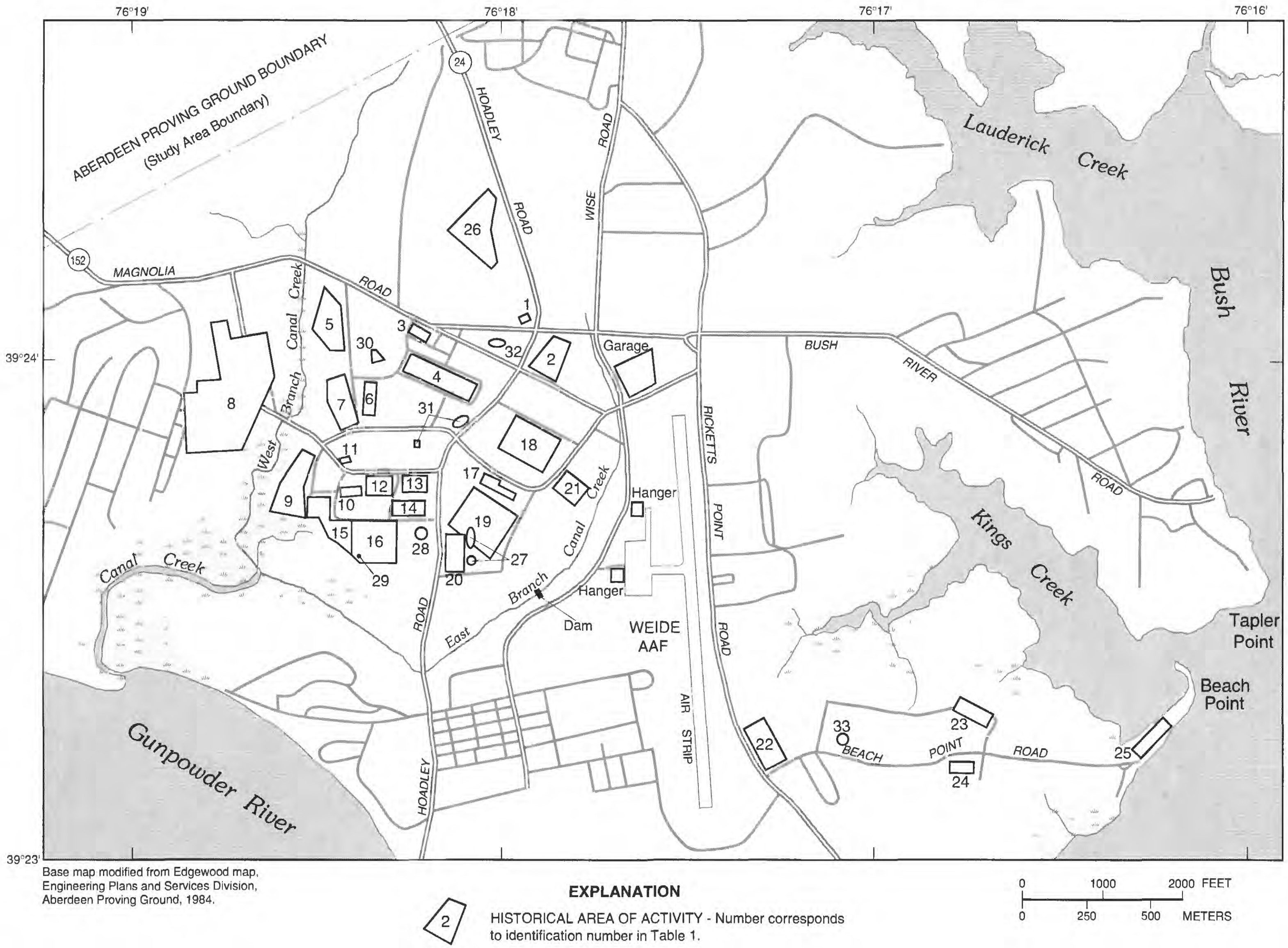
Pilot or experimental manufacturing was done to support the design of production-scale activities. In some cases, the distinction between production scale and pilot scale is unclear because some plants were operated as both. Much of the pilot-scale work during 1920-41 was with arsenic-containing agents, CN, and CC2. The experimental plants area (fig. 13) was the location of pilot manufacturing of mustard and of arsenic-containing agents such as lewisite, adamsite, diphenylchloroarsine, and methyldichloroarsine. Pilot studies of CC2 manufacturing and clothing impregnating were largely done in building 103, but some studies were also done in the experimental plants area. Pilot CN studies were done in the mustard-plant area.

During WW2, the number of pilot-scale manufacturing operations increased. The pilot operations took place in many of the same buildings as those used during 1920-41, but additional buildings were also used. The building 87 complex was used for most of the pilot-production studies done after WW2 in the Canal Creek area. A large part of the research and development work in this pilot plant involved the production of nerve agents, including the cholinesterase-inhibiting organophosphorus compounds GB and VX. Pilot-plant facilities were also constructed in 1943 in buildings 344, 345, and 346, which are presently (1992) called the building 37xx complex, in the southeastern part of the study area (fig. 13). Little information is available on early operations in the building 37xx complex, but nitrogen mustard could have been manufactured in this plant. Since the 1960's, the building 37xx complex has been used as a laboratory for agent and pyrotechnic testing.

Various munitions-filling operations have been conducted since 1918 and have included production- and experimental-scale filling with chemical agents and smoke, pyrotechnic, and incendiary materials. (Smoke munitions are designed for signaling or screening; pyrotechnic munitions are low-energy explosives designed to produce illumination, heat, and smoke; and, incendiaries are designed to destroy a target by melting or igniting it.) Production-scale filling activities were greatest during WW2, whereas most filling operations since WW2 have been on a pilot scale.

The first and second filling units were used only briefly during WW1 and intermittently after WW1 (fig. 13; table 1). The third filling unit in building 501 was not used during WW1 but was used later for mustard and white phosphorus (WP) filling. During WW2, facilities used for production-scale filling with chemical agents included building 60, building 84, the building 101 complex, and the mustard plant area.

The filling plants in buildings 31 and 90 were used mainly to fill smoke munitions with WP. Building 90 has been active as a WP filling plant for the longest period, operating on a production scale



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

EXPLANATION

2 HISTORICAL AREA OF ACTIVITY - Number corresponds to identification number in Table 1.

Figure 13. Selected historical areas of chemical manufacturing, munitions filling, waste disposal, and other activities in the Canal Creek area. (Refer to corresponding ID numbers in table 1 for detailed information on major historical activities.)

Table 1. *Summary of selected historical chemical-manufacturing, munitions-filling, and waste-disposal activities in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[Adapted from Nemeth (1989). Entries queried (?) where uncertain, dashed where information is not applicable; ft, feet]
ID: Identification number given in figure 13. **Building number or name:** "Complex" indicates that several buildings make up one plant, and number is given for main building. **Year demolished:** ND, not demolished; WW1, WW2: World War I, World War II. **Major activities:** BZ, an incapacitating agent; CN, tear agent (chloroacetophenone); CNB, CN mixed with benzene and carbon tetrachloride; CNS, CN mixed with chloroform and chloropicrin; CC2, impregnite material for protective clothing; CS, riot control tear gas agent; DM, adamsite, an arsenical; FS, smoke mixture containing sulfur trioxide and chlorosulfonic acid; GA, a nerve agent; HC, smoke mixtures containing hexachloroethane, Type C HC is most commonly used; WP, white phosphorus; PWP, plasticized white phosphorus.

ID	Past building number or name	New building number	Year constructed	Year demolished	Major activities	Approximate date range
1	99	5032	1918	ND	Incendiary bomb filling (production scale) .	1918-1930's
					WP filling (production scale).	? - ?
					Experimental and pilot-scale mixing and filling (primarily WP; also mustard, triethyl aluminum, explosive pellets, GA).	WW2-1981
2	31	S-5023	1918	1960's?	WP filling (production scale).	1918-end of WW2
					Metallic sodium filling (production scale).	1950's
3	90	5188	1941	ND	Miscellaneous production-scale filling plant.	1941-42
					WP and PWP production-scale filling plant.	1940's-1960's
					WP and PWP pilot-scale filling.	1960's-present
4	60	5185	1942	ND	Mustard filling (production scale).	1942-45
					Standby mustard-filling plant.	1945- mid-1960's
					Miscellaneous activities, including supply handling and warehouse; production and packing of filters and masks; cleaning and storage of production equipment.	1945-mid-1960's
					Machine shop and metal plating.	Mid-1960's -1975
5	77 complex	5641	1941	ND	DM manufacturing and production-scale filling.	1941-end of WW2
					Various mixing, filling, loading, and testing activities with smoke, pyrotechnic, and incendiary mixtures.	After WW2-1960"s
					Whetlerite manufacturing.	1961-64
6	84	5604	1941	ND	Production-scale filling (phosgene, mustard, FS, CNB, CNS).	1941-end of WW2
					Protective equipment plant.	1960s-?
					Thermite bomb washout.	After WW2?
					Bomb body degreasing.	Korean War period
					Cleaning and storage of production equipment.	End of WW2-1960's
7	87 complex ("pilot plant")	5625	1942	ND	CC2 production-scale manufacturing.	1942
					Pilot-scale manufacturing and research and development work with chemical agents, primarily nerve agents.	Mid-1940's-1986
					Pilot-scale filling of munitions with agents	1945-85
					Chemical laboratory.	1978-86
8	WW1 Cl plant (702-713)	--	1918	?	Production-scale chlorine manufacturing.	1918
9	WW2 Cl plant (120-129)	5552	1943	?	Production-scale chlorine manufacturing (leased by Diamond Alkali Company from shortly after WW2 until 1968).	1943-68
10	58	5380	1941	ND	Production-scale manufacturing of tear agents CN, CNB, CNS.	1941-44
					Production-scale manufacturing of the riot-control agent CS.	1959-60
11	701	5325	1918	ND	Part of WW1 Cl plant.	1918-?
					DM munition assembly.	1941-43
					Production-scale filling with napalm, jellied gasoline, and oil and metal incendiary mixtures.	1943-44
12	101 complex	5360	1918	ND	Phosgene plant	1918-late 1930's
					Production-scale filling with DM.	1941
					Machine and metal parts fabrication shop; metal plating.	WW2-mid-1960's

Table 1. *Summary of selected historical chemical-manufacturing, munitions-filling, and waste-disposal activities in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

ID	Past building number or name	New building number	Year constructed	Year demolished	Major activities	Approximate date range
13	88	5350	1922	?	Machine shop and metal-plating.	1922-1960's
14	103	5385	1918	Late 1960's	Chlorpicrin production-scale manufacturing. CC2 production-scale manufacturing. Clothing impregnating (mostly small scale and experimental work). Machine shop.	1918 1933-42 1930-67 End of WW1-WW2
15	Experimental plants (622, 642, 643, 644, 648)	Varied	1918-29	Most ND	Experimental and pilot-scale manufacturing of chemicals; majority of work was with arsenicals; other work involved CC2, Whetlerite, clothing impregnating and laundering; some buildings were also part of mustard manufacturing plant.	1918-1960"s
16	Mustard plant area (600 series)	Varied	1918-?	Varied	Sulfur mustard production and filling; different buildings were involved in production in WW1 and WW2 plants; greatest production and filling occurred during WW1 and WW2.	1918-50?
17	73	5238	1942	ND	Production-scale clothing impregnating; failure of solvent recovery system.	1942
18	1st filling unit (1-4)	--	1918	1938-41?	Production-scale munitions filling; used all chemical agents during WW1 except mustard; briefly used during WW1 and only intermittently after WW1.	1918-30's?
19	2nd filling unit (301-304)	--	1918	1930's	Production-scale munitions filling with all WW1 chemical agents; briefly used during WW1 and only intermittently after WW1.	1918-30's?
20	503 complex	5265	1918	ND	Incendiary bomb filling (production scale). Production-scale smoke filling, primarily with HC and some colored smoke; became known as the smoke pot plant. Research and development work and pilot-scale production of pyrotechnic smoke mixtures primarily included HC, colored smoke mixtures, and red phosphorus (most recently); other materials used include CS, CN, DM, WP, BZ, and mustard.	1942 WW2 End of WW2 -present
21	3rd filling unit (501)	5110	1918	1960's	Production-scale filling plant; constructed but not used in WW1. Mustard filling (pilot scale and production scale). Production-scale WP filling; some experimental filling after WW2. Present building 5100 constructed at same site (research laboratory).	-- 1938-41 1942-? Late 1960's-present
22	330 complex	3330	1943	ND	Chemical laboratories	1942-present
23	344-346	3724-3726	1943	ND	Called the building-37xx complex in Nemeth (1989). Pilot plant for unknown activities; possibly manufacturing of nitrogen mustard and experimental filling work. Laboratories with test chambers for agent and pyrotechnic testing.	-- 1943-? 1960's-present
24	Pyrotech. (2348)	3580	1952	ND	Research and development facility for preparing and loading pyrotechnics.	1952-present
25	Beach Point test site	--	--	--	Clothing impregnating in mobile plants (solvent and water process). Semipermanent clothing impregnating facility (water process). Testing of liquid rocket fuels. Testing of pyrotechnic materials and smoke generators.	1943 1943?-47? 1960's Post-WW2-1970
26	Salvage yard	--	--	--	Salvage yard for temporary storage and processing of scrap and salvageable items, mostly scrap metal and wood; some disposal of wastes, including drums containing chemicals. Fire-training pit.	1940's-late 1960's 1972-78

Table 1. *Summary of selected historical chemical-manufacturing, munitions-filling, and waste-disposal activities in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

ID	Past building number or name	New building number	Year constructed	Year demolished	Major activities	Approximate date range
27	Smoke-burning sites	--	--	--	Smoke mixtures burned for testing and disposal purposes; associated with smoke pot plant and research facility in building 503; HC and experimental smoke mixtures were burned.	WW2-1975
28	Sand pit	--	--	--	Sand pit used for building construction during WW1.	WW1
					Dump site for miscellaneous wastes including scrap, possibly chemicals, and contaminated equipment; became known as the building 103 dump because of its location.	End of WW1-early 1940's
29	Mustard plant waste pit	--	--	--	Pit used to dispose of some mustard manufacturing wastes.	1937-43
30	Phossy water ponds	--	--	--	Unlined ponds constructed to receive wastewater from WP and PWP filling operations in building 90 (5188).	1964?-early 1980's
31	Building 30 laboratory disposal pits	--	--	--	Disposal pits for toxic wastes from chemical laboratory in old building 30 (also called Laboratory #1); two pits 5 ft square, possibly a larger pit to the north.	WW1?-1945?
32	Building 65 laboratory disposal pits	--	--	--	Disposal pits for toxic wastes from chemical laboratory in old building 65 (also called Laboratory #2); actual size unknown.	Early 1920's-mid-1940's
33	Building 330 laboratory disposal pits	--	--	--	Disposal pit or pits for toxic wastes from chemical laboratory in old building 330; possibly only one pit 6 ft by 12 ft by 12 ft deep.	1943-late 1940's

from the 1940's to the 1960's and on a pilot scale from the 1960's until the present (1992). Incendiary bomb filling was done in building 99 from 1918 until the 1930's, in the building 503 complex during 1942, and in building 701 during 1943-44 (fig. 13 and table 1). After the 1930's, building 99 was used for WP filling for an unknown period of time and for various experimental filling studies from WW2 until 1981. The building 503 complex, which became known as the smoke pot plant, was used after 1942 for production-scale filling of smoke materials and for pilot-scale work with smoke and pyrotechnic mixtures. HC smoke mixtures, which contain hexachloroethane as the primary ingredient, were commonly used in the building 503 plant. The building 77 complex was used for adamsite (DM) manufacturing and filling during WW2 and was then used for a variety of mixing, filling, and loading activities with smoke, pyrotechnic, and incendiary mixtures until the 1960's. Pyrotechnic materials were also prepared and loaded in the research and development facility in building 2348 (later known as building 3580), which is in the southeastern part of the study area (fig. 13).

Other activities that could have had a deleterious effect on the environment include the operation of machine and maintenance shops, motor-pool garages, and the airfield. Machine and maintenance shops have been located in many different buildings since 1917; some of the larger shops, including the building 101 complex and buildings 88, 103, and 60, are shown in figure 13. Machine-shop activities consisted mainly of fabricating metal parts for munitions and other equipment, cleaning production equipment, and metal plating. An open lot at the north end of the airfield (fig. 13) was used as a motor-pool garage and maintenance facility from WW1 until at least 1966. The main gasoline service station that has been in use from WW2 until the present is also in this area. Aircraft-maintenance facilities, or hangars, have been in operation since WW1. One hangar was constructed in 1926 and another in 1943.

Waste-Disposal Practices

Organic solvents, such as carbon tetrachloride, 1,1,2,2-tetrachloroethane, and trichloroethylene, were probably the most common wastes produced in large quantities from the manufacturing, filling, and other miscellaneous activities in the Canal Creek area (Nemeth, 1989). All the major manufacturing plants (fig. 13), except for the chlorine plants, used solvents as raw materials, decontaminating agents, or cleaning agents. The most common inorganic constituents present in manufacturing wastes were chloride and sodium. Liquid and solid chemical wastes have been generated by past operations in the Canal Creek area.

The primary method of waste disposal from WW1 until the late 1970's was by discharge of untreated wastes to the sewer systems. The sewerlines from most of the manufacturing and filling plants discharged to the East or West Branches Canal Creek (fig. 14). Exceptions include the buildings in the southeastern part of the study area (fig. 13), where sewerlines discharged to Kings Creek. The mobile clothing-impregnating units that operated at Beach Point also discharged wastes to the Bush River or Kings Creek. Solid wastes such as sludges and tars were commonly disposed of through the sewers if the wastes could be thinned with water or held at elevated temperatures to keep them fluid.

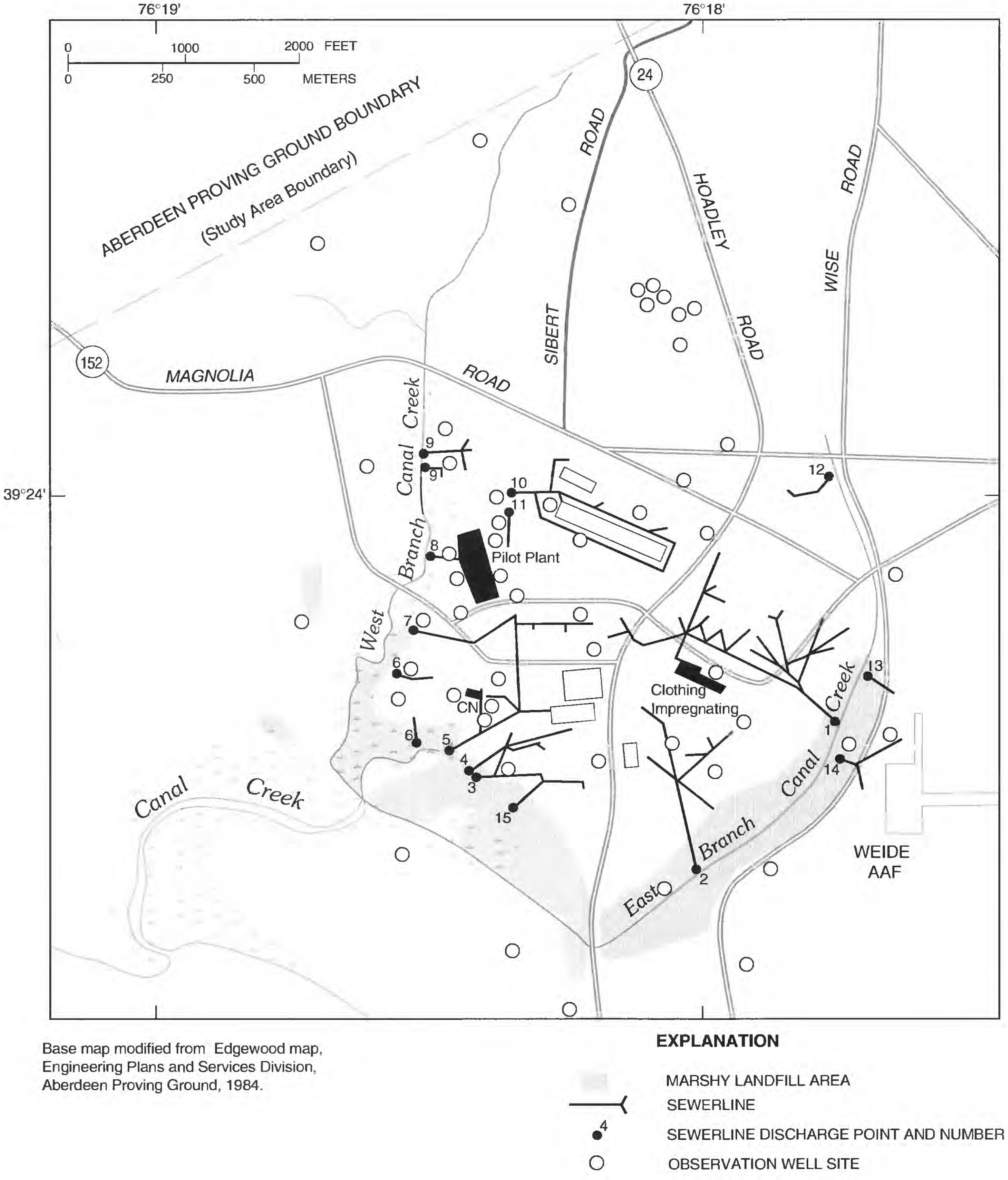
Before and during WW2, wastes generally received little or no treatment before they were discharged. The sewer system (fig. 14), which received both sanitary and chemical wastes, was constructed of vitrified clay during WW1. The sewerlines probably would have leaked a small amount of waste even without any major cracks or other problems. Waste treatment increased after WW2, and a new sanitary-sewer system and wastewater-treatment plant were constructed during the 1940's. Chemical wastes, however, still went to the older system (fig. 14), which discharged to Canal Creek. During the late 1970's, all discharges of untreated wastes to the creek were stopped.

The sewerline discharge points designated 1, 3, and 5 in figure 14 were the major discharge points during WW1 (Nemeth, 1989, p. 789). Discharge point 1 received wastes from the first and third filling units, point 3 received wastes from the mustard plant area, and point 5 received wastes from the building 103 complex. Other discharges through the sewerlines during WW1 included wastes from the WP filling plant in building 31 (discharge point 12) and from the second filling unit (discharge point 2).

The volume of wastes discharged to Canal Creek increased greatly during WW2 as existing plants were remobilized and new plants were constructed. Some of the manufacturing plants or support facilities and the corresponding discharge points (figs. 13 and 14) that were active during WW2 included the following: clothing-impregnating plant in building 73 and WP filling plant in building 501--discharge point 1; smoke filling plant in building 503--discharge point 2; experimental plants area and mustard plant area--discharge point 3; CN plant in building 58 and the machine shops--discharge point 5; WW2 chlorine plant--discharge point 6; filling plant in building 701--discharge point 7; CC2 production in the building 87 complex--discharge point 8; DM manufacturing and filling in the building 77 complex--discharge point 9; WP filling plant in building 90--discharge point 10; WP filling plant in building 31--discharge point 12; airfield hangar--discharge point 13.

Wastes that would not flow through the sewer systems were commonly dumped or buried in the marsh areas along Canal Creek. Thin layers of fill material were spread inward from the edges of the marsh along most of both branches of Canal Creek (fig. 14). The Canal Creek channel and marsh areas were considerably wider in some areas before landfilling took place. Some of the old sewerlines terminated at areas that are now covered with fill material (fig. 14), such as those near the mustard area. A variety of chemical wastes, including tars, sludges, and empty chemical containers, were placed in landfill areas in addition to sanitary wastes (Nemeth, 1989, p. 173). Photographs taken during WW1 show evidence of dumping along the east side of the West Branch Canal Creek, and large amounts of mustard are known to have been disposed of immediately south of the mustard-manufacturing area during WW1 and WW2 (figs. 13 and 14). Landfilling took place along the East Branch Canal Creek from the 1940's until 1972.

Other waste-disposal areas are known to have existed in the Canal Creek area, including the salvage yard, smoke burning sites, the sand pit, a mustard waste pit, phossy water ponds, and laboratory disposal pits (fig. 13 and table 1). The salvage yard (fig. 13), which has also been called the G-Street dump, was used primarily as a handling and processing area for any items that were considered salvageable (Nemeth, 1989, p. 627). A small amount of chemical waste was disposed of in the salvage yard, and chemical containers were often stored temporarily in the yard. A fire training pit, which would have required the use of fuels, was also operated in the salvage yard (table 1). An interim remedial action began in 1990 at the salvage yard to remove drums and other wastes at the surface.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 14. Sewerlines and landfill areas along the East and West Branches of Canal Creek. (Adapted from Nemeth, 1989.)

Various smoke mixtures were burned at the smoke burning sites for testing and disposal purposes during operations in the building 503 complex from WW2 through 1975 (Nemeth, 1989, p. 805). Two areas to the east of building 503 are still ash covered and bare of vegetation. As part of the RFA, ash and soil samples were collected from the burning sites and analyzed (Nemeth, 1989, p. 809). Above-background concentrations of zinc, cadmium, chromium, lead, and silver were found in the samples; and low concentrations of volatile and semivolatile organic compounds associated with smoke mixtures and their burning, such as hexachloroethane, tetrachloroethylene, hexachlorobenzene, and dye compounds, were present.

A sand pit (fig. 13) was excavated during WW1 and used later as a dump site for miscellaneous scrap and possibly chemical wastes (Nemeth, 1989, p. 784). The sand pit, also called the building 103 dump, is about 300 ft in diameter and 25-ft deep and was probably used as a waste-disposal site until it was covered in the early 1940's. The pit contained trucks and other equipment that may have been chemically contaminated. Recent soil erosion at the site has partially exposed a storage tank that is approximately 12 ft in length and 6 ft in diameter. The contents of the tank were sampled by the U.S. Army Chemical Research, Development and Engineering Center (CRDEC) and found to be mostly bromobenzyl cyanide, a French-manufactured riot-control tear gas from the WW1 era.

A pit in the former mustard plant area (fig. 13) was used during aproximately 1937-1943 to dispose of mustard manufacturing wastes (Nemeth, 1989, p. 810). The pit, which was approximately 10 to 20 ft in diameter, was dug primarily to receive "wild run" batches of mustard. A "wild run"--the formation of a gummy mass of mustard, sulfur, and other constituents (Nemeth, 1989, p. 31)--could occur when conditions such as temperature were not controlled precisely during mustard manufacturing. Before the disposal pit was dug, "wild runs" were discharged directly to the marsh south of the plant. "Wild runs" are believed to have been infrequent during 1937-43; however, a single "wild run" could have resulted in 6 tons of waste discharged to the pit because a 6-ton reactor was used in the mustard manufacturing plant. In addition to "wild runs," wastes from cleaning and contaminating the reactor were probably discharged to the pit. Standard operating procedures for the mustard pit specified that a chlorinated lime slurry be placed over the waste in the pit.

The phossy water ponds (fig. 13) were unlined ponds constructed to receive wastewater from the WP filling operations in building 90 (Nemeth, 1989, p. 813). Because WP burns when exposed to air, munitions generally were filled with WP under water. The wastewater, called phossy water, was the principal waste generated from WP storage, holding, and filling tanks. The principal chemical constituents of phossy water are phosphoric acids from oxidation of WP, WP in particulate form, and unseparated sludge (Nemeth, 1989, p. 133). One pond, constructed sometime between 1964 and 1970, was about 100 ft wide and 175 ft long. A second, triangular pond, constructed in the early 1970's, is about 14,700 ft^2 in area and has a minimum depth of 3 ft; this pond has a capacity of approximately 330,000 gal.

The ponds probably had sprinkler systems to enhance evaporation and oxidation of WP in the wastewater. Overflow from the ponds would have discharged to the West Branch Canal Creek. The 1979-83 upgrade of the sanitary sewer system is assumed to have eliminated discharge to the phossy water ponds (Nemeth, 1989, p. 813). Presently, the second phossy water pond contains water, whereas the area to the west where the first pond was located is often dry or contains only small amounts of water.

Toxic materials disposal pits (fig. 13) were located near three buildings used as chemical laboratories in the past: building 30, building 65, and building 330 (table 1). The locations of buildings 30 and 65 are not shown on figure 13, but they were in the immediate vicinity of the disposal pits. Toxic materials disposed of in these pits would have included military-related chemical agents, but the exact materials considered toxic would have changed over the years. Few records can be found on the type of materials placed in the pits. The laboratories probably did research on most of the chemical agents produced in the Canal Creek area. Laboratory work generally produced less than several gallons of a particular chemical agent in each batch. Thus, the laboratories typically disposed of a variety of different chemicals in small quantities.

Information from a surveyor's field book indicates that two 5-ft^2 pits were used by the building 30 laboratory, and other information indicates that there also was a larger disposal pit (Nemeth, 1989, p. 799). The approximate location of the building 65 disposal pit, or pits, is based on information from a surveyor's field book and aerial photographs (Nemeth, 1989, p. 799); the suspected pit location is presently covered by tall grass that is different from the surrounding vegetation. The approximate location of the disposal pit in the building 330 area (fig. 13) is based on an interview with an individual who worked in the area. The pit opening probably was about 6 ft by 12 ft, and the depth was about 6 ft. The pit was used during about 1943-47.

METHODS OF INVESTIGATION

Ground-Water Sampling

Sampling Network Numbering System, Construction, and Design

A total of 152 observation wells were installed during two phases of drilling--87 wells during the first phase and 65 wells during the second phase. The observation wells were installed at 77 sites that generally consist of clusters of 2 to 6 wells screened at different depths, although only 1 well was installed at several sites (fig. 2). Each well is screened in one of the three major aquifers; most wells are screened in the Canal Creek aquifer (table 2). Several wells are screened in unidentified sand lenses that are not in the three major aquifers.

A local well number (for example, CC-1A) was assigned to each well. The prefix "CC-" in the local number denotes the Canal Creek area. The site numbers for wells installed during the first phase range from 1 to 44, whereas all site numbers for the wells installed at new sites during the second phase are in the 100's (fig. 2 and table 2). Individual wells at a site are designated with a letter following the site number, beginning with "A" for the shallowest well (table 2). The local number without the "CC-" prefix will be used to refer to well sites, wells, and ground-water samples throughout this report (for example, "well site 1," "well 1A," or "sample from well 1A").

Several wells were installed during the second phase at first-phase well clusters; some of these wells, including 7A.1, 12A.1, 33B.1, are distinguished by the ".1" in their well numbers to indicate their screen depth relative to the first-phase wells at the site (table 2). In addition, wells 36B, 36C, and 36D, which are screened in the Canal Creek aquifer, and wells 6C and 28C, which are screened in the lower confined aquifer, were also installed at previously established sites. Well W6, which was installed by the U.S. Army before this study (fig. 2), also was included in the ground-water-sampling network; well W7, another U.S. Army well, was included in the water-level-measurement network but was not sampled.

Descriptions of the methods used for well construction, collection of lithologic data, and borehole geophysics are given in Oliveros and Vroblesky (1989, p. 6). Hollow-stem augers usually were used to drill wells whose depths are less than 120 ft; mud-rotary drilling with organic-free bentonite drilling fluid usually was used for wells whose depths are greater than 120 ft (table 2). Sediment samples were collected as the wells were drilled by placing a 5-ft core barrel inside the hollow-stem augers or by using a 2-ft-long split-spoon sampler in the mud-rotary holes. Lithologic descriptions of these sediment samples were used along with natural-gamma logs of the hole to determine screen placement at each well.

The wells were constructed of flush-joint polyvinyl chloride (PVC) screens and casing that have an outside diameter of 4 in. Most wells have 5-ft-long screens with a slot size of 0.01 in.; however, three wells (4B, 5C, and 29A) have different screen lengths (table 2) because the screens were placed to avoid thin silty clay layers. A quartz sand pack was set from the bottom of the screened interval to 2 ft above the top of the screen, and a 2- to 3-ft-thick bentonite seal was set above the sand pack. The annular space was then grouted to land surface with Portland Type V cement containing 4 percent bentonite.

In the first phase of drilling, wells were placed in the vicinity of suspected contaminated areas identified by use of historical information that was available at the time. After ground-water samples were collected and analyzed from these first-phase wells, wells were installed during the second phase to define more completely the extent and sources of contamination, and in some cases, to address possible source areas that were identified by newly acquired historical information. Because the RFA work was ongoing during the USGS investigation, some pertinent historical information, such as the locations of some possible contaminant source areas, was not available until after the first and second phases of well installation were completed. Thus, not all major possible sources were targeted with wells. Safety of the drillers and of the employees in nearby buildings was another concern in placement of the well sites. Because of suspected hazards, such as mustard, in much of the marsh areas along West Branch Canal Creek, wells were installed only around the edges of the marsh.

Suspected sources near the West Branch Canal Creek that were targeted during the first phase include (1) the pilot plant in the building 87 complex and building 84 (well sites 16, 17, 21, and 30); (2) the phossy water ponds (well site 13); (3) the DM plant in the building 77 complex (well sites 14 and 15); (4) the CN plant in building 58 (well site 26, 27, and 28); (5) the mustard plant area (well site 25); (6) the sand pit (well site 23); and (7) the salvage yard (well sites 37 to 43) (figs. 2 and 13). The sewerline extending south from the CN plant in building 58 (figs. 13 and 14) was known to have

Table 2. *Construction data for wells in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[**Site identification number:** Latitude and longitude plus a 2-digit sequence number; **Altitude.** In feet above sea level; **Drilling method:** Auger, well installed by use of hollow-stem auger; Mud rotary, well installed by use of mud rotary with bentonite mud; **Aquifer:** S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer; I, unidentified isolated sand lens; **Depth of boring, screened interval:** In feet below land surface]

Local number	Site identification number	Permit number	Altitude of land surface	Drilling method	Depth of boring	Screened interval	Aquifer
CC-1A	392335076172201	HA-81-2983	8.1	Auger	27	22-27	S
CC-1B	392335076172202	HA-81-2984	7.8	Auger	52	47-52	CC
CC-1C	392335076172203	HA-81-2985	8.0	Auger	72	67-72	CC
CC-1D	392335076172204	HA-81-2986	8.3	Mud rotary	154	149-154	LC
CC-1E	392335076172205	HA-81-2987	8.4	Mud rotary	173	168-173	LC
CC-1F	392335076172206	HA-88-0929	8.1	Mud rotary	198	183-188	LC
CC-2A	392328076182701	HA-81-2988	8.8	Auger	36	31-36	CC
CC-2B	392328076182702	HA-81-2989	8.6	Mud rotary	145	140-145	LC
CC-2C	392328076182703	HA-81-2990	7.5	Mud rotary	187	175-180	LC
CC-3A	392323076165001	HA-81-2993	18.8	Mud rotary	140	135-140	CC
CC-3B	392323076165002	HA-81-2994	19.2	Mud rotary	165	160-165	CC
CC-4A	392323076173601	HA-81-2996	23.6	Auger	83	78-83	CC
CC-4B	392323076173602	HA-81-2997	24.2	Mud rotary	99	88-90, 95-99	CC
CC-5A	392327076175501	HA-81-2999	17.5	Auger	20	15-20	S
CC-5B	392327076175502	HA-81-3000	16.8	Auger	59	54-59	CC
CC-5C	392327076175503	HA-81-3001	17.8	Auger	85	73.5-75.5, 80.5-82.5, 83-85	CC
CC-6A	392344076172101	HA-81-3003	26.0	Auger	63	58-63	CC
CC-6B	392344076172102	HA-81-3004	26.4	Auger	86	79.5-84.5	CC
CC-6C	392344076172103	HA-88-0930	25.9	Auger	123	115-120	LC
CC-7A.1	392332076172403	HA-81-4050	28.0	Auger	73	56-63	CC
CC-7A	392332076172401	HA-81-3005	28.3	Auger	90	85-90	CC
CC-7B	392332076172402	HA-81-3006	28.0	Auger	107	102-107	CC
CC-8A	392334076171301	HA-81-3007	18.5	Auger	52	46-52	I
CC-8B	392334076171302	HA-81-3008	18.4	Auger	80	75-80	CC
CC-8C	392334076171303	HA-81-3009	18.1	Auger	95	89.5-94.5	CC
CC-8D	392334076171304	HA-81-3010	21.6	Auger	115	110-115	CC
CC-8E	392334076171305	HA-81-3011	20.2	Mud rotary	202	196.5-201.5	LC
CC-9A	392316076171201	HA-81-3012	19.9	Auger	13	8-13	S
CC-9B	392316076171202	HA-81-3013	19.9	Mud rotary	123	118-123	CC
CC-10A	392317076164001	HA-81-3015	18.4	Auger	17	12-17	S
CC-11A	392332076161901	HA-81-3017	13.8	Mud rotary	138	133-138	CC
CC-11B	392332076161902	HA-81-3018	13.5	Mud rotary	161	156-161	CC
CC-12A.1	392308076164303	HA-88-0931	16..7	Auger	24	14-19	S
CC-12A	392308076164301	HA-81-3019	17.4	Mud rotary	145	132-137	CC
CC-12B	392308076164302	HA-81-3020	16.5	Mud rotary	170	160-165	CC
CC-13A	392401076182401	HA-81-3021	8.3	Auger	29	24-29	CC
CC-13B	392401076182402	HA-81-3022	8.3	Auger	56	51-56	CC
CC-14A	392407076183001	HA-81-3023	7.5	Auger	30	25-30	CC
CC-14B	392407076183002	HA-81-3024	7.4	Auger	55	50-55	CC
CC-15A	392404076183001	HA-81-3025	5.7	Auger	24	19-24	CC
CC-16A	392357076185201	HA-81-3027	11.7	Auger	23	18-23	CC
CC-16B	392357076185202	HA-81-3028	12.0	Auger	38	33-38	CC
CC-16C	392357076185203	HA-81-3029	11.8	Auger	88	83-88	LC
CC-16D	392357076185204	HA-81-3030	12.1	Mud rotary	120	115-120	LC
CC-17A	392354076185201	HA-81-3031	10.1	Auger	24	19-24	CC
CC-17B	392354076185202	HA-81-3032	10.2	Auger	35	30-35	CC
CC-17C	392354076185203	HA-81-3033	10.3	Auger	103	98-103	LC
CC-18A	392400076180601	HA-81-3034	19.8	Auger	52	47-52	CC
CC-18B	392400076180602	HA-81-3035	19.9	Auger	70	65-70	CC
CC-19A	392348076181401	HA-81-3036	28.4	Auger	11	6-11	I
CC-19B	392348076181402	HA-81-3037	28.4	Auger	58	53-58	CC
CC-20A	392341076175401	HA-81-3038	11.2	Auger	16	11-16	S
CC-20B	392341076175402	HA-81-3039	10.9	Auger	34	25-30	S

Table 2. *Construction data for wells in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

Local number	Site identification number	Permit number	Altitude of land surface	Drilling method	Depth of boring	Screened interval	Aquifer
CC-20C	392341076175403	HA-81-3040	10.4	Auger	59	54-59	CC
CC-20D	392341076175404	HA-81-3041	10.8	Auger	74	68-73	CC
CC-21A	392358076182401	HA-81-3043	14.2	Auger	35	30-35	CC
CC-22A	392337076175701	HA-81-3048	11.7	Auger	27	22-27	S
CC-22B	392337076175702	HA-81-3049	11.9	Auger	50	45-50	CC
CC-22C	392337076175703	HA-81-3050	12.3	Auger	70	65-70	CC
CC-23A	392339076181301	HA-81-3051	20.4	Auger	21	16-21	S
CC-23B	392339076181302	HA-81-3052	20.4	Auger	57	52-57	CC
CC-25A	392338076182301	HA-81-3056	12.1	Auger	27	22-27	CC
CC-25B	392338076182302	HA-81-3057	12.1	Auger	45	40-45	CC
CC-26A	392342076182601	HA-81-3058	12.9	Auger	20	15-20	CC
CC-26B	392342076182602	HA-81-3059	13.0	Auger	40	35-40	CC
CC-26C	392342076182603	HA-81-3060	13.6	Mud rotary	149	144-149	LC
CC-27A	392343076183301	HA-81-3061	11.4	Auger	23	18-23	CC
CC-27B	392343076183302	HA-81-3062	11.2	Auger	40	35-40	CC
CC-28A	392340076183401	HA-81-3063	10.9	Auger	21	16-21	CC
CC-28B	392340076183402	HA-81-3064	10.8	Auger	50	45-50	CC
CC-28C	392340076183403	HA-88-0932	10.3	Auger	137	120-125	LC
CC-29A	392328076180201	HA-81-3065	6.5	Auger	15	7.7-9.7, 12.5-15	S
CC-29B	392328076180202	HA-81-3066	6.6	Auger	47	42-47	CC
CC-30A	392355076182201	HA-88-0933	21.4	Auger	42	36-41	CC
CC-31A	392350076184301	HA-81-4076	9.1	Auger	37	25-30	CC
CC-32A	392311076161601	HA-81-4046	13.3	Auger	19	10.5-15.5	S
CC-32B	392311076161602	HA-81-4047	14.1	Auger	43	21-26	S
CC-33A	392314076161401	HA-81-4048	14.3	Auger	19	11-16	S
CC-33B.1	392314076161403	HA-88-0934	14.5	Auger	48	41-46	S
CC-33B	392314076161402	HA-81-4049	14.2	Auger	70	62-67	S
CC-34A	392312076161501	HA-81-4045	14.6	Auger	22	14-19	S
CC-35A	392307076162801	HA-81-4044	14.2	Auger	50	24-29	S
CC-36A	392340076180201	HA-81-4075	14.5	Auger	26	10-15	S
CC-36B	392340076180202	HA-88-0935	14.3	Auger	44	39-44	CC
CC-36C	392340076180203	HA-88-0936	14.2	Auger	62	56-61	CC
CC-36D	392340076180204	HA-88-0937	14.2	Auger	93	88-93	CC
CC-37A	392415076180001	HA-81-4043	32.1	Auger	43	23-28	CC
CC-38A	392416076175001	HA-81-4042	31.6	Auger	48	34-39	CC
CC-39A	392416076180301	HA-81-4041	31.4	Auger	29	20-25	CC
CC-39B	392416076180302	HA-81-4040	31.5	Auger	63	35-40	CC
CC-40A	392417076180101	HA-81-4039	31.2	Auger	34	26-31	CC
CC-41A	392417076180201	HA-81-4038	34.6	Auger	57	39-44	CC
CC-42A	392415076175701	HA-81-4037	33.8	Auger	49	22-27	CC
CC-43A	392414076175801	HA-88-0938	30.0	Auger	57	33-38	CC
CC-44A	392405076183701	HA-81-4077	11.9	Auger	37	16-21	CC
CC-101A	392341076174001	HA-88-0939	12.3	Auger	14	5-10	S
CC-101B	392341076174002	HA-88-0940	12.3	Auger	28	17-22	CC
CC-101C	392341076174003	HA-88-0941	11.6	Auger	56	45-50	CC
CC-102A	392339076172201	HA-88-0942	23.4	Auger	74	65-70	CC
CC-102B	392339076172202	HA-88-0943	23.0	Auger	89	81-86	CC
CC-102C	392339076172203	HA-88-0944	25.8	Auger	118	100-105	CC
CC-104A	392333076170201	HA-88-0945	12.4	Auger	87	76-81	CC
CC-104B	392333076170202	HA-88-0946	12.7	Auger	99	91-96	CC
CC-104C	392333076170203	HA-88-0947	13.0	Auger	130	125-130	CC
CC-106A	392320076175601	HA-81-4078	22.8	Auger	96	90-95	CC
CC-107A	392404076180301	HA-81-4063	29.7	Auger	58	51-56	CC
CC-107B	392404076180302	HA-81-4064	29.3	Auger	88	66-71	CC
CC-108A	392358076180001	HA-81-4065	29.6	Auger	60	55-60	CC
CC-108B	392358076180002	HA-81-4066	29.4	Auger	74	68-73	CC

Table 2. *Construction data for wells in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

Local number	Site identification number	Permit number	Altitude of land surface	Drilling method	Depth of boring	Screened interval	Aquifer
CC-109A	392357076181401	HA-81-4061	17.0	Auger	47	38-43	CC
CC-109B	392357076181402	HA-81-4062	17.2	Auger	69	59-64	CC
CC-110A	392353076182001	HA-81-4054	22.8	Auger	53	40-45	CC
CC-111A	392352076182601	HA-81-4051	15.1	Auger	32	25-30	CC
CC-111B	392352076182602	HA-81-4052	16.2	Auger	43	31-36	CC
CC-112A	392351076183101	HA-81-4053	9.8	Auger	39	29-34	CC
CC-113A	392345076182701	HA-81-4055	15.3	Auger	40	30-35	CC
CC-113B	392345076182702	HA-81-4056	15.1	Auger	64	51-56	CC
CC-114A	392344076182401	HA-81-4057	18.2	Auger	20	12-17	S
CC-114B	392344076182402	HA-81-4058	17.0	Auger	44	36-41	CC
CC-114C	392344076182403	HA-81-4059	17.8	Auger	64	53-58	CC
CC-115A	392346076182401	HA-81-4060	27.4	Auger	60	43-48	CC
CC-117A	392343076170201	HA-88-0948	9.1	Auger	83	78-83	CC
CC-117B	392343076170202	HA-88-0949	9.1	Auger	103	95-100	CC
CC-118A	392401076181601	HA-81-4071	14.7	Auger	39	32-37	CC
CC-118B	392401076181602	HA-81-4072	15.0	Auger	59	51-56	CC
CC-120A	392406076175701	HA-81-4067	32.0	Auger	64	55-60	CC
CC-120B	392406076175702	HA-81-4068	32.1	Auger	74	65-70	CC
CC-121A	392348076170401	HA-88-0950	10.4	Auger	93	68-93	CC
CC-121B	392348076170402	HA-88-0951	10.1	Auger	105	91-96	CC
CC-122A	392425076181501	HA-88-0952	28.9	Auger	43	22-27	CC
CC-123A	392316076181501	HA-88-0953	27.9	Auger	91	77-82	CC
CC-123B	392316076181502	HA-88-0954	27.7	Auger	109	101-106	CC
CC-124A	392355076173401	HA-81-4073	17.4	Auger	19	13-18	S
CC-124B	392355076173402	HA-81-4074	17.3	Auger	74	67-72	CC
CC-126A	392314076164601	HA-88-0955	24.0	Auger	24	13-18	S
CC-127A	392316076170401	HA-88-0956	24.4	Auger	18	6-11	S
CC-128A	392314076165901	HA-88-0957	22.3	Auger	14	6-11	S
CC-129A	392312076170301	HA-88-0958	27.5	Auger	33	17.5-22.5	S
CC-130A	392359076182301	HA-81-4069	14.8	Auger	41	32-37	CC
CC-130B	392359076182302	HA-81-4070	14.2	Auger	54	47-52	CC
CC-131A	392310076164101	HA-88-0959	12.8	Auger	18	11.5-16.5	S
CC-132A	392309076163901	HA-88-0960	16.7	Auger	18	11-16	S
CC-133A	392343076175401	HA-88-0961	23.6	Auger	24	15-20	S
CC-133B	392343076175402	HA-88-0962	23.3	Auger	74	60-65	CC
CC-134A	392323076182401	HA-88-0963	21.0	Auger	79	70-75	CC
CC-134B	392323076182402	HA-88-0964	20.6	Auger	99	93-98	CC
CC-135A	392309076164501	HA-88-0965	20.4	Auger	33	14-19	S
CC-136A	392340076165101	HA-88-0966	23.0	Auger	104	98-103	CC
CC-136B	392340076165102	HA-88-0967	23.5	Auger	144	133-138	CC
CC-138A	392351076181401	HA-88-0968	32.5	Auger	12	5-10	I
CC-139A	392437076183101	HA-88-0969	29.0	Auger	101	61-66	LC
CC-140A	392443076184401	HA-88-0970	32.0	Auger	89	81-86	LC
CC-W6	392403076172701	HA-81-1493	25.9	Auger	90	55-90	CC
CC-W7	392207076172201	HA-81-1494	26.2	Auger	140	119-139	CC

leaked organic solvents; thus, site 26 was placed near the sewerline, and sites 27 and 28 were placed downgradient along the presumed direction of shallow ground-water flow. Site 19 was placed where the building 30 laboratory disposal pit was originally believed to be, but the location of the pit was later revised on the basis of newly discovered historical information. Site 18 was intended to be an upgradient background well for the building 87 pilot plant area. Although contaminant sources were not thought to exist north or northeast of site 18 at the time these wells were drilled, volatile organic compounds were found in the first set of ground-water samples collected at site 18 (Lorah and Vroblesky, 1989, p. 54). Well sites 31 and 44 were placed in the vicinity of the WW1 chlorine plant. One well screened in the surficial aquifer was placed in the building 503 area at one of the smoke burning sites.

Several well sites were added near the West Branch Canal Creek during the second phase of drilling, on the basis of water-quality data received after sampling of the wells installed during the first phase (Lorah and Vroblesky, 1989) and newly discovered historical information. Because contaminants were found at well sites placed downgradient and upgradient from the pilot plant in the building 87 complex during the first phase of well installation, additional well sites were placed upgradient during the second phase, including well sites 110, 130, 118, and 109 (fig. 2). Well sites 111 and 112 were also placed downgradient to help define distribution of ground-water contaminants. Because contaminants were found in samples from wells at site 18, well sites 107, 108, and 120 were installed upgradient from site 18 during the second phase. The existence of the building 65 laboratory disposal pit (fig. 13) had recently been discovered during the RFA investigation, and this pit was thought to be a probable source of the contamination at site 118. Thus, well sites 107 and 108 were placed downgradient from the pit location, and well site 120 was placed upgradient. During the second phase, well sites 113 and 114 were added near the former CN plant in building 58, and well site 115 was installed as an upgradient background site for the CN plant. Well site 114, which includes a water-table well, was placed next to a benzene storage building. A well screened in the surficial aquifer was placed at site 138, immediately downgradient from the revised location of the building 30 laboratory disposal pit.

Most of the wells installed during the first phase near and to the east of the East Branch Canal Creek were placed to define the source and extent of contamination found previously in the past water-supply wells (fig. 2). Historical records indicate that the solvent-recovery system for the former clothing-impregnating plant in building 73 (fig. 13) had failed, releasing solvents to the sewerline that discharged near well site 1 (figs. 2 and 14). Well site 20 was placed downgradient from the plant; site 1 was placed near the sewer-discharge point; and, well sites 5, 4, 7, 8, 9, 3, 11, and 12 were placed so that the extent of the plume could be better defined.

The analytical results of the ground-water samples collected during the first phase indicated widespread contamination in the Canal Creek aquifer downgradient from the former clothing-impregnating plant in building 73 (Lorah and Vroblesky, 1989). Sites 106, 117, 102, 104, and 136 were installed during the second phase to define further the distribution and extent of this contamination. Well sites 123 and 134 were added to detect migration of contaminants toward the Gunpowder River. Well site 133 was placed immediately next to the suspected source, the former clothing-impregnating plant. Well site 101 was placed downgradient from an airport drain pit to determine if this could also be a source of the contamination. Relatively low levels of contaminants were measured in the ground water at site 6 during the first phase. During the second phase, well site 124 was installed near the motor-pool area (figs. 2 and 13) to determine if this area was the source of contamination detected at site 6.

Several well sites in the southeastern part of the study area contain wells screened only in the surficial aquifer and were placed so that sources unrelated to the clothing-impregnating plant in building 73 could be investigated. Well sites 32 to 35 were installed at Beach Point, the site of clothing-impregnating tests. Well site 10 consists of one well screened in the surficial aquifer near the building 37xx complex where a pilot plant had operated. Well site 126 was added upgradient from the building 37xx complex during the second phase of drilling. Newly discovered historical information obtained before the second phase of drilling indicated the possible existence of another laboratory disposal pit near the building 330 laboratory (fig. 13). Well sites 127, 128, and 129 each consist of one well screened in the surficial aquifer around the suspected pit location. Because of new information obtained on past activities in the pyrotechnics facility near the building 37xx complex (fig. 13), shallow wells were also installed at well sites 12 and 135 adjacent to the facility (fig. 2). Well sites 131 and 132 were placed downgradient from this pyrotechnics facility.

Other well sites installed during the second phase include sites 122, 139, and 140. Site 122, which consists of one well screened in the Canal Creek aquifer, was installed north of the main manufacturing and disposal sites in the study area. This site placement was designed to provide background water-quality information for the Canal Creek aquifer in the study area. After Harford County installed new water-supply wells northwest of the Canal Creek study area, well sites 139 and 140 were installed near the boundary of the army base (fig. 2). Water-quality monitoring at these well sites would allow detection of contaminant migration from the Canal Creek area toward the Harford County wells.

Sampling Methods

Field methods

Ground-water samples were collected from 87 wells during the first sampling period (November 1986 through April 1987), 123 wells during the second sampling period (July through September 1988), 80 wells during the third sampling period (April-May 1989), and 73 wells during the fourth sampling period (September-October 1989) (table 3). Table 3 shows the wells that were sampled during each period and the general types of chemical analyses done on each sample. Samples were collected for analysis of inorganic constituents and volatile organic compounds at most wells; samples were also collected at selected sites for semivolatile organic compounds during the last three sampling periods (table 3). The specific inorganic and organic constituents analyzed during the four sampling periods are shown in tables 4 to 8. Sampling methodology consisted of purging the wells; collecting, filtering, and bottling samples to be sent to contract laboratories; and conducting field measurements of pH, water temperature, dissolved oxyen, specific conductance, and alkalinity (reported as bicarbonate). The sampling and analytical methods used during the first sampling period are given in Lorah and Vroblesky (1989, p. 20-25).

Before sampling, a minimum of two well volumes of water was purged from each well, except for those wells that became dry before the two well volumes could be removed. Three different types of equipment were used for purging during the second sampling period--Teflon bailers, a bladder pump and packer system, and air-displacement purge pumps. Teflon bailers, which were 1.5 in. in diameter and attached to Teflon-coated stainless-steel cables, were used for the shallow wells that had water-column lengths less than about 10 ft. A bladder pump and packer system was used for some of the deep wells. Use of a packer with the deep wells greatly reduced the volume of water that had to be purged because the water in the casing could be sealed off above the screen. The packer was placed above the well screen, and the bladder pump was attached below the packer near the screened interval. The bladder pumps were made of stainless steel with Teflon bladders and could be taken apart easily in the field for servicing and decontaminating. The sample discharge tubing was also Teflon. The packer was constructed of Viton. The bladder pump and packer were lowered down the well and inflated with a portable oil-less air compressor. Air-displacement purge pumps that had a pumping rate of 4 to 5 gal/min were used to purge most of the wells during the second sampling period. The purge pumps, which were constructed of stainless steel and PVC, were placed near the top of the water column and lowered as the water level in the well declined. To prevent aeration of water in the aquifer around the well, field personnel avoided lowering the purge pump to depths greater than 10 ft above the top of the screened interval. Purge pumps were used for purging only and never for collecting samples.

During the third and fourth sampling periods (April-May 1989 and September-October 1989), the bladder pump and packer system was not used to purge wells. Either a Teflon bailer or a Keck pump, which is a positive displacement helical-rotor submersible pump, was used to purge shallow wells that had water-column lengths less than about 10 ft. The Keck pump is constructed of stainless steel and PVC with Teflon tubing and can pump at a rate of about 1 gal/min from a depth of 50 ft. An air-displacement purge pump was used for the remaining wells that were sampled, as was done during the second sampling period.

The water level in the well was allowed to recover before samples were collected. During the second sampling period, samples were collected from most wells with either a Teflon or stainless-steel bailer. To allow a controlled rate of sample flow from the bailer, field personnel attached a bottom-discharge fitting with a 0.25-in. inside-diameter Teflon tube approximately 6 in. long. The bottom-discharge fitting, which minimized aeration of the water during sample collection, was necessary for collection of samples to be analyzed for volatile compounds. If the water-column length was greater than approximately 8 ft in the shallow wells, a stainless-steel point-source bailer, which also had a Teflon bottom-discharge fitting, was used to collect samples from the screened interval. The bladder pumps were used to collect samples from wells that were purged using the bladder pump and packer system. The inflation pressure could be decreased on the bladder pump to control the sample flow rate. During the third and fourth sampling periods, the

Table 3. *Number of ground-water samples collected and general types of analyses done for four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[**Aquifers:** S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer; I, unidentified isolated sand lens; **Laboratories:** EE, Envirodyne Engineers; NL, Northern Laboratories and Engineering; ADL, A.D. Little (USATHAMA class contract); **Analyses:** I, inorganic compounds; TOH, total organic halogen (TOH analysis only indicated if V was not done); V, volatile organic compounds by gas chromatography/mass spectrometry; VL, volatile organic compounds with library search; H, halocarbon analysis for volatile compounds by gas chromatography; S, semivolatile organic compounds; SL, semivolatile organic compounds with library search; G, scan by gas chromatography-flame ionization detector; E, explosives; O, organosulfur compounds; (N), analyses done by U.S. Geological Survey National Water-Quality Laboratory; --, not sampled]

		ANALYSES BY EE/NL		ANALYSES BY ADL	
Local number	**Aquifer**	**Nov. 1986- April 1987 (87 wells sampled)**	**July-Sept. 1988 (123 wells sampled)**	**April-May 1989 (80 wells sampled)**	**Sept.-Oct. 1989 (73 wells sampled)**
CC-1A	S	I, V, G	I, V	I, H	I, VL
CC-1B	CC	I, V, G	I, VL, SL	I, H, O; I, V, S, (N)	I, VL, H
CC-1C	CC	I, V, G	I, VL, SL	I, H, O	I, VL
CC-1D	LC	I, V, G	--	I, VL, SL, (N)	--
CC-1E	LC	I, V, G	--	I, VL, SL, (N)	--
CC-1F	LC	I, V, G	--	--	--
CC-2A	CC	I, V, G	--	--	--
CC-2B	LC	I, V, G	--	--	--
CC-2C	LC	I, V, G	--	--	--
CC-3A	CC	I, V, G	I, V	--	--
CC-3B	CC	I, V, G	I, V	--	--
CC-4A	CC	I, V, G	I, V	--	--
CC-4B	CC	I, V, G	I, VL	--	--
CC-5A	S	I, V, G	--	--	--
CC-5B	CC	I, TOH, G	--	--	--
CC-5C	CC	I, V, G	I, VL	--	I, VL
CC-6A	CC	I, V, G	I, V	--	--
CC-6B	CC	I, V, G	I, VL	--	--
CC-6C	LC	--	I, V, G, S	--	--
CC-7A.1	CC	--	I, V, G, S	--	--
CC-7A	CC	I, V, G	I, VL, SL	I, H	I, VL
CC-7B	CC	I, V, G	I, VL, SL	I, H; V, (N)	I, VL, H
CC-8A	I	I, TOH, G	--	--	--
CC-8B	CC	I, V, G	I, VL, SL I, V, S, (N)	I, H;	I, VL, H
CC-8C	CC	I, V, G	I, V	I, H	I, VL
CC-8D	CC	I, V, G	I, VL	I, H	I, VL
CC-8E	LC	I, V, G	--	I, VL, SL, (N)	--
CC-9A	S	I, V, G	I, V	--	--
CC-9B	CC	I, V, G	I, V	--	--
CC-10A	S	I, V, G	V	H	--
CC-11A	CC	V, G	--	I, VL, SL, (N)	I, VL
CC-11B	CC	I, V, G	--	I, VL, SL, (N)	I, VL
CC-12A.1	S	--	I, VL, G, SL	H, SL, O	--
CC-12A	CC	I, TOH, G	--	--	--
CC-12B	CC	I, V, G	--	--	--
CC-13A	CC	I, V, G	I, VL, SL	I, H, SL, O	I, VL
CC-13B	CC	I, V, G	I, V	I, H	I, VL
CC-14A	CC	I, V, G	V	--	--
CC-14B	CC	I, V, G	V	--	--
CC-15A	CC	I, V, G	I, V	--	--
CC-16A	CC	I, V, G	I, VL, SL	I, VL, SL, O	I, VL, H, SL
CC-16B	CC	I, V, G	I, VL	I, VL, SL, O	I, VL
CC-16C	LC	I, V, G	--	I, VL, SL, (N)	--
CC-16D	LC	I, V, G	--	--	--
CC-17A	CC	I, V, G	I, VL, SL	I, H	I, VL
CC-17B	CC	I, V, G	I, VL	I, H	I, VL
CC-17C	LC	I, V, G	Mercury only	I, VL, SL, (N)	--

Table 3. *Number of ground-water samples collected and general types of analyses done for four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

		ANALYSES BY EE/NL		ANALYSES BY ADL	
Local number	**Aquifer**	**Nov. 1986- April 1987 (87 wells sampled)**	**July-Sept. 1988 (123 wells sampled)**	**April-May 1989 (80 wells sampled)**	**Sept.-Oct. 1989 (73 wells sampled)**
CC-18A	CC	I, V, G	I, V, SL	I, H	I, VL
CC-18B	CC	I, V, G	I, VL	I, H	I, VL
CC-19A	I	I, V, G	--	--	--
CC-19B	CC	I, V, G	--	--	--
CC-20A	S	I, V, G	I, V	I, VL, SL, (N)	I, VL
CC-20B	S	I, V, G	I, VL	I, H	I, VL
CC-20C	CC	I, V, G	I, V	I, VL, SL, (N)	I, VL
CC-20D	CC	I, V, G	I, VL, SL	I, H	I, VL, H
CC-21A	CC	I, V, G	I, VL	I, H	I, VL
CC-22A	S	I, V, G	I, V	--	--
CC-22B	CC	I, V, G	I, VL	I, H	I, VL
CC-22C	CC	I, V, G	I, V	--	I, VL
CC-23A	S	I, V, G	--	--	I, VL, SL
CC-23B	CC	I, V, G	I, VL	I, H, SL, O	I, VL
CC-25A	CC	I, V, G	I, VL, SL	I, H, SL, O	I, VL
CC-25B	CC	I, V, G	I, V	--	--
CC-26A	CC	I, V, G	I, VL, SL	I, VL, SL, O	I, VL
CC-26B	CC	I, V, G	I, VL	I, VL	I, VL
CC-26C	LC	I, V, G	--	I, VL, SL, (N)	--
CC-27A	CC	I, V, G	I, VL	I, VL, SL, O	I, VL, H
CC-27B	CC	I, V, G	I, VL	I, VL	I, VL
CC-28A	CC	I, V, G	I, VL, SL	I, VL, SL, O	I, VL
CC-28B	CC	I, V, G	I, V	I, VL	I, VL
CC-28C	LC	--	I, V, G, S	--	--
CC-29A	S	I, V, G	I, V	--	--
CC-29B	CC	I, V, G	I, V	--	--
CC-30A	CC	I, V, G	I, VL	I, H, SL, O	I, VL
CC-31A	CC	I, V, G	--	--	--
CC-32A	S	I, V, G	I, V	--	--
CC-32B	S	I, V, G	I, V	--	--
CC-33A	S	I, V, G	I, V	I, H	I, VL
CC-33B.1	S	--	I, V, G	--	--
CC-33B	S	I, V, G	I, VL, SL	I, H, SL, O	I, VL, H
CC-34A	S	I, V, G	I, V	--	--
CC-35A	S	V, G	--	--	--
CC-36A	S	I, V, G	--	--	--
CC-36B	CC	--	I, VL, G	I, H	I, VL
CC-36C	CC	--	I, V, G	I, H	I, VL
CC-36D	CC	--	I, V, G	--	--
CC-37A	CC	I, V, G	--	--	--
CC-38A	CC	I, V, G	--	--	--
CC-39A	CC	I, V, G	VL, SL	--	--
CC-39B	CC	I, V, G	V	--	--
CC-40A	CC	I, V, G	--	--	--
CC-41A	CC	I, G	--	--	--
CC-42A	CC	I, G	V	--	--
CC-43A	CC	I, TOH, G	--	--	--
CC-44A	CC	I, V, G	--	--	--
CC-101A	S	--	I, VL, G, S	--	--
CC-101B	CC	--	I, VL, G, SL	--	--
CC-101C	CC	--	I, V, G	--	--
CC-102A	CC	--	I, V, G	--	--
CC-102B	CC	--	I, VL, G, S	I, H,	I, VL
CC-102C	CC	--	I, VL, G, SL	I, H	I, VL
CC-104A	CC	--	I, V, G, S	--	--
CC-104B	CC	--	I, VL, G, SL	I, H	I, VL

Table 3. *Number of ground-water samples collected and general types of analyses done for four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

		ANALYSES BY EE/NL		ANALYSES BY ADL	
Local number	**Aquifer**	**Nov. 1986- April 1987 (87 wells sampled)**	**July-Sept. 1988 (123 wells sampled)**	**April-May 1989 (80 wells sampled)**	**Sept.-Oct. 1989 (73 wells sampled)**
CC-104C	CC	--	VL, G, S	I, H	I, VL
CC-106A	CC	--	V, G	--	--
CC-107A	CC	--	I, V, G	I, H, SL, O	I, VL
CC-107B	CC	--	I, VL, G	I, H	I, VL
CC-108A	CC	--	I, VL, G	I, VL, SL, O	I, VL, H, SL
CC-108B	CC	--	I, VL, G, S	I, VL	I, VL
CC-109A	CC	--	I, VL, G	I, H	I, VL
CC-109B	CC	--	I, V, G	--	--
CC-110A	CC	--	I, VL, G, SL	I, H	I, VL
CC-111A	CC	--	I, VL, G	I, VL, SL, O	I, VL, SL
CC-111B	CC	--	I, VL, G	I, H, SL, O	I, VL
CC-112A	CC	--	I, VL, G, SL	I, VL, SL, E, O	I, VL, H, SL
CC-113A	CC	--	I, VL, G, SL	I, VL,H	I, VL
CC-113B	CC	--	I, VL, G, S	I, VL	I, VL
CC-114A	S	--	I, VL, G	I, VL	I, VL
CC-114B	CC	--	I, VL, G, SL	I, VL	I, VL
CC-114C	CC	--	I, V, G	I, VL	I, VL
CC-115A	CC	--	I, VL, G	I, VL	I, VL
CC-117A	CC	--	I, VL, G	--	I, VL, SL
CC-117B	CC	--	I, V, G	--	--
CC-118A	CC	--	I, VL, G	I, H	I, VL, SL
CC-118B	CC	--	I, VL, G	I, H	I, VL
CC-120A	CC	--	I, VL, G, SL	I, H, VL, SL, E, O; I, VL, SL I, SL, VL, (N)	
CC-120B	CC	--	I, VL, G, SL	I, VL	I, VL, SL
CC-121A	CC	--	I, V, G	--	--
CC-121B	CC	--	I, V, G	--	--
CC-122A	CC	--	I, VL, G, S	I, H	I, VL
CC-123A	CC	--	I, V, G, S	--	--
CC-123B	CC	--	I, V, G	--	--
CC-124A	S	--	I, V, G	--	--
CC-124B	CC	--	I, VL, G, SL	--	--
CC-126A	S	--	I, V, G, S	--	--
CC-127A	S	--	I, V, G	H, SL, O	--
CC-128A	S	--	I, V, G, S	H, SL, O	--
CC-129A	S	--	I, VL, G, SL	H, SL, O	--
CC-130A	CC	--	I, V, G	I, H	I, VL
CC-130B	CC	--	I, V, G, S	I, H	I, VL, SL
CC-131A	S	--	I, V, G	--	--
CC-132A	S	--	I, V, G	--	--
CC-133A	S	--	I, V, G	I, H	I, VL
CC-133B	CC	--	I, VL, G	I, H	I, VL
CC-134A	CC	--	I, V, G	--	I, VL, SL
CC-134B	CC	--	I, V, G	--	--
CC-135A	S	--	I, VL, G	H, SL, O	--
CC-136A	CC	--	I, V, G	I, VL, SL, (N)	I, VL
CC-136B	CC	--	I, V, G	I, VL, SL, (N)	I, VL
CC-138A	I	--	Well dry	H, SL, O	--
CC-139A	LC	--	I, VL, G	--	--
CC-140A	LC	--	I, V, G, S	--	--
W6	CC	--	I, VL, G, SL	--	I, VL, SL

Table 4. *Inorganic constituents for which analyses were done for ground-water samples collected during four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[All units are in milligrams per liter. Dashes indicate that analysis was not performed; NA indicates that analysis was performed but no detection limit is reported]

	Reported detection limits during the sampling periods			
	Nov. 1986-April 1987 (Northern [1])	**July-Sept. 1988 (Northern [1]))**	**April-May 1989 (A.D. Little [2])**	**Sept.-Oct. 1989 (A.D. Little [2])**
	WATER-QUALITY MEASUREMENTS AND MAJOR CONSTITUENTS			
pH [3]	NA	NA	NA	NA
Water temperature [3]	NA	NA	NA	NA
Dissolved oxygen [3]	0.1	0.1	0.1	0.1
Specific conductance [3]	NA	NA	NA	NA
Dissolved solids	1.0	1.0	10	--
Calcium	.10	.10	.078	.078
Magnesium	.10	.10	.027	.027
Sodium	.010	.10	.49	.49
Potassium	.10	.10	--	.44
Bicarbonate [3]	1.0	1.0	1.0	1.0
Sulfate	1.0	.20	.15	.15
Chloride	5.0	.01-.10	.32	.32
Iron	.008	.010	.024-.026	.024-.026
Silica	.15	.10	.56	.56
	MINOR CONSTITUENTS			
Ammonia (as N)	0.20	0.10	--	--
Nitrate (as N)	--	--	--	0.18
Nitrite (as N)	.01-.02	.01-.03	--	--
Ammonia + organic nitrogen (as N)	.10-.50	.20	--	.05-.32
Nitrite + Nitrate (as N)	.03-.05	.03-.05	0.030	--
Phosphorus	.01	.01	--	--
Sulfide	1.0	.50-1.0	--	--
Fluoride	.88	.10	.070	.070
Bromide	--	.10	.050	.050
Cyanide	.01	.01	--	--
Manganese	.002	.001	.001	.001
Aluminum	--	--	.16-.18	.16-.18
Antimony	.024	.003	.067-.072	.072
Arsenic	.005	.001	.001-.003	.003
Barium	--	--	.001	.001
Beryllium	.001-.010	.001-.010	--	--
Boron	.050-.10	.010-.10	.26	.26
Cadmium	.001-.002	.001	.003	.003
Chromium	.001-.006	.001	.050	.050
Copper	.002-.004	.001	.021	.021
Lead	.050	.001	.005	.005
Mercury	.0002-.0005	.0005	.0005	--
Nickel	.005-.010	.001	.030	.030
Selenium	.001-.005	.001-.002	.004	.004
Silver	--	--	.0003	.0003
Thallium	--	--	.045	.045
Zinc	.002	.010	.044	.042

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[1] Analyses by Northern Laboratories and Engineering, Inc., Valparaiso, Ind.

[2] Analyses by Arthur D. Little, Cambridge, Mass.

[3] Measured in the field.

Table 5. *Volatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry and those included in the halocarbon analysis by gas chromatography for ground-water and surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[USEPA, U.S. Environmental Protection Agency; USATHAMA, U.S. Army Toxic and Hazardous Materials Agency]

Volatile organic compound (USEPA Method 624)	**USATHAMA code**	**Halocarbon (USEPA Method 601)**
Acetone [1]	ACET	No
Benzene	C6H6	No
Bromodichloromethane	BRDCLM	Yes
Bromoform	CHBR3	Yes
Bromomethane	CH3BR	No
2-Butanone [1]	MEK	No
Carbon disulfide [1]	CS2	No
Carbon tetrachloride	CCL4	Yes
Chlorobenzene	CLC6H5	Yes
Chlorodibromomethane	DBRCLM	Yes
Chloroethane	C2H5CL	Yes
2-Chloroethylvinyl ether	2CLEVE	No
Chloroform	CHCL3	Yes
1,2-Dichlorobenzene [1]	12DCLB	Yes
1,3-Dichlorobenzene [1]	13DCLB	Yes
1,4-Dichlorobenzene	14DCLB	Yes
1,1-Dichloroethane	11DCLE	Yes
1,2-Dichloroethane	12DCLE	Yes
1,1-Dichloroethylene	11DCE	Yes
1,2-*trans*-Dichloroethylene	12DCE	Yes
1,2-Dichloropropane	12DCLP	Yes
1,3-Dichloropropane [1]	13DCP	No
cis-1,3-Dichloropropene	C13DCP	Yes
trans-1,3-Dichloropropene	T13DCP	Yes
1,2-Dimethylbenzene [1]	12DMB	No
1,3-Dimethylbenzene [1]	13DMB	No
Ethylbenzene	ETC6H5	No
2-Hexanone [1]	MNBK	No
Methyl chloride (chloromethane)	CH3CL	Yes
4-Methyl-2-pentanone [1]	MIBK	No
Methylene chloride	CH2CL2	Yes
Styrene [1]	STYR	No
1,1,2,2-Tetrachloroethane	TCLEA	Yes
Tetrachloroethylene	TCLEE	yes
Toluene	MEC6H5	No
1,1,1-Trichloroethane	111TCE	Yes
1,1,2-Trichloroethane	112TCE	Yes
Trichloroethylene	TRCLE	Yes
Trichlorofluoromethane	CCL3F	No
Vinyl acetate [1]	C2AVE	No
Vinyl chloride	C2H3CL	Yes

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[1] Analyzed quantitatively with this method for ground-water samples collected during April-May and September-October 1989 and for surface-water samples collected during June 1989; not analyzed for ground-water samples collected during November 1986-April 1987 and July-September 1988 or for surface-water samples collected during September 1988.

Table 6. *Semivolatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry on ground-water and surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[Units in micrograms per liter; USATHAMA, U.S. Army Toxic and Hazardous Materials Agency; laboratory given in parantheses; alternative compound name in brackets; --, not analyzed]

Semivolatile compound (USEPA Method 624)	USATHAMA code	Detection limit in 1988 (Environmental Engineers)	Detection limit in 1989 (A.D. Little)
Acenapthene	ANAPNE	10	14
Acenaphthylene	ANAPYL	10	19
Anthracene	ANTRC	10	20
Benzo(a)anthracene	BAANTR	10	14
Benzo(b)fluoranthene	BBFANT	10	23
Benzo(k)fluoranthene	BKFANT	10	21
Benzoic acid	BENZOA	50	50
Benzo(g,h,i)perylene	BGHIPY	10	7.1
Benzo(a)pyrene	BAPYR	10	10
Benzyl alcohol	BZALC	10	10
4-Bromophenyl phenyl ether	4BRPPE	10	10
bis(2-Chloroethoxy)methane	B2CEXM	10	10
bis(2-Chloroethyl) ether	B2CLEE	10	8.1
bis(2-Chloroisopropyl) ether	B2CIPE	--	10
Butylbenzyl phthalate	BBZP	10	10
Di-n-butyl phthalate	DNBP	10	10
4-Chloroaniline	4CANIL	--	10
2-Chloronaphthalene	2CNAP	10	9.6
2-Chlorophenol	2CLP	10	10
4-Chlorophenylmethyl sulfide	CPMS	--	5.9
4-Chlorophenylmethyl sulfone	CPMSO2	--	38
4-Chlorophenylmethyl sulfoxide	CPMSO	--	6.8
4-Chlorophenyl-phenylether	4CLPPE	10	10
4-Chloro-3-methylphenol	4CL3C	10	10
Chrysene	CHRY	10	15
Dibenzo(a,h)anthracene	DBAHA	10	7.5
Dibenzofuran	DBZFUR	10	10
1,2-Dichlorobenzene	12DCLB	10	10
1,3-Dichlorobenzene	13DCLB	10	8.5
1,4-Dichlorobenzene	14DCLB	10	4.4
3,3'-Dichlorobenzidine	33DCBD	20	20
2,4-Dichlorophenol	24DCLP	10	10
Diethylphthalate	DEP	10	10
2,4-Dimethylphenol	24DMPN	10	10
Dimethylphthalate	DMP	10	10
2,4-Dinitrophenol	24DNP	50	50
2,4-Dinitrotoluene	24DNT	10	5.5
2,6-Dinitrotoluene	26DNT	--	6.6
Dithiane	DITH	--	7.7
bis(2-Ethylhexyl) phthalate	B2EHP	10	32
Fluoranthene	FANT	10	20
Fluorene	FLRENE	10	10
Hexachlorobenzene	CL6BZ	10	8.3
Hexachlorobutadiene	HCBD	10	18
Hexachlorocyclopentadiene	CL6CP	10	10
Hexachloroethane	CL6ET	10	5.1
Indeno(1,2,3-c,d)pyrene	ICDPYR	10	7.2
Isophorone	ISOPHR	10	10
2-Methylnaphthalene	2MNAP	10	10
2-Methylphenol [2-Cresol]	2MP	10	10

Table 6. *Semivolatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry on ground-water and surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

[Units in micrograms per liter; USATHAMA, U.S. Army Toxic and Hazardous Materials Agency; laboratory given in parantheses; alternative compound name in brackets; --, not analyzed]

Semviolatile compound (USEPA Method 624)	USATHAMA code	Detection limit in 1988 (Environmental Engineers)	Detection limit in 1989 (A.D. Little)
4-Methylphenol [4-Cresol]	4MP	10	10
Naphthalene	NAP	10	17
Nitrobenzene	NB	10	10
2-Nitroaniline	2NANIL	50	50
3-Nitroaniline	3NANIL	50	50
4-Nitroaniline	4NANIL	50	50
2-Nitrophenol	2NP	10	10
4-Nitrophenol	4NP	50	50
N-Nitrosodiphenylamine	NNDPA	10	10
N-Nitroso-di-n-propylamine	NDNPA	10	4.5
Di-n-octyl phthalate	DNOP	10	15
1,4-Oxathiane [Thioxane]	OXAT	--	9.1
Pentachlorophenol	PCP	50	50
Phenanthrene	PHANTR	10	22
Phenol	PHENOL	10	10
Pyrene	PYR	10	17
1,2,3-Trichlorobenzene	123TCB	--	3.6
1,2,4-Trichlorobenzene	124TCB	10	2.8
2,4,5-Trichlorophenol	245TCP	50	50
2,4,6-Trichlorophenol	246TCP	10	10
		PESTICIDES	
Aldrin	ALDRN	--	12
a-Benzenehexachloride [a-BHC]	ABHC	--	6.8
b-Benzenehexachloride [b-BHC]	BBHC	--	4.9
w-Benzenehexachloride [w-BHC]	DBHC	--	6.4
q-Benzenehexachloride [Lindane]	LIN	--	5.8
Chlordane	CLDAN	--	30
2,2-*bis*(para-Chlorophenyl)-1,1-dichloroethane [p,p'-DDD]	PPDDD	--	9.7
2,2-*bis*(para-Chlorophenyl)-1,1-dichloroethene [p,p'-DDE]	PPDDE	--	9.3
2,2-*bis*(para-Chlorophenyl)-1,1,1-trichloroethane [p,p'-DDT]	PPDDT	--	7.3
Dieldrin	DLDRN	--	11
a-Endosulfan [Endosulfan I]	AENSLF	--	3.0
b-Endosulfan [Endosulfan II]	BENSLF	--	6.0
Endosulfan sulfate	ESFSO4	--	6.0
Endrin	ENDRN	--	6.6
Endrin ketone	ENDRNK	--	6.0
Heptachlor	HPCL	--	6.2
Heptachlor epoxide	HPCLE	--	7.2
Malathion	MLTHN	--	7.3
Methoxychlor	MEXCLR	--	30
Parathion	PRTHN	--	4.7

Table 7. *Organosulfur compounds for which analyses were done by gas chromatography on selected ground-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[USATHAMA, U.S. Army Toxic and Hazardous Materials Agency; units in micrograms per liter]

Organosulfur compound	USATHAMA code	Detection limit
Benzothiazole	BTZ	3.5
4-Chlorophenylmethyl sulfide	CPMS	4.7
4-Chlorophenylmethyl sulfoxide	CPMSO	14.3
4-Chlorophenylmethyl sulfone	CPMSO2	13.7
Dithiane	DITH	2.2
1,4-Oxathiane	OXAT	2.1

Table 8. *Explosive compounds for which analyses were done by high pressure liquid chromatography for selected ground-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[USATHAMA, U.S. Army and Hazardous Materials Agency; units in micrograms per liter]

Explosive compound	USATHAMA code	Detection limit
1,3,5-Trinitrobenzene	135TNB	0.20
1,3-Trinitrobenzene	13DNB	.10
2,4,6-Trinitrotoluene	246TNT	.50
2,4-Trinitrotoluene	24DNT	.60
2,6-Trinitrotoluene	26DNT	.30
Cyclotetramethylenetetranitramine	HMX	1.10
Nitrobenzene	NB	10.0
Cyclotrimethylenetrinitramine [cyclonite]	RDX	.50
N-methyl-N,2,4,6-tetranitroaniline [nitramine]	TETRYL	.50

Keck pump was used to collect samples from most wells. The pump was placed at the screened interval, and the flow rate was controlled to prevent aeration of samples to be analyzed for volatile compounds.

Decontamination of the bailers, bladder pumps, and tubing between sampling of wells consisted of rinsing the equipment at least three times with distilled water. To decontaminate the Keck pump and its tubing, field personnel placed the pump in a PVC pipe and ran it while the pipe was filled several times with tap water and then several times with distilled water. All sampling equipment was also rinsed with the sample water several times before samples were collected. In addition, sampling and filtering equipment was cleaned thoroughly with laboratory detergent and rinsed with tap water and distilled water before sampling of wells in the lower confined aquifer or other wells were the ground water was previously found to be uncontaminated.

Filtration and preservation of samples was done in the field. Samples for analyses of all inorganic chemical constituents, except sulfide, were filtered through 0.1-µm membrane filters using a peristaltic pump. Before samples were collected from another well, the filter stands and Tygon tubing used with the peristaltic pumps were rinsed thoroughly with distilled water and with water from the well that was to be sampled. The Tygon tubing was replaced frequently. After filtration, samples to be analyzed for major cations and metals were acidified to pH 2 with concentrated nitric acid; samples to be analyzed for ammonia, nitrite-nitrate as nitrogen, and total phosphorous were acidified to pH 2 with sulfuric acid; and samples to be analyzed for cyanide were raised to pH 12 with sodium hydroxide.

Samples to be analyzed for sulfide and organic compounds did not require filtration and were collected directly from the sampling device into the appropriate bottles. The preservatives zinc acetate and sodium hydroxide were added to the sample bottles for sulfide analysis before the bottles were filled with water. Samples for sulfide analyses were collected only from those wells where dissolved-oxygen concentrations had been found to be less than approximately 1.0 mg/L. Samples to be analyzed for semivolatile organic compounds, also called base/neutral- and acid-extractable organic compounds (BNA's), were collected in gallon dark-glass bottles. Samples to be analyzed for total organic carbon (TOC) and total phenols were collected in 250-mL dark-glass bottles and were preserved with sulfuric acid. Samples to be analyzed for explosives and organosulfur compounds were collected in 1-L dark-glass bottles.

Special care was taken to ensure minimum aeration of the samples collected for analyses of sulfide, volatile organic compounds (VOC's), and total organic halogen (TOH). Samples to be analyzed for VOC's were collected in two or three 40-mL dark-glass vials; each vial was filled with a slow, steady stream of water and allowed to overflow by several times its volume. The glass vials were immediately sealed with caps lined with a Teflon septum and were checked for bubbles. If bubbles were observed, a new sample was collected. Samples to be analyzed for TOH were collected using the same procedure as for VOC's and were collected in 40- or 250-mL dark-glass bottles with Teflon-lined caps.

Additional samples were collected for tritium analyses during the third sampling period and for methane analyses during the second, third, and fourth sampling periods. Plastic bottles with conical plastic inserts in the caps were used to collect unfiltered samples for tritium analyses. During the second sampling period, samples for methane analyses were collected by use of the same procedure and sample containers that were used to collect for VOC's; the samples were analyzed in a contract laboratory by gas chromatography. During the last two sampling periods, samples for methane analyses were collected by use of a glass syringe to extract a minimally aerated sample from a slow, steady stream of water flowing from the Keck pump or bailer. The syringes were rinsed several times while held in the flowing stream of water to ensure that all air bubbles were expelled and that water unexposed to air was drawn into the syringe. A needle was then attached to the syringe, and the sample was injected into 24-mL serum bottles with rubber stoppers. Before samples were collected, the serum bottles were prepared in the laboratory by adding a few grains of mercuric chloride, inserting the rubber stopper, flushing the bottle with nitrogen gas, and attaching an aluminum crimp seal. Bottles were prepared and samples were analyzed at the USGS National Research Center, Reston, Va.

All sample containers were placed immediately on ice in coolers. At the end of each day, the samples were packed in the coolers and sent by overnight airfreight to laboratories for chemical analysis. Chain-of-custody forms were completed and sealed inside of each cooler.

The project quality-assurance program included collection of quality-control samples. Duplicate or replicate samples and field blanks were collected for approximately 10 to 15 percent of the total number of wells sampled during each period. Duplicate samples to be analyzed for inorganic constituents were collected by use of two filter stands and peristaltic pumps; two sample bottles were filled simultaneously as water was pumped from the same source. Duplicate samples to be analyzed for VOC's were filled from the same bailer. During the third sampling period, two sets of duplicate samples were collected at three wells--one set was analyzed by the regular contract laboratory and the other set-was analyzed by the USGS National Water-Quality Laboratory for an independent check of analytical results.

Two types of blanks, trip blanks and equipment blanks, were collected in the field during each sampling period. Trip blanks were prepared by pouring distilled water directly into the appropriate sample containers. After ground-water samples were collected at a well, equipment blanks were prepared by decontaminating the field equipment and then pouring or pumping distilled water through the equipment (including filter stands for the inorganic constituents) into sample containers. The trip and equipment blanks were labeled and treated as ground-water samples and were shipped to the laboratory in the same cooler as the ground-water samples.

Dissolved oxygen, water temperature, specific conductance, pH, and alkalinity were measured in the field immediately after the wells were purged and allowed to recover. The dissolved-oxygen concentration was measured with a dissolved-oxygen meter that was equipped with a probe and submersible stirrer attached to the meter with a 50-ft-long cable. After the meter was calibrated to saturated air, dissolved oxygen was measured with the probe and stirrer assembly placed at the screened interval of the well or at a depth of 50 ft in wells where the screen was deeper than 50 ft.

Water temperature, pH, and specific conductance were measured in glass beakers immediately after collection of unfiltered water. Water temperature was measured with a laboratory-grade glass thermometer marked in increments of 0.1 °C. Temperature was also recorded from the dissolved-oxygen, pH, and specific conductance meters. The pH was determined with a commercial pH meter equipped with a gel-filled combination pH electrode and an automatic temperature-compensator probe. The meter was calibrated with pH 4.00 and 7.00 buffers before the sample was collected. If the pH of the sample was greater than 7.00, the meter was recalibrated with pH 7.00 and 10.00 buffers and the pH was reread on a fresh sample. Specific conductance was measured with a field/laboratory conductance meter with a glass conductivity cell and temperature probe. Although the specific-conductance meters were calibrated by the manufacturer, calibration was checked frequently with standard reference solutions.

Alkalinity titrations were done on a 100-mL filtered sample. The sample was stirred continuously by a battery-powered magnetic stirrer while a Hach Digital Titrator was used to add sulfuric acid until a pH of about 3.9 was reached. Alkalinity was calculated as the endpoint of the curve generated from pH as a function of the cumulative volume of acid added. Records were kept describing daily field procedures, meter calibrations, and meter readings.

Analytical methods

The same laboratories were used during the first and second sampling periods (table 3); analytical methods are described in Lorah and Vroblesky (1989, p. 24-25). During the first sampling period, semivolatile compounds were analyzed by gas chromatography/mass spectrometry (GC/MS), according to USEPA Method 625 (U.S. Environmental Protection Agency, 1979a), only if a preliminary gas chromatography-flame ionization detector (GC-FID) scan of the sample showed a concentration above the detection limit of 124 µg/L. During the second sampling period, however, selected ground-water samples were analyzed for semivolatile organic compounds by USEPA Method 625, regardless of the results of GC-FID scans. GC-FID scans for semivolatile organics were done during the second sampling period for all wells that were installed during the second phase of drilling.

Different laboratories were used during the last two sampling periods than during the first and second sampling periods (table 3). Laboratory analyses of ground-water samples for the last two sampling periods were contracted to Arthur D. Little, Inc., under the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) class contract (table 3). Inorganic constituents analyzed for during each sampling period and the reported detection limits are listed in table 4. Organic consituents analyzed for are listed in tables 5 through 8; in addition, analyses were done for TOH, TOC, and total phenols.

The same analytical methods were used by Arthur D. Little, Inc., during both sampling periods, and analyses were done in accordance with USATHAMA's quality-control and assurance program (U.S. Army Toxic and Hazardous Materials Agency, 1990). Concentrations of chloride, sulfate, fluoride, bromide, nitrite, and nitrate anions were determined by ion chromatography. Concentrations of major cations and most metals, except silver, arsenic, lead, and selenium, were determined by inductively coupled argon-plasma spectroscopy. Concentrations of silver, arsenic, lead, and selenium were determined by graphite furnace atomic-absorption spectrometry.

Concentrations of VOC's were determined quantitatively by a purge-and-trap GC/MS method (USEPA Method 624). If peaks appeared in the chromatogram that did not match any of the compounds given in table 5, a computerized mass-spectral library search was done to make a tentative identification of the compound. Concentrations of these tentatively identified organic compounds (TIOC's) should be considered semiqualitative or, at best, semiquantitative. Compounds that could not be identified by mass-spectral library search were reported as estimated concentrations of unknown compounds.

Halocarbon analyses by gas chromotagraphy (GC) (USEPA Method 601) were used for many samples during the third sampling period instead of the GC/MS method to measure VOC's. Both methods can be used to analyze many of the same VOC's, except the halocarbon method cannot be used to analyze for nonhalogenated aromatic compounds such as benzene (table 5). The halocarbon analyses were used mainly because the analytical cost is approximately one half the cost of the GC/MS method. Another advantage is that the halocarbon analysis generally has method detection limits of 1 µg/L for most VOC's, whereas the GC/MS method generally has method detections limits of 5 or 10 µg/L.

The major disadvantage of the halocarbon method compared to the GC/MS method is that compound identifications by the halocarbon method are not absolute because only the retention time of the compound of interest, compared to that of a standard, is used to make the identification. Other compounds could elute at the same time. Compounds are identified more confidently by the GC/MS method because each compound has a unique mass spectral fingerprint. Therefore, samples for analysis by the halocarbon method only were collected at sites where VOC's in the ground water had been previously characterized by GC/MS analyses (table 3). Duplicate samples were collected during the last two sampling periods and analyzed for VOC's by the GC/MS method and the GC method (table 3) so that comparisons could be made between the two methods.

Semivolatile organic compounds (table 6) were analyzed by GC/MS after the sample was serially extracted with methylene chloride. Library searches for semivolatile compounds were also done to attempt to identify any unknown peaks. In addition, selected samples (table 3) were analyzed for organosulfur compounds by GC (table 7) and for explosives by high pressure liquid chromatography (table 8). Many of the compounds given by the organosulfur and explosives methods were also included in the semivolatile analysis (table 6), but the organosulfur and explosives methods have lower method detection limits.

Surface-Water Sampling

Sampling-Network Design and Numbering System

Surface-water samples were collected from the West and East Branch Canal Creek, at the mouth of the Gunpowder River, and from Kings Creek and the Bush River in the area that borders Beach Point (fig. 15). Most of the surface-water sampling sites (fig. 15) are located in areas where contaminated ground water most likely discharges and near past sewerline-discharge points (fig. 14). In addition, sampling sites 32 and 33 were located at the farthest upstream extent of the West and East Branches Canal Creek (fig. 15) to give an indication of background surface-water quality, although the tidal character of the creeks limits the reliability of the background sites. Surface-water sites 21 and 22 in the main stem of Canal Creek (fig. 15) were placed to follow possible downstream and offsite transport of contaminants from the West and East Branches Canal Creek to the Gunpowder River.

Surface-water samples were labeled with the appropriate site number preceded by the prefix "CCSW-", which indicates surface water from the Canal Creek area (fig. 15). In addition, a "U" following the site number indicates an unfiltered sample, whereas an "F" indicates a filtered sample.

Sampling Methods

Field methods

Surface-water samples were collected at 31 sites in September 1988 and at 30 of the same sites in June 1989 (fig. 15). Surface-water samples were collected at low tide when ground water would be a larger component of the surface-water flow than at high tide. Samples from interconnected streams were collected in as short a time period as feasible, about 4 hours, to minimize differences in water quality caused by changing tidal conditions. On both sampling trips, samples were collected on one day along the West Branch Canal Creek, the East Branch Canal Creek, and the main stem of Canal Creek; samples were collected two days later from Kings Creek and the Bush River (fig. 15). Three teams of field help were used each day to collect samples simultaneously at different sites.

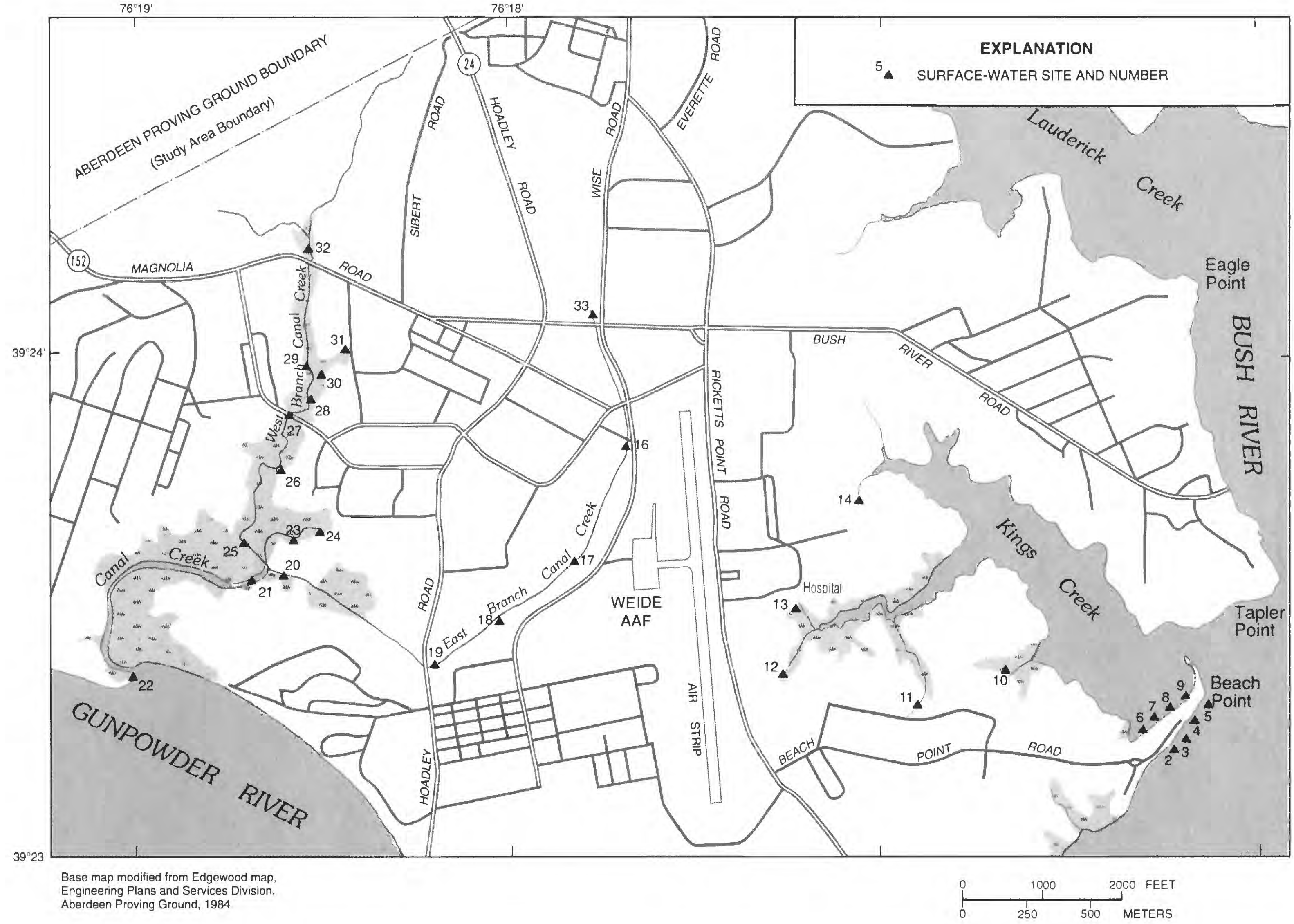
A canoe was used to reach most of the sampling sites along the West Branch Canal Creek and the main stem of Canal Creek, and a small boat powered with an electric motor was used to reach the sites that surround Beach Point (fig. 15). The remaining sites were accessed on foot.

Water temperature, pH, specific conductance, and dissolved oxygen were measured in the field at each site by use of the same procedures described in the ground-water methods section. Alkalinity titrations were performed in the field at selected sites. Samples for inorganic constituents and VOC's were collected at most sites, although only samples for VOC's were collected at two sites near Beach Point. Samples were also collected for analysis of semivolatile organic compounds at 16 and 20 sites during the September 1988 and June 1989 sampling periods, respectively.

At most of the sites, the samples collected for inorganic analyses were not filtered; however, split samples were collected and filtered for inorganic analyses at about 30 percent of the sites during each sampling period. None of the samples collected for organic analyses were filtered. Unfiltered samples were usually collected by dipping the sample containers about 3 to 5 in. below the surface of the water. Special care was taken to minimize aeration of the samples to be analyzed for VOC's. Filtered samples were collected by one of two methods: (1) collecting unfiltered samples from the stream in empty jugs, rinsed with distilled water and then immediately filtering the water from the jugs into the sample containers, or (2) placing the intake tubes from the peristaltic pump into the stream and filtering the water directly into the sample containers. The same general filtering procedure and equipment was used to collect surface-water and ground-water samples (see previous section), except 0.45-µm membrane filters were used for the surface-water samples. Replicate samples for analyses of inorganic constituents and VOC's were collected at about 22 percent of the sites during each sampling period.

Preservatives were added to the appropriate samples in the field (see Methods section on ground-water sampling), and sample containers were immediately placed in coolers on ice. On the next day, the coolers were repacked with fresh ice, and the samples were shipped by overnight airfreight to the analytical laboratories.

In addition to the two sampling trips in September 1988 and June 1989, samples were collected and analyzed for VOC's at three sites in December 1989 when Canal Creek was covered extensively by ice. A small hole was made in the ice, and the sample vials were filled by dipping them several inches below the surface of the water.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984

Figure 15. Locations of surface-water sampling sites in the Canal Creek area.

Analytical methods

The surface-water samples collected in September 1988 were analyzed for organic compounds by Envirodyne Engineers (St. Louis, Mo.) and for inorganic compounds by Northern Laboratories (Valparaiso, Ind.); surface-water samples collected in June 1989 were analyzed by Arthur D. Little, Inc., under USATHAMA class contract. The three samples collected in December 1989 were analyzed for VOC's by the USGS National Water-Quality Laboratory.

Surface-water samples were analyzed for many of the same chemical constituents as ground-water samples, and similar analytical techniques were used. Surface-water samples collected in September 1988 were analyzed for the same inorganic constituents as for ground-water samples collected during the second sampling period (table 4), except that sulfide and ammonia plus organic nitrogen concentrations were not determined in the surface-water samples. Surface-water samples collected in June 1989 were analyzed for the same inorganic constituents as for ground-water samples collected during the third sampling period (table 4), except that several additional constituents (salinity, suspended solids, beryllium, and phosphate) were determined in the surface-water samples. Volatile and semivolatile organic compounds that were determined in surface-water samples are listed in tables 5 and 6.

Soil Sampling

Sampling-Network Design and Numbering System

The primary objective of soil sampling was to assist in identifying sources of ground-water contamination. Thus, soil-sampling sites (fig. 16) were located near observation wells where contamination had been detected in the ground water and near suspected contaminant source areas. Soil samples were not collected in a large area east of the East Branch Canal Creek (fig. 16) because the upper confining unit that overlies the Canal Creek aquifer is thick in this area (fig. 6) and the surficial aquifer is either not present or was not sampled. Thus, contaminated soil could not be a source of the ground-water contamination delineated in this area. The resources that were available for soil sampling were instead concentrated in the area between the West and East Branches Canal Creek. Soil samples could not be collected in some areas because of safety concerns. Soil samples were given sequential numbers from 1 to 46 corresponding to the site number (fig. 16); the prefix "CCSL-" means "Canal Creek area soil sample."

Sampling Methods

Soil samples were collected at 46 sites (fig. 16) in September 1989. A stainless-steel shovel was used to dig a hole from 1 to 2 ft deep, and the shoveled soil was placed onto a stainless-steel tray. Stainless-steel scoops were then used to mix the soil before composite samples from each site were placed in dark amber glass jars with Teflon-lined caps. Sample containers were placed immediately on ice in coolers. All equipment was thoroughly washed and then rinsed with distilled water between sites. Duplicate samples were collected at four sites for quality control.

Soil samples were analyzed for selected inorganic compounds, VOC's, and semivolatile organic compounds (tables 9 and 10). All analyses were done by Environmental Science and Engineering, Inc., under USATHAMA class contract.

Modeling of Ground-Water Flow

Modular Finite-Difference Flow Model

Ground-water flow in the Canal Creek area was simulated by use of the USGS modular ground-water-flow model, MODFLOW (McDonald and Harbaugh, 1988). The model simulates the advective flow of ground water in three dimensions by using equations of boundary conditions and a finite-difference approximation to the following ground-water-flow equation (McDonald and Harbaugh, 1988, p. 2-1):

$$\frac{d}{dx}\left(K_{xx}\frac{dh}{dx}\right)+\frac{d}{dy}\left(K_{yy}\frac{dh}{dy}\right)+\frac{d}{dz}\left(K_{zz}\frac{dh}{dz}\right)-W = S_s\frac{dh}{dt} \quad (1)$$

where

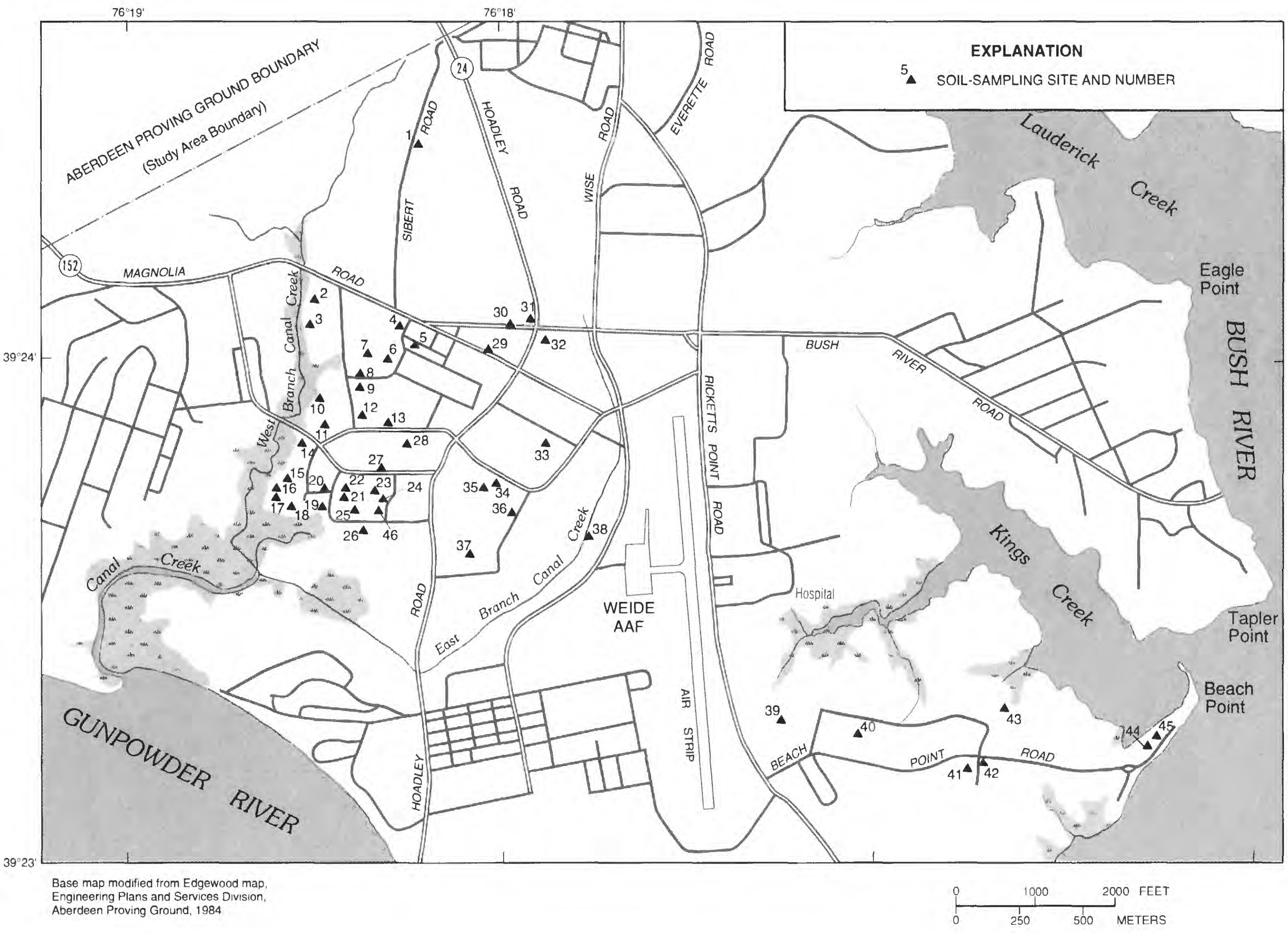
K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (Lt^{-1});

h is the total head (L);

W is a volumetric flux per unit volume and represents sources and (or) sinks of water (t^{-1});

S_s is the specific storage of the porous material (L^{-1}); and

t is time (t).



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984

Figure 16. Locations of soil-sampling sites in the Canal Creek area.

Table 9. *Volatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry on soil samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[USATHAMA, U.S. Army Toxic and Hazardous Materials Agency; units in micrograms per gram dry soil]

Volatile organic compound	USATHAMA code	Detection limit
Acetic acid	C2AVE	<0.03
Acetone	ACET	.002
Acrolein	ACROLN	.1
Acrylonitrile	ACRYLO	.1
Benzene	C6H6	.002
Bromodichloromethane	BRDCLM	.003
Bromoform	CHBR3	.007
Bromomethane	CH3BR	.006
2-Butanone	MEK	.07
Carbon disulfide	CS2	.004
Carbon tetrachloride	CCL4	.007
Chlorobenzene	CLC6H5	.0009
Chloroethane	C2H5CL	.01
2-Chloroethylvinyl ether	2CLEVE	.01
Chloroform	CHCL3	.0009
Chloromethane	CH3CL	.009
cis-1,3-Dichloropropylene	C13DCP	.003
Dibromochloromethane	DBRCLM	.003
Dichlorobenzene	CL2BC	.10
1,1-Dichloroethane	11DCLE	.002
1,2-Dichloroethane	12DCLE	.002
1,1-Dichloroethylene	11DCE	.004
1,2-Dichloroethylene	12DCE	.003
1,2-Dichloropropane	12DCLP	.003
Ethylbenzene	ETC6H5	.002
2-Hexanone	MNBK	.03
4-Methyl-2-pentanone	MIBK	.03
Methylene chloride	CH2CL2	.012
Styrene	STYR	.003
1,1,2,2-Tetrachloroethane	TCLEA	.002
Tetrachloroethylene	TCLEE	.0008
Toluene	MEC6H5	.0008
trans-1,3-Dichloropropene	T13DCP	.003
1,1,1-Trichloroethane	111TCE	.004
1,1,2-Trichloroethane	112TCE	.005
Trichloroethylene	TRCLE	.003
Trichlorofluoromethane	CCL3F	.006
Vinyl chloride	C2H3CL	.006
Xylenes	XYLEN	.002

In the model, ground water is assumed to be uniform in temperature and density, and flow is assumed to be laminar. The model solves a system of simultaneous linear equations for each node of a block-centered, finite-difference grid using the Strongly Implicit Procedure (SIP). The solution represents hydraulic heads for specific points in space and time.

Modular Model Statistical Processor

To aid analysis of model simulations and thereby facilitate model calibration, the computer program MMSP (Modular Model Statistical Processor) was used (Scott, 1990). When used in conjunction with MODFLOW, the MMSP program can read input and output data, calculate descriptive statistics, generate histograms, perform logical tests using relational operators, calculate data arrays using arithmetic operators, and calculate flow vectors (Scott, 1990, p. 1). For the Canal Creek area model, the MMSP program was used primarily to calculate statistics comparing measured and simulated heads in 103 wells in the Canal Creek area.

Table 10. *Semivolatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry on soil samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[USATHAMA, U.S. Army Toxic and Hazardous Materials Agency; units in micrograms per gram dry soil; alternative compound name in brackets]

Semivolatile organic compound	USATHAMA code	Detection limit
Acenapthene	ANAPNE	0.04
Acenaphthylene	ANAPYL	.03
Anthracene	ANTRC	.03
Benzidine	BENZID	.85
Benzo(a)anthracene	BAANTR	.17
Benzo(b)fluoranthene	BBFANT	.21
Benzo(k)fluoranthene	BKFANT	.07
Benzoic acid	BENZOA	6.1
Benzo(g,h,i)perylene	BGHIPY	.25
Benzo(a)pyrene	BAPYR	.25
Benzyl Alcohol	BZALC	.19
4-Bromophenyl phenyl ether	4BRPPE	.03
bis(2-Chloroethoxy)methane	B2CEXM	.06
bis(2-Chloroethyl) ether	B2CLEE	.03
bis(2-Chloroisopropyl) ether	B2CIPE	.20
bis(2-Ethylhexyl) phthalate	B2EHP	.62
2,2-*bis*(para-Chlorophenyl)-1,1-dichloroethane	PPDDD	.3
2,2-*bis*(para-Chlorophenyl)-1,1-dichloroethene	PPDDE	.31
2,2-*bis*(para-Chlorophenyl)-1,1,1-trichloroethane	PPDDT	.31
Butylbenzyl phthalate	BBZP	.17
Di-n-butyl phthalate	DNBP	.06
Dieldrin	DLDRN	.31
1,2-Diphenylhydrazine	12DPH	.14
4-Chloroaniline	4CANIL	.81
2-Chloronaphthalene	2CNAP	.04
2-Chlorophenol	2CLP	.06
4-Chlorophenyl phenyl ether	4CLPPE	.03
Chrysene	CHRY	.12
Dibenzo(a,h)anthracene	DBAHA	.21
Dibenzofuran	DBZFUR	.04
1,2-Dichlorobenzene	12DCLB	.11
1,3-Dichlorobenzene	13DCLB	.13
1,4-Dichlorobenzene	14DCLB	.10
3,3'-Dichlorobenzidine	33DCBD	6.3
2,4-Dichlorophenol	24DCLP	.18
Diethylphthalate	DEP	.24
2,4-Dimethylphenol	24DMPN	.69
Dimethylphthalate	DMP	.17
4,6-Dinitro-2-cresol	46DN2C	.55
2,4-Dinitrophenol	24DNP	1.2
2,4-Dinitrotoluene	24DNT	.14
2,6-Dinitrotoluene	26DNT	.09
Di-n-octyl phthalate	DNOP	.19
Fluoranthene	FANT	.07
Fluorene	FLRENE	.03
Hexachlorobenzene	CL6BZ	.03
Hexachlorobutadiene	HCBD	.23
Hexachlorocyclopentadiene	CL6CP	6.2
Hexachloroethane	CL6ET	.15
Indeno(1,2,3-c,d)pyrene	ICDPYR	.29
Isophorone	ISOPHR	.03
3-Methyl-4-chlorophenol	4CL3C	.10
2-Methylnaphthalene	2MNAP	.05
2-Methylphenol [2-Cresol]	2MP	.29
4-Methylphenol [4-Cresol]	4MP	.24
Naphthalene	NAP	.04
Nitrobenzene	NB	.05
2-Nitroaniline	2NANIL	.06
3-Nitroaniline	3NANIL	.45
4-Nitroaniline	4NANIL	.41

Table 10. *Semivolatile organic compounds for which quantitative analyses were done by gas chromatography/mass spectrometry on soil samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued*

Semivolatile organic compound	USATHAMA code	Detection limit
2-Nitrophenol	2NP	0.14
4-Nitrophenol	4NP	1.4
N-Nitrosodimethylamine	NNDMEA	.14
N-Nitrosodiphenylamine	NNDPA	.19
N-Nitroso-di-n-propylamine	NNDNPA	.20
Pentachlorophenol	PCP	1.3
Phenanthrene	PHANTR	.03
Phenol	PHENOL	.11
Pyrene	PYR	.03
1,2,4-Trichlorobenzene	124TCB	.04
2,4,5-Trichlorophenol	245TCP	.10
2,4,6-Trichlorophenol	246TCP	.17
	PESTICIDES AND PCB'S	
Aldrin	ALDRN	.33
a-Benzenehexachloride [a-BHC]	ABHC	.27
b-Benzenehexachloride [b-BHC]	BBHC	.27
w-Benzenehexachloride [w-BHC]	DBHC	.27
q-Benzenehexachloride [Lindane]	LIN	.27
a-Chlordane	ACLDAN	.33
q-Chlordane	GCLDAN	.33
a-Endosulfan [Endosulfan I]	AENSLF	.62
b-Endosulfan [Endosulfan II]	BENSLF	.62
Endosulfan sulfate	ESFSO4	.62
Endrin	ENDRN	.45
Endrin aldehyde	ENDRNA	.53
Endrin ketone	ENDRNK	.45
Heptachlor	HPCL	.13
Heptachlor epoxide	HPCLE	.33
Keto-endrin	KEND	.53
Methoxychlor	MEXCLR	.33
PCB 1016	PCB016	1.4
PCB 1221	PCB221	1.4
PCB 1232	PCB232	1.4
PCB 1242	PCB242	1.4
PCB 1254	PCB254	2.3
PCB 1248	PCB248	2.0
PCB 1260	PCB260	2.6
Toxaphene	TXPHEN	2.6

Particle Tracker

The particle tracker MODPATH (Pollock, 1989), a postprocessor to MODFLOW, was used to compute three-dimensional pathlines that simulate advective ground-water flow. Pathline analysis is a useful tool in estimating the probable advective movement of contaminants and in simulating the effects of potential remedial-action pumping. MODPATH uses heads and intercell flow rates obtained from steady-state MODFLOW simulations and an estimate of effective porosity to compute the principal velocity components at points within a model cell (Pollock, 1989, p. 5). This information is used to compute location and traveltime of a particle through a cell. MODPATH presents results graphically, producing vertical sections or areal plots of forward and backward particle tracks, as well as time series analysis.

Geographic Information System Applications

A Geographic Information System (GIS), ARC/INFO, was used to facilitate model data manipulation and representation. For the Canal Creek ground-water-flow model, an ARC/INFO data base was created relating the model grid to model parameters such as hydraulic conductivity, leakance, transmissivity, and aquifer thickness. Once a model parameter was changed, the values of that parameter for the entire model grid were downloaded into a computer file formatted for model input. ARC/INFO was also used to plot areal maps of each model parameter after model calibration was completed.

GROUND-WATER CONTAMINATION

The following sections on ground-water contamination include discussions of the distribution, possible sources, and probable fate and movement of inorganic and organic constituents detected in ground water in the Canal Creek area. Data collected during each of the four ground-water sampling periods are included--November 1986 to April 1987, July to September 1988, April to May 1989, and September to October 1989. Most of the ground-water-chemical data for the last three sampling periods are given in tables Appendix B1 to B6 at the end of this report, although some data for less widespread contaminants and for quality-control samples are presented in the text. Ground-water-chemical data collected during the first sampling period were reported previously by Lorah and Vroblesky (1989), but will also be used for comparative analyses in this report.

Much of the discussion about the types and distribution of inorganic and organic constituents focuses on the ground-water-chemical data collected during the second sampling period, because the sampling network was largest during this period (table 3) and because data-validation problems were encountered during the last two sampling periods. These data-validation problems include a large number of inorganic and organic analyses for which concentrations were reported as greater-than values (Appendixes B3 to B6). The other three sets of ground-water-chemical data are used primarily to discuss changes in concentrations observed among the sampling periods, to confirm the occurrence of elevated or excessive [2] concentrations, and to describe the occurrence of constituents that were not analyzed for during the second sampling period.

Ground-water contamination is widespread in the Canal Creek study area. Chlorinated VOC's are considered the major contaminants because of their prevalence and relatively high concentrations. Although some inorganic constituents and other types of organic compounds were detected in elevated concentrations in the ground water, the inorganic contaminants were generally found only at sites where substantial VOC concentrations also were detected in the ground water. Thus, the presence of VOC's are used as the general criterion in this report to define whether ground water at a site is contaminated.

Specifically, TOH is used in this report as the general criterion of contamination because it indicates the sum of halogenated VOC's in a sample. TOH is a measure of the total halogen (chlorine, bromine, fluorine) concentration associated with VOC's. In this study, a sample was considered to be contaminated by anthropogenic compounds if TOH concentrations were greater than 5 μg/L and VOC's not known to be common laboratory contaminants were detected. A sample was considered to be uncontaminated if (1) TOH was less than 5 μg/L or (2) TOH was slightly greater than 5 μg/L and the only VOC's detected were common laboratory contaminants. The VOC's methylene chloride, ethylbenzene, and toluene are used extensively in analytical laboratories and are often introduced to water samples through exposure in the laboratory (Lorah and Vroblesky, 1989, p. 53). Methylene chloride was the most common VOC detected in laboratory method blanks that were analyzed during this study. A few samples had TOH concentrations less than 5 μg/L and contained very low concentrations of VOC's that are not common laboratory contaminants. These samples were defined as uncontaminated because such low concentrations could be attributed to minor cross-contamination during sampling, shipping, or analysis, as well as to analytical error.

Sites where contamination was detected in samples collected from wells screened in the Canal Creek aquifer are shown in figure 17; sites where contamination was detected in samples collected from wells screened in the surficial aquifer, unidentified isolated sand lenses, and the lower confined aquifer are shown in figure 18. Many well sites contain more than one well screened in the Canal Creek aquifer (table 2), and a few sites contain more than one well screened in the surficial and lower confined aquifers. For a well site to be identified as uncontaminated in figures 17 and 18, samples collected from all the wells screened in the particular aquifer at a site must have been uncontaminated. Ground-water-chemical data collected on all four sampling periods were considered. Most wells were sampled more than once to confirm the absence or presence of contamination (table 3).

Most of the samples collected from the Canal Creek aquifer and surficial aquifer were contaminated (figs. 17 and 18). Contamination was detected in the Canal Creek aquifer at 48 of the 64 sites (75 percent) with wells screened in this aquifer. Contamination was detected in the surficial aquifer at 19 of the 25 sites (76 percent) with wells screened in this aquifer. Contamination was not detected in the isolated sand lenses or in the lower confined aquifer (fig. 18).

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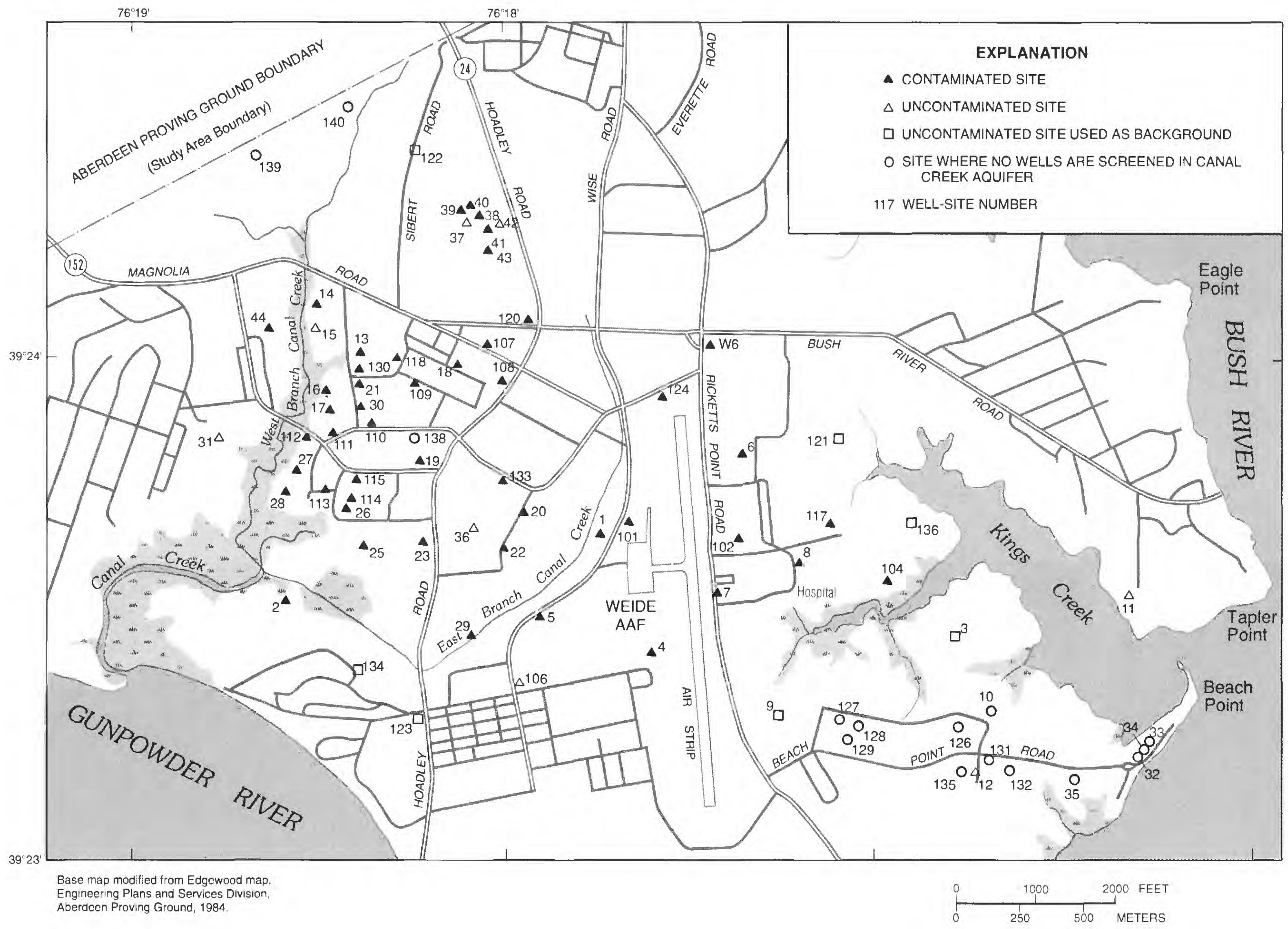
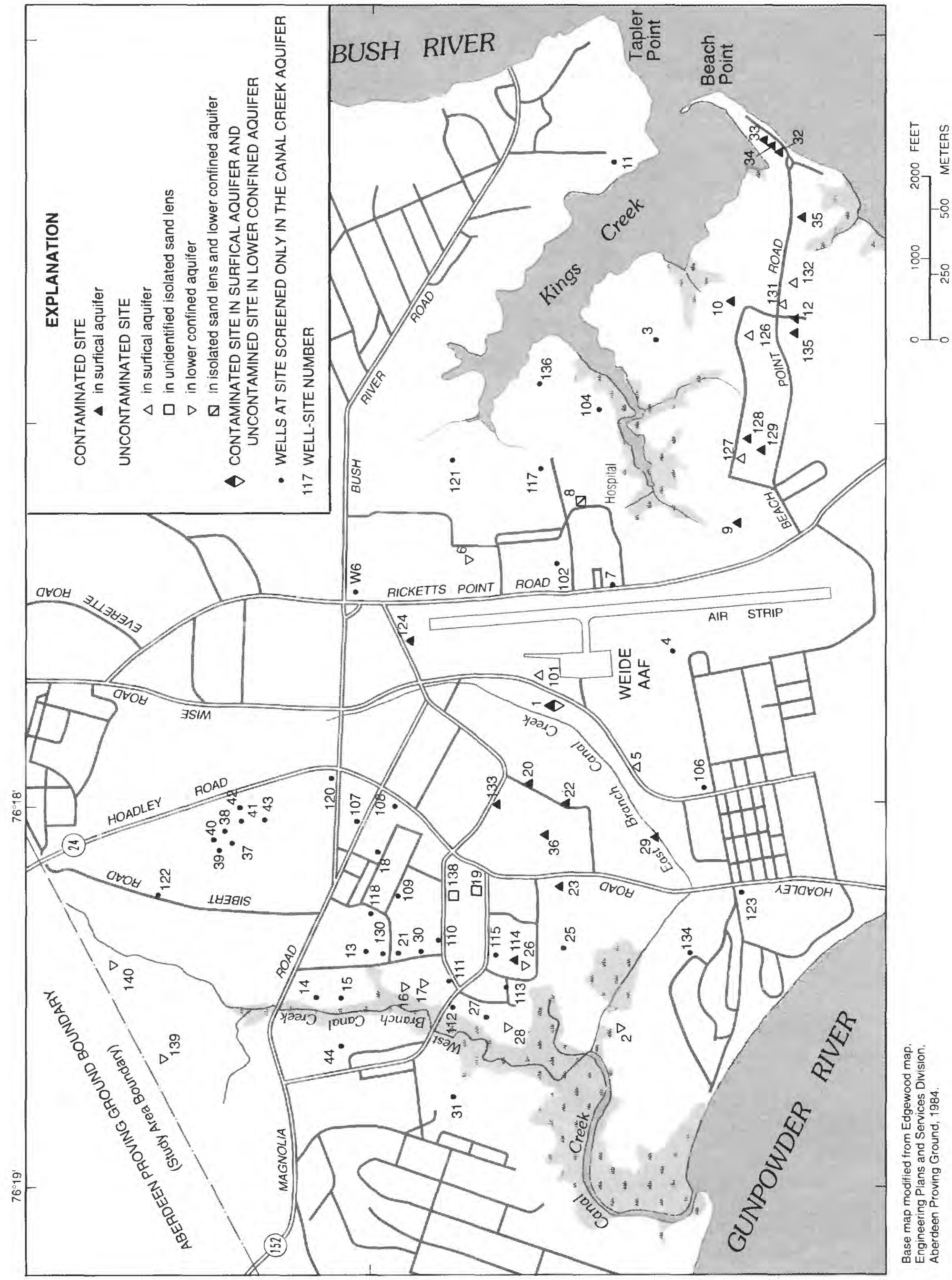
[2] "Elevated" is used to refer to concentrations of a constituent that are higher than background concentrations, whereas "excessive" is used to refer to concentrations that exceed Federal regulatory limits for the constituent to drinking water.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 17. Locations of contaminated and uncontaminated observation-well sites in the Canal Creek aquifer



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 18. Locations of contaminated and uncontaminated observation-well sites in the surficial aquifer, unidentified isolated sand lenses, and lower confined aquifer.

Knowledge of the natural (background) ground-water chemistry is needed to assess the distribution and behavior of contaminants. Background conditions of ground water in the Canal Creek area are difficult to define, however, because of the extensive contamination and the long history of chemical manufacturing and waste disposal. In this report, background chemistry in the Canal Creek aquifer is represented by the ground-water chemistry observed at 11 wells located among 7 sites (fig. 17). These background wells or well sites were selected by use of the following criteria: (1) TOH concentrations in samples collected at the site indicate that the ground water is uncontaminated, (2) grout used in well construction did not affect the water chemistry, and (3) either the upper confining unit is present or the site is not near probable contaminant sources. Most of the well sites where ground water was designated as representative of background conditions in the Canal Creek aquifer (fig. 17) are located where a thick confining unit lies above the aquifer (fig. 6).

The surficial aquifer is unprotected by a confining unit throughout the study area, and probable contaminant sources are near all the sites where wells were screened in the surficial aquifer (figs. 13 and 18). Thus, no satisfactory background chemistry is available for the surficial aquifer. Instead, for discussion in this report, the ground-water chemistry at five of the six sites that were considered to be uncontaminated in the surficial aquifer (sites 101, 127, 126, 131, and 132 in fig. 18) will be compared to surficial-aquifer chemistry at contaminated sites. The surficial-aquifer well at site 5 is not included in this discussion because samples were not collected at this site during the second sampling period.

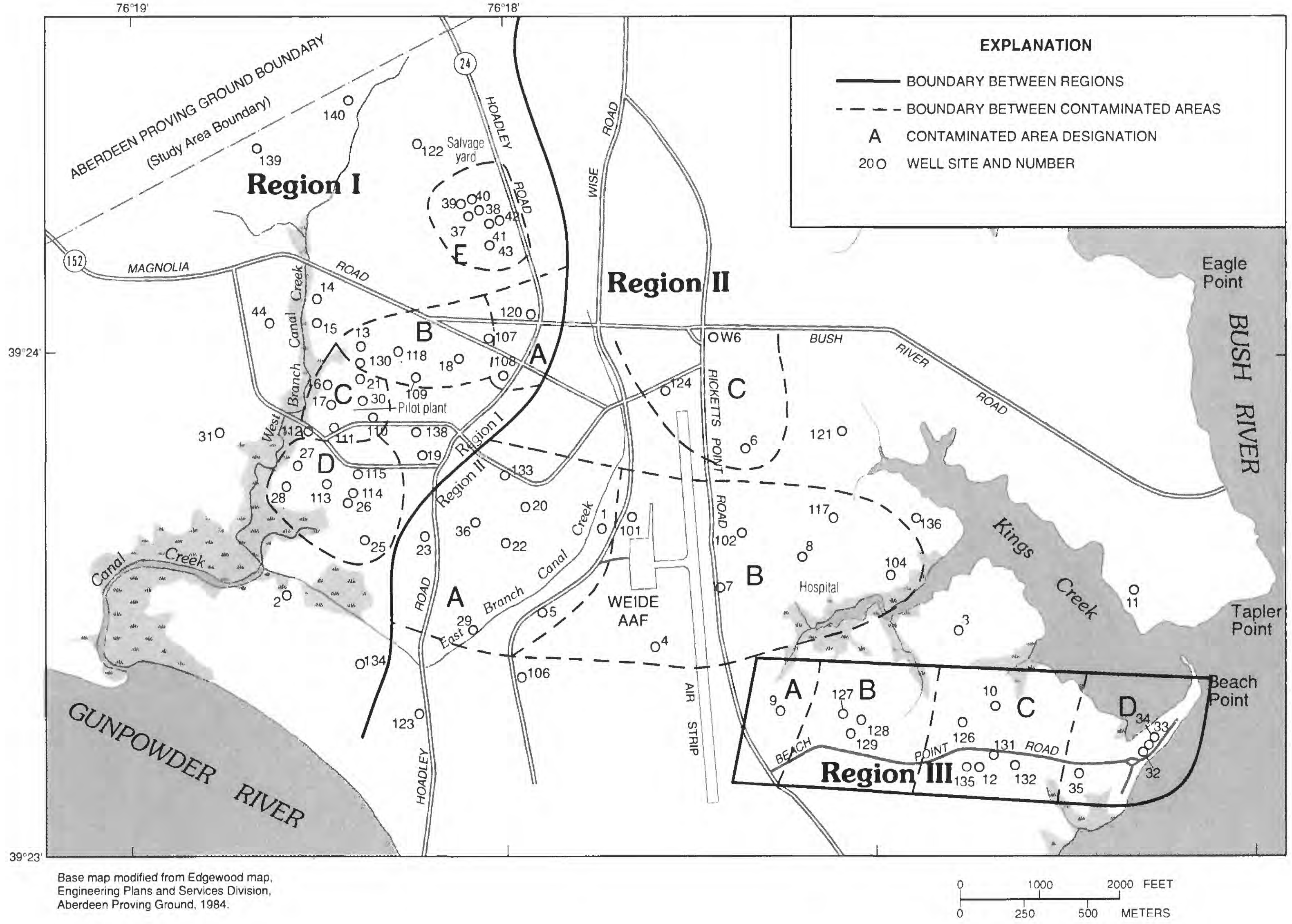
To facilitate specific discussion of the ground-water contamination, USGS investigators divided the study area into three regions (Regions I, II, and III), each subdivided into areas denoted by capital letters (fig. 19), to produce an index map of the contaminated areas. Figure 19 integrates information on both aquifers in which contamination was detected--the surficial aquifer and the Canal Creek aquifer. Division of the study area into the three regions is based primarily on the hydrogeologic framework and the ground-water-flow system of the surficial and Canal Creek aquifers. In Regions I and II (fig. 19), the Canal Creek aquifer and the surficial aquifer, where it is present, are considered to be one interconnected aquifer because of the hydrogeologic framework (fig. 3). In Region III, the Canal Creek aquifer and surficial aquifer are distinct, unconnected aquifers.

The types and distributions of major contaminants observed in the surficial and Canal Creek aquifers were used to divide the regions into areas of contamination (areas IA and IB, for example) that seemed to have been affected by different sources. The areas of contamination (fig. 19) were divided on the basis of distinct contaminant characteristics that were observed in the individual areas. Thus, differing contaminant characteristics, combined with the hydrogeology, were used to delineate areas within the three regions that seem to have been affected by anthropogenic sources specific to that area.

Past and present ground-water-flow conditions were considered when establishing the regions. The general directions of ground-water flow in the Canal Creek aquifer and the location of a ground-water-flow divide that exists under present unstressed conditions are shown in figure 20. Substantial amounts of ground water were pumped from the standby water-supply wells (fig. 2) from at least 1950 until about 1968. Because much of the chemical manufacturing and waste disposal occurred before or during this period of pumping, directions of ground-water flow during the pumping (fig. 21) would have had a large effect on the migration and eventual distribution of ground-water contaminants.

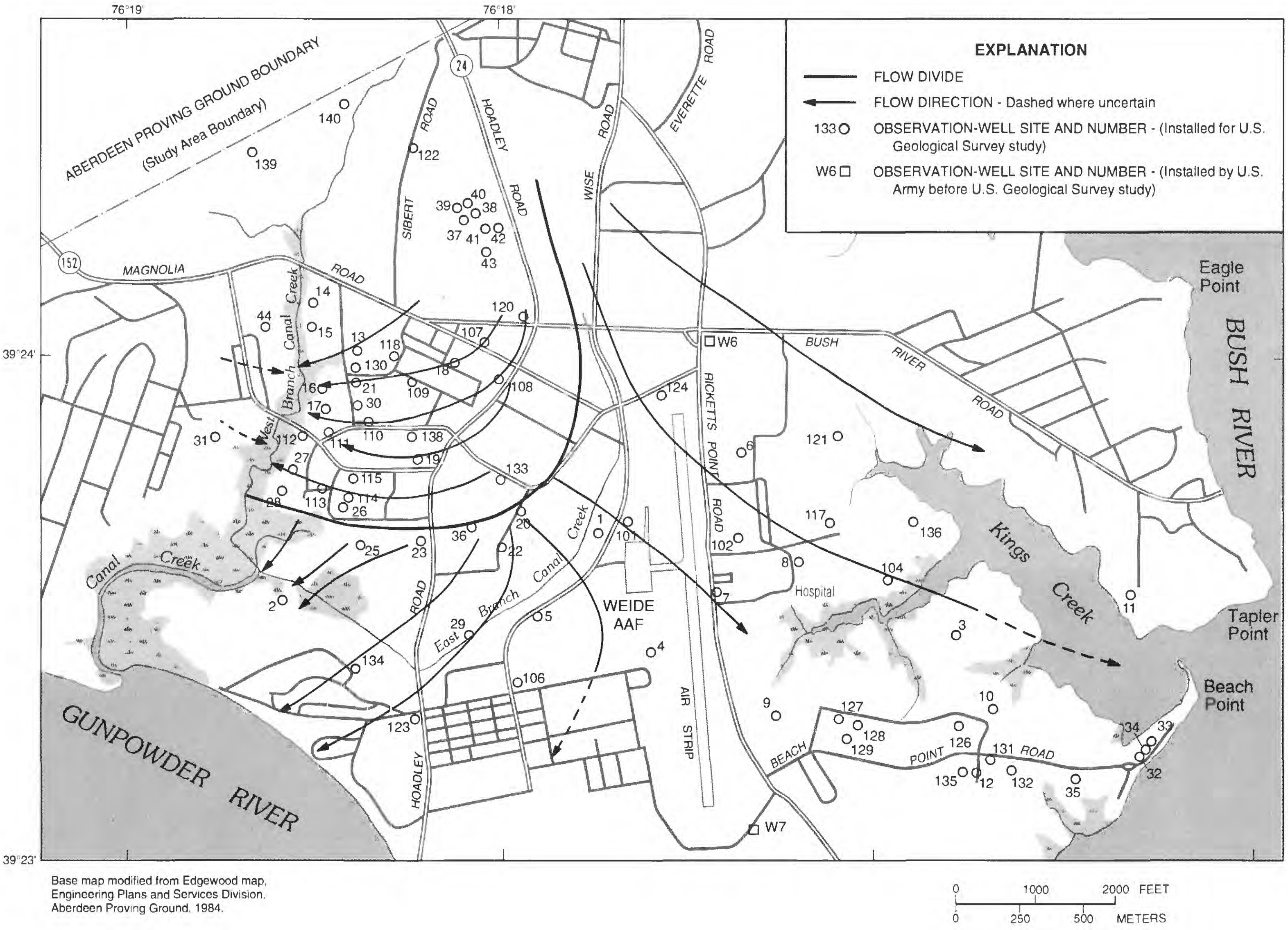
The ground-water-flow model developed for the Canal Creek area was used to simulate flow directions and locations of flow divides that existed in the past (fig. 21). Model simulations were done by use of pumping records for 1957 and are explained more fully in the section on evaluation of selected pumping alternatives. Pumping strongly affected flow directions in the Canal Creek aquifer in Region II, resulting in eastward flow rather than the present southeastward flow (figs. 19 and 20). Pumping also caused the location of the major ground-water-flow divide to shift to the west. The boundary between Regions I and II (fig. 19) was drawn to coincide with the approximate position of the ground-water-flow divide in the Canal Creek aquifer during pumping (fig. 21). Thus, the regions indicate which areas of contamination were most likely connected by past (about 1950-68) ground-water flow paths.

Region I is characterized by shallow flow in the unconfined or semiconfined part of the Canal Creek aquifer and in the surficial aquifer. Ground-water-flow directions in this region are currently toward the West Branch Canal Creek and a small part of the lower East Branch Canal Creek; these



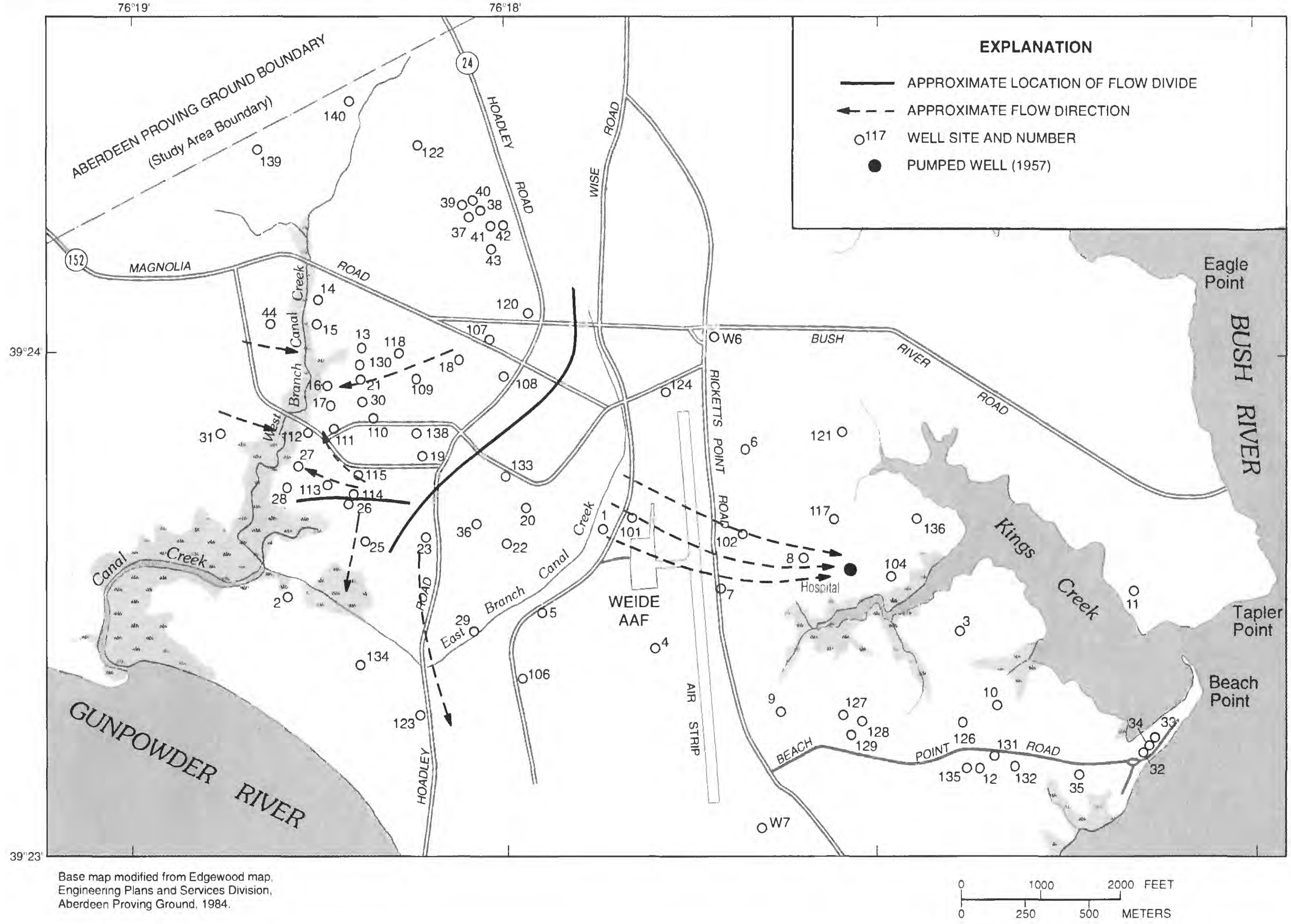
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 19. Locations of Regions I, II, and III and subdivided ground-water-contamination areas in the Canal Creek study area.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

Figure 20. Ground-water-flow directions in the Canal Creek aquifer under present (1992) unstressed conditions.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 21. Approximate ground-water-flow directions in the Canal Creek aquifer simulated by use of pumpage records from 1957.

flow directions were not altered substantially during pumping. Most of the wells in Region I are screened in the Canal Creek aquifer rather than in the surficial aquifer; however, ground water in the Canal Creek aquifer in much of this region is under water-table conditions because the upper confining unit is absent or thin (fig. 6). The surficial and Canal Creek aquifers are in direct hydraulic contact where the upper confining unit is absent (fig. 6), and they function as one shallow flow system.

Region II is characterized mainly by flow in the deep confined part of the Canal Creek aquifer. However, the Canal Creek aquifer is unconfined and in direct hydraulic connection with the surficial aquifer where a paleochannel eroded the upper confining unit (fig. 3). The paleochannel, which extends approximately parallel to the East Branch Canal Creek, includes the area of Region II that is west of the East Branch Canal Creek (fig. 19). Some ground water discharges to the East Branch Canal Creek in this unconfined area of the Canal Creek aquifer, but most ground water enters the deep confined flow system (fig. 3) and flows to the southeast under present conditions (fig. 20).

To the west of the East Branch Canal Creek in Region II, the surficial and Canal Creek aquifers are directly connected, and ground-water contaminants were detected in both of the aquifers (figs. 17 and 18). East of the East Branch Canal Creek in Region II, the surficial aquifer is absent, and the Canal Creek aquifer is overlain by a thick upper confining unit. Ground-water contaminants in this deep confined part of the Canal Creek aquifer probably entered upgradient where the aquifer is unconfined.

In Region III (fig. 19), the surficial aquifer is separated from the Canal Creek aquifer by the upper confining unit, which is about 80 to 100 ft thick in this region. Contaminants were observed only in the surficial aquifer in Region III (figs. 17 and 18), and their distribution and movement probably were not affected by the previous pumping in the Canal Creek aquifer.

Although distinct patterns in contaminant distributions help to define possible contaminant sources within each delineated area, the boundaries between the areas are not meant to indicate that these are isolated, individual contaminant plumes. Most of the areas within each region are connected by present or past ground-water-flow directions (figs. 20 and 21) and probably contain contaminants from more than one source. Exact source definition is complicated by (1) the large amount and types of manufacturing and other activities that took place in the study area since 1917; (2) the ground-water pumping that occurred before 1968; (3) the various ways in which contaminants were released, including spills, discharge through sewers, and disposal of wastes in the marshes and in pits; and (4) the incomplete historical data on manufacturing, waste disposal, and pumping.

Inorganic Constituents

The inorganic ground-water chemistry in the Canal Creek area was characterized in this study by measurements of dissolved solids, specific conductance, pH, and dissolved oxygen and by analyses for 9 major inorganic constituents and 27 minor inorganic constituents (table 4). Major inorganic constituents are calcium, magnesium, sodium, potassium, iron, silica, chloride, sulfate, and bicarbonate. Minor constituents, which are defined here as those inorganic constituents that usually are present in concentrations of less than 5 mg/L, include nitrogen species, phosphorus, sulfide, fluoride, bromide, cyanide, manganese, boron, arsenic, and various trace metals. This section of the report includes a discussion of the horizontal and vertical distribution of inorganic constituents in ground water in the Canal Creek area and the probable sources of those constituents that were detected in elevated or excessive concentrations. Quality-control samples and data validation for the inorganic data also are presented.

The data set from the second sampling period (July-September 1988), which is primarily used to discuss the concentrations and distribution of inorganic constituents, is divided into categories on the basis of the aquifer from which the sample was collected and whether the samples from the site were determined to be uncontaminated or contaminated (figs. 17 and 18; Appendix B1). The categories assigned to the samples include contaminated Canal Creek aquifer, grout-affected Canal Creek aquifer, background Canal Creek aquifer, contaminated surficial aquifer, uncontaminated surficial aquifer, and lower confined aquifer. All the samples collected from the lower confined aquifer were uncontaminated.

The inorganic chemistry of background or uncontaminated ground water is highly variable among the three aquifers and at different locations within each aquifer (fig. 22). This natural chemical variability can be caused by heterogeneities in the aquifer material, differing flow paths and distances from recharge areas, and differing compositions in recharge water.

Background or uncontaminated samples from the three aquifers generally contain a higher percentage of sodium plus potassium than magnesium (fig. 22). However, uncontaminated samples from three

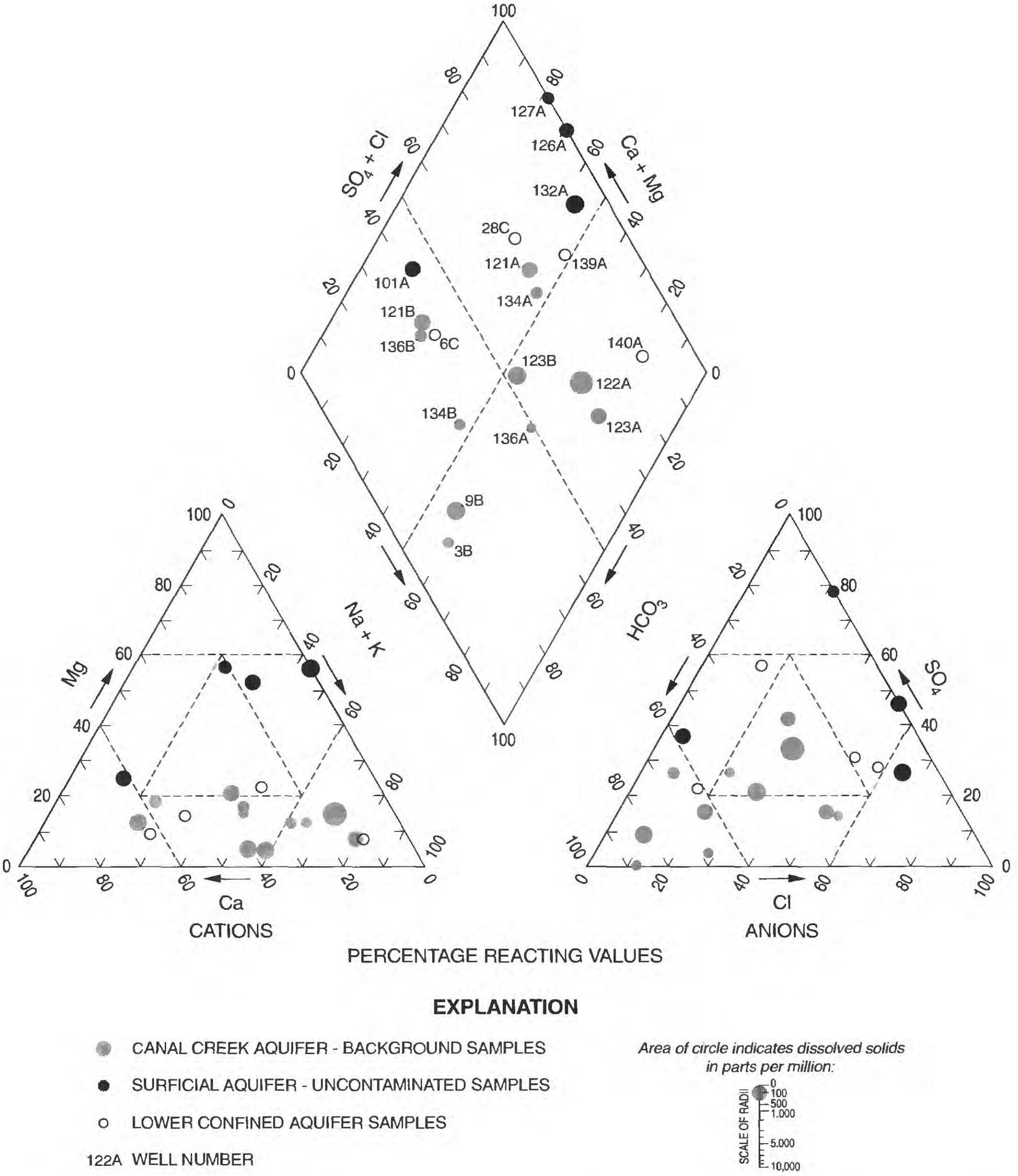


Figure 22. Major-ion composition of background samples from the Canal Creek aquifer, uncontaminated samples from the surficial aquifer, and samples from the lower confined aquifer, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

wells screened in the surficial aquifer have a distinctly lower percentage of sodium plus potassium and a higher percentage of magnesium than observed for background water in the Canal Creek aquifer or in the lower confined aquifer (fig. 22). Samples from these three wells also have a lower percentage of bicarbonate. The three wells are in Region III (fig. 19), where a thick confining unit separates the surficial and Canal Creek aquifers. The other well where uncontaminated water was collected from the surficial aquifer, well 101A, is in Region II near the paleochannel, where the confining unit between the surficial and Canal Creek aquifers is thin. The major ion composition in the sample from well 101A is more similar to the composition of water from the Canal Creek aquifer than to the other surficial aquifer samples (fig. 22).

In some wells, reactions between the ground water and the cement, or grout, used in well construction are suspected to have affected the chemical quality of water in the well. Grout-affected water generally is not used to describe the inorganic ground-water chemistry because reactions with the grout alter the pH and the concentrations of major and minor inorganic constituents (Lorah and Vroblesky, 1989, p. 41). Typically, the pH of well water that is contaminated with alkaline grout is anomalously high and can reach 11 to 12 (Sara and Gibbons, 1991, p. 585). Lorah and Vroblesky (1989) have shown that water affected by grout is characterized by high pH and high potassium and bicarbonate concentrations. The Piper, or trilinear, diagram in figure 23 is a plot of the major-ion composition of grout-affected samples that were collected during the second sampling period. The grout-affected samples are clearly different from those samples whose pH was normal, and they are primarily distinguished by their higher percentage of potassium (fig. 23). All the grout-affected samples collected during the second sampling period are from wells screened in the Canal Creek aquifer.

Concentrations of inorganic constituents measured during all four ground-water sampling periods were compared to Federal drinking-water regulations established by the USEPA under the Safe Drinking Water Act (U.S. Environmental Protection Agency, 1989, 1990a-e, 1991a-c) (table 11). Dissolved solids, chloride, iron, manganese, fluoride, aluminum, antimony, arsenic, beryllium, cadmium, lead, mercury, nickel, and thallium were detected in concentrations that exceed current primary maximum contaminant levels (MCL's) or secondary maximum contaminant levels (SMCL's) during the course of this study.

MCL's represent enforceable health-based regulations for public drinking-water systems, whereas SMCL's are recommended limits for drinking water that were set mainly to provide acceptable aesthetic and taste characteristics. Maximum contaminant level goals (MCLG's) are nonenforceable health-based goals that are meant to represent the amount of a contaminant that would result in no known or anticipated adverse health effects after a lifetime of exposure. When MCLG's are proposed, the feasibility of monitoring for or removing contaminants to the proposed MCLG level is not taken into consideration, whereas the enforceable MCL's must be set at a level of acceptable risk that is feasibile. MCLG's for known or probable carcinogens are typically established at a concentration of zero.

Quality Control and Data Validation

Quality-control samples were used to characterize the effects of analytical error and field or laboratory contamination on the ground-water-chemical data. Quality-control samples that were analyzed for inorganic constituents include method blanks, which were prepared in the laboratory at the time of sample analysis, and replicate ground-water samples, trip blanks, and equipment blanks, all of which were prepared in the field.

Analytical data for the laboratory method blanks are not shown because major and minor inorganic constituents were detected infrequently in the blanks and their concentrations were generally at least an order of magnitude lower than the concentrations observed in the ground-water samples. Analytical data for replicate samples are given in Appendixes B1, B3, and B5 for the last three sampling periods, and analytical data for the quality-control blanks collected in the field are given in tables 12-14.

The precision, or reproducibility, of the sampling and analytical procedures can be determined by evaluating the analytical data for each set of replicate samples. For the four sampling periods (in chronological order), 9, 14, 9, and 8 replicate sets of samples were analyzed for inorganic constituents. The median percent difference between replicate samples was less than 5 percent for most of the major constituents analyzed during the four sampling periods. For the second sampling period, median percent differences were greater than 5 percent for two major constituents, chloride (7.0) and sulfate (8.4).

In the data sets from the third and fourth sampling periods, percent differences between the replicate analyses were higher for more major constituents than in the data set for the second sampling period. For the third sampling period, median percent differences between the replicate concentrations were greater than 5 percent for magnesium (9.4), sodium (7.1), and iron (8.4); and for the fourth sampling period, median percentage of differences were high for sodium (10), potassium (20), chloride (14), and iron (6.1). The laboratory that analyzed samples collected during the last two sampling periods commonly reported concentrations as greater-than values or as less-than values that exceeded the usual reported detection limits. Thus, the median differences observed for the last two sets of data could be high because fewer data were available to determine the medians.

The error inherent in the analyses of the major inorganic constituents can also be checked by calculating the cation-anion balance of a water sample. When concentrations of all the major anions and cat-

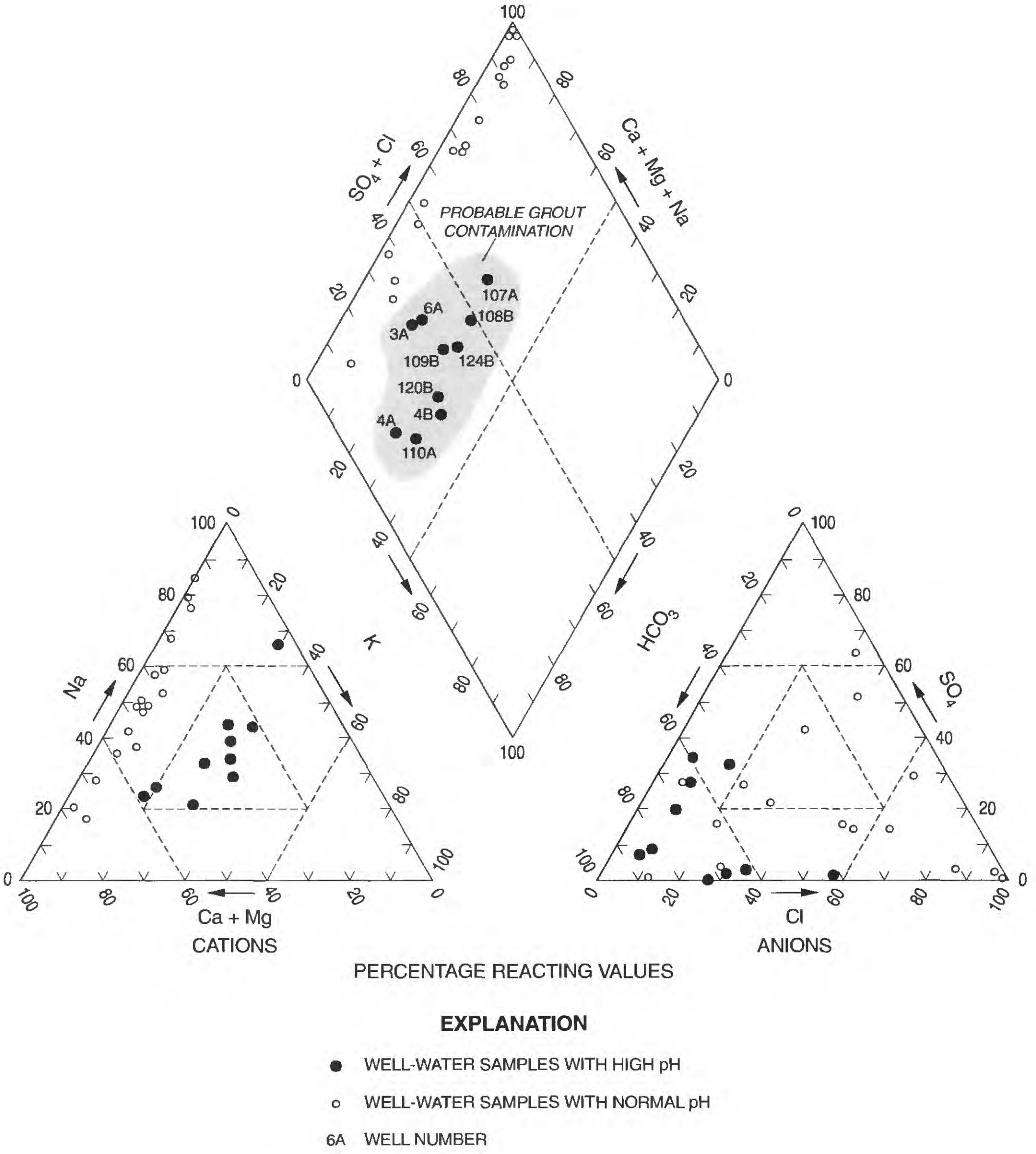


Figure 23. Major-ion composition of water in wells believed to be affected by grout and in wells not affected by grout in the Canal Creek area, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

ions have been determined, the sum of the cations, in milliequivalents per liter, should equal the sum of the anions expressed in the same units (Hem, 1985, p. 164). The charge balance error is generally less than 5 percent for a background water sample; however, samples containing high concentrations of organic contaminants could have much higher charge-balance errors because all the species generally included in the ionic balance might not be determined.

Charge-balance errors were calculated for all complete major-ion analyses available from the four sampling periods; replicate samples were not included. The sample size consisted of 85 complete analyses for the first data set and 114 analyses for the second data set. In both the first and second data sets, mean charge-balance errors were approximately 6.5 percent, and sample standard deviations were about 8.5 percent.

Table 11. *Enforceable and nonenforceable Federal drinking-water regulations for inorganic constituents*

[Compiled from U.S. Environmental Protection Agency (1989, 1990a-e, 1991a-c); units are in milligrams per liter unless otherwise noted; dashes indicate that regulation does not exist as of May 1995; slashes (400/500) indicate two proposed levels.]

Inorganic constituent	MCL [1]	MCLG [2]	Proposed MCLG [3]	SMCL [4]
		INDICATOR OR MAJOR CONSTITUENT		
pH (standard units)	--	--	--	6.5-8.5
Total dissolved solids	--	--	--	500
Chloride	--	--	--	250
Sulfate	--	--	400/500	250
Iron	--	--	--	.3
		MINOR CONSTITUENT		
Ammonia (as N)	--	--	--	--
Nitrate (as N)	10	10	--	
Nitrite (as N)	1.0	1.0	--	--
Ammonia + organic nitrogen (as N)	--	--	--	--
Nitrite + nitrate (as N)	10	10	--	--
Phosphorus	--	--	--	--
Sulfide	--	--	--	--
Fluoride	4.0	4.	--	2.0
Bromide	--	--	--	--
Cyanide	.2	--	.2	--
Manganese	--	--	--	.05
Aluminum	--	--	--	.05 to .2
Antimony	.006	--	.003	--
Arsenic	.05	--	--	--
Barium	2.0	2.0	--	--
Beryllium	.004	--	0	--
Boron	--	--	--	--
Cadmium	.005	.005	--	--
Chromium	.1	.1	--	--
Copper	1.3π	1.3	--	1.0
Lead	.015π	0	--	--
Mercury	.002	.002	--	--
Nickel	.1	--	.1	--
Selenium	.05	.05	--	--
Silver	--	--	--	.1
Thallium	.002	--	.0005	--
Zinc	--	--	--	5.0

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[1] MCL, Maximum Contaminant Level: Enforceable, health-based regulation that is to be set as close to the Maximum Contaminant Level Goal (MCLG) as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of U.S.Environmental Protection Agency finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration).

[2] MCLG, Maximum Contaminant Level Goal: MCLG is a nonenforceable health goal that is to be set at the level at which no known or anticipated adverse effects on the health of persons occur and that allows an adequate margin of safety. Formerly called Recommended Maximum Contaminant Level (RMCL).

[3] Proposed MCLG, Proposed Maximum Contaminant Level Goal

[4] SMCL, Secondary Maximum Contaminant Level: Contaminants that affect the aesthetic quality of drinking water. At high concentrations or values, health implications as well as aesthetic degradation may also exist. SMCL's are not Federally enforceable but are intended as guidelines for the States.

π Treatment techniques must be employed which result in concentrations in tap water samples no greater than the MCL.

Table 12. *Inorganic-chemical data for quality-control blanks collected in the field during the second sampling period (July-September 1988)*

[All concentrations are for dissolved constituents in units of milligrams per liter; in the sample number, the "-T" or "-F" indicates a trip blank or equipment blank, respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; --, not analyzed for]

Constituent	Sample number and sampling date											
	CC-1B-F 8/18/88	CC-1B-T 8/18/88	CC-8B-T 8/11/88	CC-8B-F 8/11/88	CC-16B-T 7/25/88	CC-16B-F 7/25/88	CC-18A-T 7/18/88	CC-18A-F 7/18/88	CC-25A-T 8/1/88	CC-25A-F 8/1/88	CC-26B-T 7/27/88	CC-26B-F 7/27/88
Dissolved solids	2.0	16	<1.0	<1.0	<1.0	<1.0	1.5	13	8.0	11	8.0	11
Calcium	<.001	.16	.31	1.4	.77	.86	2.3	.33	.34	<.10	.85	.29
Magnesium	<.10	<.10	<.10	<.10	<.10	<.10	.18	.02	<.10	<.10	.018	<.10
Sodium	.29	.27	.19	1.0	.10	<.10	2.2	.22	.09	.07	.06	.10
Potassium	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Sulfate	<.20	<.20	<.20	<.20	2.0	.20	<.20	1.5	5.0	1.0	1.5	<.20
Chloride	1.2	<.10	1.2	.60	1.2	<.01	.57	.57	1.3	.63	1.3	1.3
Flouride	.14	<.10	<.10	<.10	.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Bromide	--	--	--	<.10	--	--	--	--	--	--	--	--
Total phosphorus	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ammonia	.11	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Nitrogen, ammonia + organic	<.20	<.20	<.20	<.20	.20	.22	.28	7.8	.26	.33	.26	.23
Nitrogen, nitrite + nitrate	.13	.23	.08	.10	.10	.17	.07	.24	.07	.13	.14	.18
Nitrite	<.02	<.02	<.02	<.02	.01	.04	<.02	<.02	<.02	<.02	<.02	<.02
Silica	<.10	<.10	<.10	<.10	.22	.18	.08	.08	.13	.11	<.10	.18
Iron	.03	.01	.02	.03	<.01	<.01	.02	.02	.03	.02	.01	.02
Manganese	.002	<.001	<.001	.002	<.001	<.001	.005	<.001	<.001	<.001	<.001	.001
Total arsenic	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Antimony	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Mercury	<.0005	<.0005	<.0005	<.0005	.0008	.0008	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005
Nickel	<.001	<.001	<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	<.001	<.001
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Boron	<.10	<.10	<.10	<.10	.03	<.01	<.01	.02	.01	.02	.01	.05
Cadmium	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Chromium	.002	<.001	<.001	<.001	.003	.001	<.001	<.001	<.001	<.001	<.001	.002
Copper	.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.003
Selenium	<.001	<.001	<.001	<.001	<.001	<.001	<.002	<.002	<.001	<.001	<.001	<.001
Lead	<.001	.002	<.001	.002	<.001	.001	.008	<.001	<.001	<.001	<.001	<.001
Zinc	<.01	<.01	<.01	.025	.33	.028	.09	<.01	<.01	<.01	<.01	<.01

Table 13. *Inorganic-chemical data for quality-control blanks collected in the field during the third sampling period (April-May 1989)*

[Analyses for all inorganic constituents listed in table 4 for April-May 1989 were done for the blanks, but only detections are given here; in the sample number, the "-T" or "-F" indicates a trip blank or equipment blank, respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; --,data not available; mg/L,milligrams per liter; µg/L, micrograms per liter]

Sample number	Sampling date	Constituent detected	Concentrations	Units
CC-1B-F	05-22-89	Barium	2.0	µg/L
CC-1B-F	05-22-89	Silver	.5	µg/L
CC-8B-F	05-25-89	Iron	31	µg/L
CC-8B-F	05-25-89	Barium	2.1	µg/L
CC-8B-F	05-25-89	Lead	9.5	µg/L
CC-8B-F	05-25-89	Zinc	43	µg/L
CC-8B-T	05-25-89	Calcium	.19	mg/L
CC-8B-T	05-25-89	Manganese	2.0	µg/L
CC-8B-T	05-25-89	Barium	2.6	µg/L
CC-8B-T	05-25-89	Lead	20	µg/L
CC-8B-T	05-25-89	Zinc	240	µg/L
CC-17C-F	06-02-89	Calcium	.03	mg/L
CC-17C-F	06-02-89	Potassium	.10	mg/L
CC-17C-F	06-02-89	Silica	.03	mg/L
CC-17C-F	06-02-89	Iron	9	µg/L
CC-17C-F	06-02-89	Copper	20	µg/L
CC-17C-F	06-02-89	Selenium	5	µg/L
CC-17C-F	06-02-89	Zinc	4	µg/L
CC-21A-F	05-04-89	Calcium	.32	mg/L
CC-21A-F	05-04-89	Manganese	9.4	µg/L
CC-21A-F	05-04-89	Barium	2.4	µg/L
CC-21A-F	05-04-89	Lead	5.5	µg/L
CC-21A-F	05-04-89	Zinc	83	µg/L
CC-25A-F	05-17-89	Calcium	.48	mg/L
CC-25A-F	05-17-89	Magnesium	.17	mg/L
CC-25A-F	05-17-89	Sodium	100	mg/L
CC-25A-F	05-17-89	Manganese	4.6	µg/L
CC-25A-F	05-17-89	Copper	210	µg/L
CC-25A-F	05-17-89	Zinc	120	µg/L
CC-113A-T	04-28-89	Dissolved solids	16	mg/L
CC-113A-T	04-28-89	Calcium	.19	mg/L
CC-113A-T	04-28-89	Sodium	1.9	mg/L
CC-113A-T	04-28-89	Iron	85	µg/L
CC-113A-T	04-28-89	Manganese	3.3	µg/L
CC-113A-T	04-28-89	Copper	370	µg/L
CC-113A-T	04-28-89	Nickel	33	µg/L
CC-113A-F	04-28-89	Dissolved solids	16	mg/L
CC-113A-F	04-28-89	Sulfate	.25	mg/L
CC-113A-F	04-28-89	Chloride	1.3	mg/L
CC-113A-F	04-28-89	Copper	420	µg/L
CC-113A-F	04-28-89	Nickel	69	µg/L
CC-113A-F	04-28-89	Zinc	110	µg/L
CC-120A-T	05-15-89	Dissolved solids	10	mg/L
CC-120A-T	05-15-89	Calcium	.21	mg/L
CC-120A-T	05-15-89	Sodium	53	mg/L
CC-120A-T	05-15-89	Iron	280	µg/L
CC-120A-T	05-15-89	Manganese	1,000	µg/L
CC-120A-F	05-15-89	Calcium	.24	mg/L
CC-120A-F	05-15-89	Chloride	.68	mg/L
CC-120A-F	05-15-89	Lead	7.4	µg/L
CC-120A-F	05-15-89	Silver	4.0	µg/L

Table 14. *Inorganic-chemical data for quality-control blanks collected in the field during the fourth sampling period(September-October 1989)*

[Analyses for all inorganic constituents listed in table 4 for September-October 1989 were done for the blanks, but only detections are given here; in the sample number, the "-T"or "-F" indicates a trip blank or equipment blank,respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; --, data not available; mg/L, milligramsper liter; µg/L, micrograms per liter]

Sample number	Sampling date	Constituent detected	Concentrations	Units
CC-8B-T	10-16-89	Potassium	0.68	mg/L
CC-8B-T	10-16-89	Iron	31	µg/L
CC-8B-T	10-16-89	Manganese	1.9	µg/L
CC-8B-T	10-16-89	Antimony	160	µg/L
CC-8B-T	10-16-89	Arsenic	24	µg/L
CC-8B-T	10-16-89	Barium	1.8	µg/L
CC-8B-T	10-16-89	Selenium	4.3	µg/L
CC-8B-T	10-16-89	Thallium	60	µg/L
CC-8B-F	10-16-89	Potassium	.90	mg/L
CC-8B-F	10-16-89	Sulfate	.20	mg/L
CC-8B-F	10-16-89	Barium	2.7	µg/L
CC-8B-F	10-16-89	Cadmium	3.4	µg/L
CC-16A-T	09-15-89	Calcium	.17	mg/L
CC-16A-T	09-15-89	Chloride	.37	mg/L
CC-16A-T	09-15-89	Nitrogen, ammonia + organic	.29	mg/L
CC-16A-T	09-15-89	Fluoride	.25	mg/L
CC-16A-T	09-15-89	Manganese	1.7	µg/L
CC-16A-T	09-15-89	Copper	260	µg/L
CC-16A-T	09-15-89	Zinc	71	µg/L
CC-16A-F	09-15-89	Calcium	.20	mg/L
CC-16A-F	09-15-89	Nitrogen, ammonia + organic	.28	mg/L
CC-16A-F	09-15-89	Iron	32	µg/L
CC-16A-F	09-15-89	Manganese	2.4	µg/L
CC-16A-F	09-15-89	Aluminum	180	µg/L
CC-16A-F	09-15-89	Barium	2.0	µg/L
CC-16A-F	09-15-89	Copper	270	µg/L
CC-16A-F	09-15-89	Zinc	120	µg/L
CC-112A-T	09-18-89	Chloride	.35	µg/L
CC-112A-T	09-18-89	Manganese	1.1	µg/L
CC-112A-T	09-18-89	Aluminum	180	µg/L
CC-112A-T	09-18-89	Copper	300	µg/L
CC-112A-T	09-18-89	Nickel	34	µg/L
CC-112A-T	09-18-89	Zinc	120	µg/L
CC-112A-F	09-18-89	Calcium	.40	mg/L
CC-112A-F	09-18-89	Chloride	.34	mg/L
CC-112A-F	09-18-89	Manganese	1.6	µg/L
CC-112A-F	09-18-89	Aluminum	190	µg/L
CC-112A-F	09-18-89	Copper	260	µg/L
CC-112A-F	09-18-89	Lead	42	µg/L
CC-112A-F	09-18-89	Silver	.99	µg/L
CC-112A-F	09-18-89	Zinc	91	µg/L
CC-113A-F	09-27-89	Calcium	.28	mg/L
CC-113A-F	09-27-89	Magnesium	.11	mg/L
CC-113A-F	09-27-89	Potassium	.44	mg/L
CC-113A-F	09-27-89	Sodium	3.4	mg/L
CC-113A-F	09-27-89	Sulfate	.88	mg/L
CC-113A-F	09-27-89	Chloride	.56	mg/L
CC-113A-F	09-27-89	Nitrogen, nitrate	1.4	µg/L
CC-113A-F	09-27-89	Manganese	8.7	µg/L
CC-113A-F	09-27-89	Aluminum	200	µg/L
CC-113A-F	09-27-89	Cadmium	5.4	µg/L
CC-113A-F	09-27-89	Zinc	120	µg/L
CC-120A-T	09-29-89	Potassium	.48	mg/L
CC-120A-T	09-29-89	Chloride	.55	mg/L
CC-120A-T	09-29-89	Iron	29	µg/L
CC-120A-T	09-29-89	Barium	1.4	µg/L
CC-120A-T	09-29-89	Boron	640	µg/L
CC-120A-F	09-29-89	Calcium	.90	mg/L
CC-120A-F	09-29-89	Chloride	10	mg/L
CC-120A-F	09-29-89	Iron	20	µg/L
CC-120A-F	09-29-89	Manganese	2.9	µg/L
CC-120A-F	09-29-89	Barium	1.8	µg/L
CC-120A-F	09-29-89	Zinc	44	µg/L

The mean charge-balance errors were almost twice as high for the analyses from the third and fourth data sets as the mean errors for the first and second data sets. The mean charge balance was 12 percent for the third data set and 11 percent for the fourth data set; the standard deviations were about 10 percent for both data sets. Potassium was not analyzed for in the third sampling period, but concentrations of potassium were generally low in the other data sets and did not have a great affect on the charge balance. However, because of other problems that were previously mentioned, major-ion analyses were incomplete for 26 percent of the samples collected during the third period and 42 percent of the samples collected in the fourth period. Thus, fewer data were available for calculation of the mean charge-balance errors for these two data sets. Even a mean error of 12 percent, however, is fairly low for inorganic analyses of contaminated water.

Analyses of quality-control blanks collected in the field during sampling indicate that cross-contamination from sampling equipment was not a problem for the major inorganic constituents (tables 12-14). Dissolved solids and some of the major inorganic constituents were commonly detected in trip and equipment blanks, but concentrations were generally much lower than those concentrations observed in both background and contaminated ground-water samples.

One extremely high concentration of sodium was detected in an equipment blank--100 mg/L in sample CC-25A-F collected during the April to May 1989 sampling period (table 13). It is unlikely that the high sodium concentration in the equipment blank resulted from improper cleaning of the sampling equipment because the ground water at well CC-25A on this sampling period was reported to contain less than 49 mg/L of sodium. The high sodium concentration in the equipment blank could have resulted from laboratory contamination of the sample. Major inorganic constituents were detected in both trip and equipment blanks, indicating that the distilled water used for the blanks contributed low concentrations of major ions to the quality-control blanks. Because distilled water and not deionized water was used, detectable concentrations of major ions in the blanks would not be unusual.

Quality-control samples analyzed for minor inorganic constituents indicate that concentrations of these compounds are generally more sensitive to analytical error and more variable between replicate samples than concentrations of the major inorganic constituents. This is not surprising, considering that the minor constituents are present in lower concentration ranges in water and have lower detection limits. The percent difference in concentrations between replicate samples was usually less than 10 percent for each of the minor inorganic constituents for the second, third, and fourth sampling periods. Concentrations of manganese, the most frequently detected minor inorganic constituent, differed the least between replicate samples; median percent differences ranged from 1.6 to 3.6 percent for the three sampling periods.

It is more difficult to quantify the error between replicate analyses for the less frequently detected minor inorganic constituents, such as the trace metals cadmium, chromium, copper, and lead. Many of the samples did not contain detectable concentrations of these minor constituents; in some sample sets, a constituent was not detected in one sample, whereas the constituent was observed in the replicate sample at a concentration that slightly exceeded the detection limit.

Minor inorganic constituents were detected in the quality-control blanks collected in the field in relatively high concentrations, especially in the blanks collected during the third and fourth sampling periods (tables 12-14). Nitrogen compounds were the most frequently detected minor inorganic constituents in the quality-control blanks collected during the second sampling period (table 12). Concentrations of nitrogen (ammonia plus organic; nitrite plus nitrate) were measured in both trip blanks and equipment blanks and often were approximately the same concentration in both blanks. The maximum concentration of ammonia plus organic nitrogen observed in the blanks (7.8 mg/L) is higher than the maximum concentration observed in any of the ground-water samples (table 12). Fluoride, boron, manganese, mercury, nickel, chromium, copper, and lead were detected in a few of the trip and equipment blanks collected during the second sampling period (table 12), but their concentrations were usually only slightly above the detection limits.

Higher concentrations of some trace metals were measured in the blanks collected during the third and fourth sampling periods than the blanks collected during the second sampling period. Trace metals that were commonly detected in the blanks for the third and fourth sampling periods include copper, nickel, lead, and zinc. Concentrations of these trace metals were commonly as high or higher in the trip blanks than in the equipment blanks, and the concentrations in both the trip and equipment blanks were almost always higher than those measured in the ground water at the site where the blanks were collected.

For example, the trip and equipment blanks that were collected after sampling well 113A during the third sampling period had copper concentrations of 370 and 420 µg/L, respectively, whereas the duplicate ground-water samples collected from well 113A had copper concentrations of less than 22 µg/L (Appendix B3). In fact, the maximum copper concentration observed in any of the ground-water samples collected during the third sampling period was 240 µg/L. For another example, a lead concentration of 42 µg/L, which is only slightly lower than the current MCL of 50 µg/L for lead (table 11), was measured in an equipment blank from site 112A in the fourth sampling period (table 14). Ground water collected from well 112A consistently had lead concentrations of less than 5 µg/L during three sampling periods (Appendixes B1, B3, and B5).

The occurrence of low concentrations of minor inorganic compounds in the equipment blanks, but not in the trip blanks, could have resulted from residue left on improperly cleaned sampling equipment. However, solutes introduced to the blanks in the field from sampling equipment, or any other method, would not explain the fact that concentrations were commonly as high or higher in the trip blanks than in the equipment blanks. In addition, the concentrations measured in the trip and equipment blanks were commonly higher than those concentrations measured in the ground-water samples collected before the blanks were prepared.

Thus, the high concentrations in the field blanks, especially those collected during the last two sampling periods, were most likely caused by a bad batch of distilled water or some type of laboratory contamination or error. The distilled water seems to be the most likely source of the contamination in the field quality-control blanks. Laboratory method blanks did not indicate laboratory contamination (unpublished data on file at the U.S. Geological Survey, Towson, Md.), and the range of concentrations in the ground water are fairly consistent over the length of the study and between replicate ground-water samples. If analytical error accounted for the high concentrations in the blanks from April to May and September to October 1989, the ground-water samples also would be expected to have higher concentrations than those observed during the two previous sampling periods.

Dissolved Solids, Specific Conductance, pH, and Dissolved Oxygen

Distribution

Measurements of dissolved solids, specific conductance, pH, and dissolved oxygen help to characterize the overall chemical nature of a water sample and can indicate contamination. Dissolved-solids concentrations measure the total mineral content of a water sample. Dissolved-solids concentration usually represents only inorganic constituents, but organic compounds can contribute to the dissolved-solids measurement when their concentrations reach parts-per-million levels (Vitale and others, 1991, p. 514). Specific conductance, which is a measure of the ability of water to conduct an electric current, is a general indication of the amount of charged ionic species in solution. Most inorganic compounds dissociate into charged ions when dissolved in water, whereas most organic compounds occur in solution as uncharged species (Hem, 1985, p. 57). SMCL's established for dissolved solids and pH (table 11) were exceeded in some ground-water samples collected in the Canal Creek area.

Dissolved-solids concentrations (fig. 24) and specific conductance were generally higher in the contaminated Canal Creek and surficial aquifer samples than in the uncontaminated samples. Median dissolved-solids concentrations were 195 and 190 mg/L in the contaminated Canal Creek and surficial aquifer samples, respectively, whereas medians for the background Canal Creek aquifer samples and the uncontaminated surficial aquifer samples were both about 85 mg/L (fig. 24). Median specific conductances were 344 and 313 µS/cm in the contaminated Canal Creek and surficial aquifer samples, respectively, whereas median specific conductances in the uncontaminated samples were about 100 and 150 µS/cm.

Samples from the lower confined aquifer, all of which were determined to be uncontaminated because of low TOH concentrations, had extremely low dissolved-solids concentrations and specific conductances. The low dissolved-solids concentrations and specific conductances are further evidence that these sites were not affected by contamination. Dissolved-solids concentrations ranged from 38 to 56 mg/L in the lower confined aquifer (fig. 24), and specific conductances ranged from 41 to 83 µS/cm.

Of the samples collected during the second period, nine samples from contaminated sites in the Canal Creek aquifer had dissolved-solids concentrations exceeding the SMCL of 500 mg/L for drinking water (fig. 24; table 11). These nine samples were collected from wells 13A, 16B, 18A, 28A, 28B, 107B, 118A, 118B, and 130B. In addition, one sample collected from a grout-affected well that is screened in the Canal Creek aquifer (well 107A) had a dissolved-solids concentration of 648 mg/L

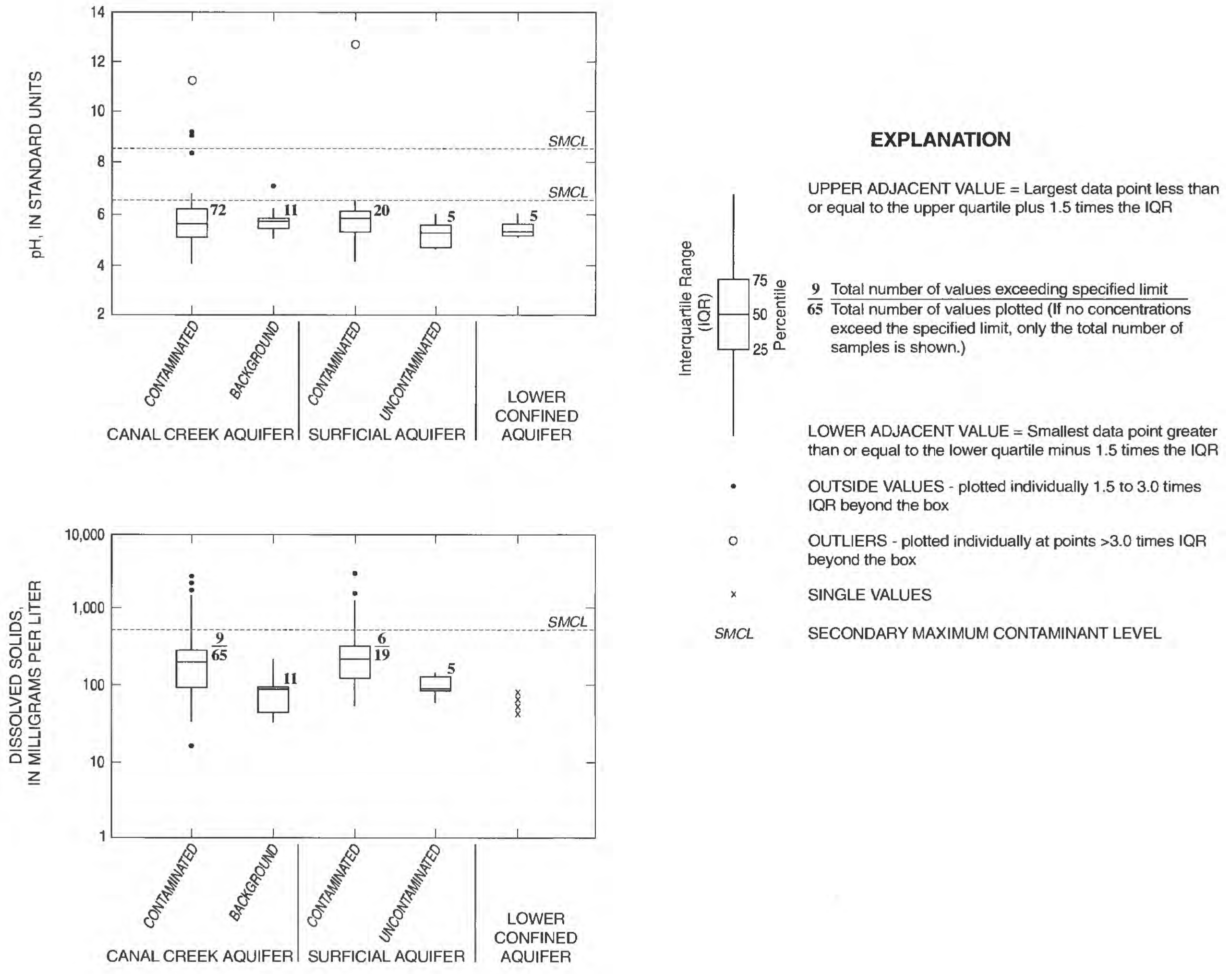


Figure 24. Range of dissolved-solids concentrations and pH in the Canal Creek aquifer, surficial aquifer, and lower confined aquifer, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

(Appendix B1). Most of these wells are located in area IB, except well 16B is near by in area IC and wells 28A and 28B are in area ID (fig. 19). The sample from well 28A had the maximum dissolved-solids concentration (2,660 mg/L) found in the Canal Creek aquifer during the second sampling period.

Six samples from contaminated sites in the surficial aquifer had dissolved-solids concentrations exceeding the SMCL of 500 mg/L for drinking water (fig. 24; table 11). Five of these six samples are from wells located on the Beach Point peninsula in area IIID (fig. 19). Dissolved-solids concentrations ranged from 514 to 2,770 mg/L in these five samples, which include wells 32A, 32B, 33B, 33B.1, and 34A. The sample collected from well 29A in the surficial aquifer in area IIA (fig. 19) also had an excessive dissolved-solids concentration (1,470 mg/L).

The range of pH in the Canal Creek, surficial, and lower confined aquifers during the second sampling period is shown in figure 24. Samples collected from both uncontaminated and contaminated well sites had pH's outside of the SMCL range of 6.5 to 8.5 (fig. 24). The pH of contaminated samples from the Canal Creek and surficial aquifers varied widely, ranging from 4.0 to 12.7. Some of this variability in the pH is probably caused by natural variations in the water chemistry along different flow paths and with changes in the composition of the aquifer material. Background and uncontaminated samples from the Canal Creek and surficial aquifers have a smaller range of pH, but the median pH's do not differ significantly between the contaminated samples and the uncontaminated or background samples.

Most of the background and uncontaminated samples had a pH of less than 6.4, indicating that the samples from the Canal Creek and surficial aquifers that had a pH significantly above 6.4 are affected by alkaline contaminants. The grout-affected samples are not included in figure 24. Several samples had anomalously high pH's but were not believed to be affected by grout, because their potassium and bicarbonate concentrations were not significantly elevated as in the grout-affected samples (fig. 23). These anomalous pH's plot as outliers in the boxplots for the contaminated samples from the Canal Creek and surficial aquifers (fig. 24).

Dissolved oxygen is consumed in ground water by natural processes, including the decomposition of natural organic matter in the aquifer material, such as lignite, and by oxidation of reduced minerals, such as pyrite. Thus, a decrease in the dissolved-oxygen content of the Canal Creek aquifer would be expected with increased distance from recharge zones and as the aquifer becomes more confined, because the supply rate of oxygen to the aquifer would be low. Background samples from the Canal Creek aquifer had dissolved-oxygen concentrations ranging from less than 0.1 to 4.2 mg/L (Appendix B1), with a median concentration of 0.95 mg/L during the second sampling period. The lowest dissolved-oxygen concentration in the background samples (less than 0.1 mg/L) was observed at well 136A, which is screened in the deep confined Canal Creek aquifer in Region II (fig. 19).

Microbial degradation of organic contaminants also consumes dissolved oxygen. The dissolved-oxygen concentrations that were observed in samples from wells screened in the Canal Creek aquifer at each well site during the second sampling period were averaged and are shown in figure 25. Although contamination is extensive in the Canal Creek aquifer in Region I and in Region II (fig. 17), dissolved-oxygen concentrations differ between the two regions. Samples from sites in Region II, which is mainly characterized by deep confined flow in the Canal Creek aquifer, had low dissolved-oxygen concentrations that were generally less than 0.5 mg/L. In contrast, many samples from sites in Region I, which is mainly characterized by shallow unconfined or semiconfined flow in the Canal Creek aquifer, had dissolved-oxygen concentrations between 1.0 and 5.0 mg/L. Oxygen supply rates to the Canal Creek aquifer are probably higher in the shallow flow system of Region I than in Region II; thus, oxygen consumed by microbial degradation reactions can be rapidly replenished in Region I.

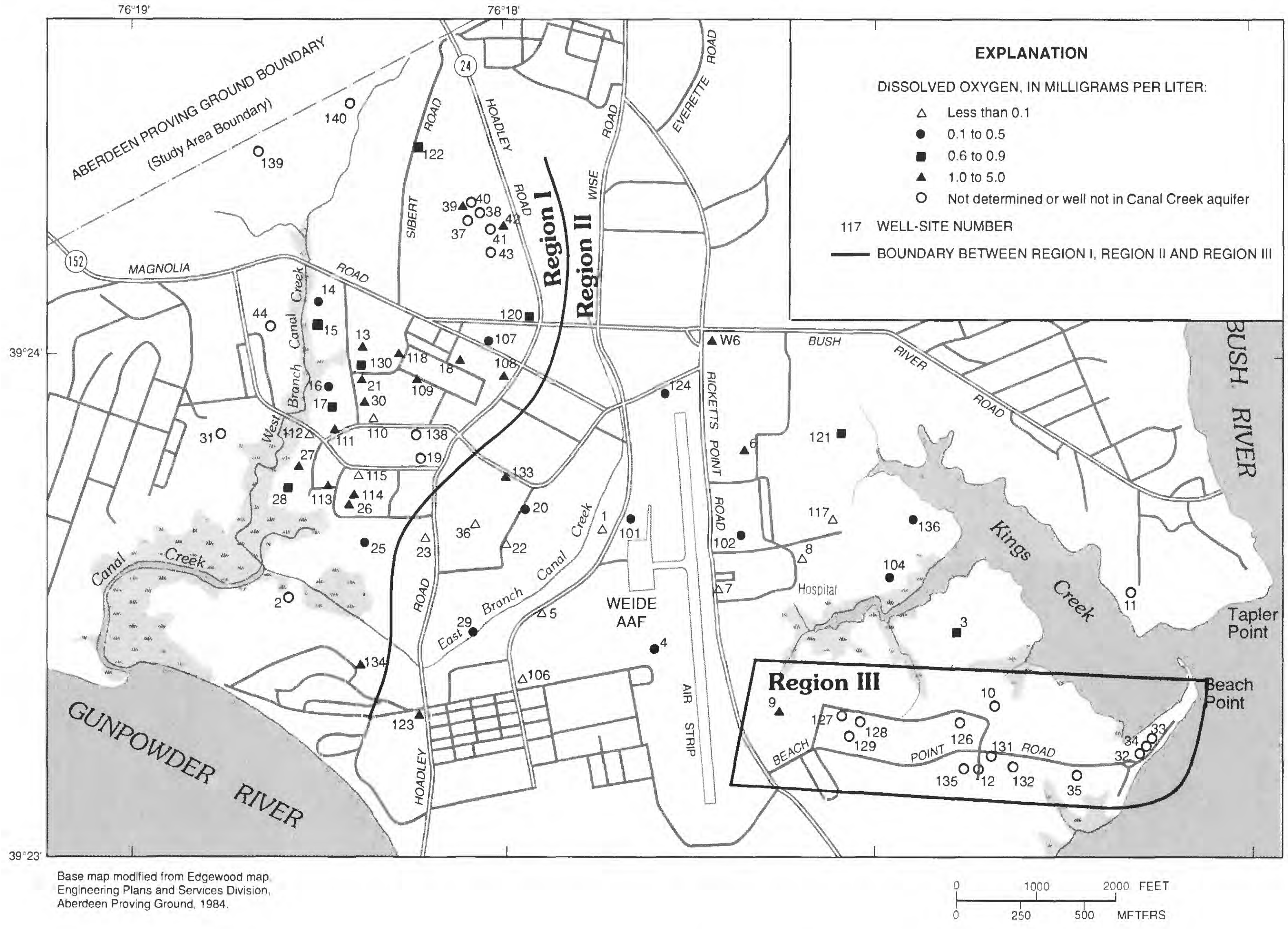
Most of the samples collected from the surficial aquifer during the second sampling period had dissolved oxygen-concentrations between 1.0 and 7.4 mg/L. However, dissolved oxygen was not detectable at some of the contaminated sites in the surficial aquifer. For example, samples from well 1A, which is screened from a depth of 22 to 27 ft in the paleochannel in Region II, had dissolved-oxygen concentrations of less than 0.1 mg/L during all four sampling periods. Samples collected from the lower confined aquifer during the second sampling period generally had dissolved-oxygen concentrations that were less than or equal to 0.5 mg/L (Appendix B1), indicating that natural oxygen consumption processes are more rapid than the oxygen supply rate to this deep, confined aquifer. The recharge area for the lower confined aquifer is north of the study area.

Dissolved-solids concentration, specific conductance, pH, and dissolved-oxygen concentration did not vary significantly during the length of the study. For example, data from 33 wells that were sampled during each of the four sampling periods demonstrates that the range and medians of specific conductance remained fairly constant during each period (fig. 26).

Probable sources

A total of 16 samples collected from contaminated sites in the Canal Creek and surficial aquifers exceeded the SMCL of 500 mg/L for dissolved solids during the second sampling period. All of the samples with elevated dissolved-solids concentrations were collected from sites that were determined to be contaminated on the basis of TOH concentrations (figs. 17 and 18). Inorganic wastes, especially sodium and chloride, were commonly associated with organic wastes disposed of in the Canal Creek area (Nemeth, 1989). Fifteen of the samples with elevated dissolved-solids concentrations also had anomalously high sodium and chloride concentrations; probable sources are discussed in the section on major constituents. The elevated dissolved-solids concentration in sample 29A is mainly caused by high calcium and bicarbonate concentrations (Appendix B1) and is probably derived from the fill material in which the well is screened.

The recommended pH range for drinking water is 6.5 to 8.5 (table 11). Most of the samples, including uncontaminated and contaminated samples, from the three aquifers in the Canal Creek area had pH's below the recommended level of 6.5 (fig. 24).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 25. Distribution of average dissolved-oxygen concentrations in the Canal Creek aquifer, second sampling period (July-September 1988).

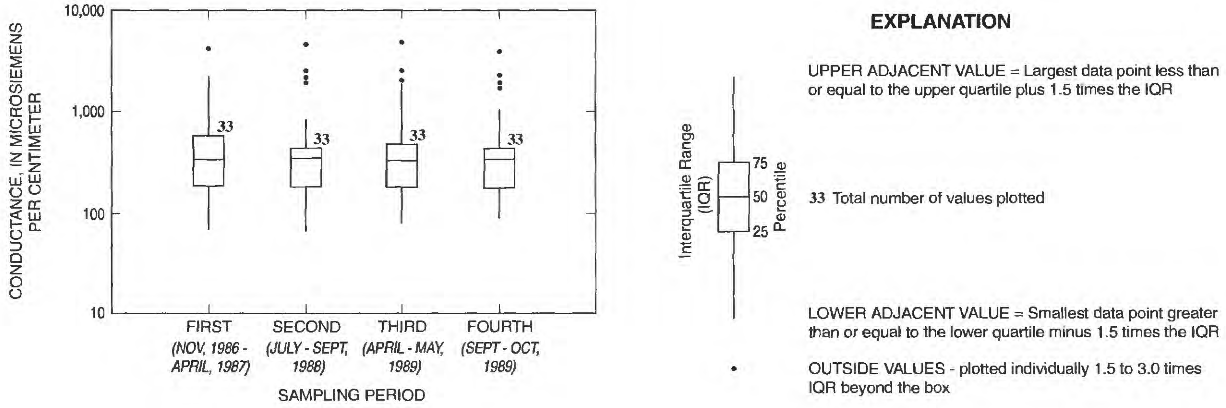


Figure 26. Range of specific conductances at 33 wells sampled during each of the four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland.

This indicates that ground water in the Canal Creek aquifer is naturally acidic. If wells affected by reactions with grout are excluded, pH's exceeded 8.5 in samples from only three wells--16B, 130B, and 29A (fig. 19). The elevated pH in water from these wells is probably caused by alkaline chemicals that were disposed of as waste. Sodium hydroxide, also called caustic soda, has been one of the most commonly used decontaminants in the Edgewood area and would have been present in much of the wastewater discharged by manufacturing and filling plants (Nemeth, 1989). Well 29A is screened in the surficial aquifer in an area along the East Branch Canal Creek where landfilling of wastes took place (fig. 14); alkaline waste from the fill could be leaching into the surficial aquifer in this area.

Major Constituents

Distribution

In this section, the distributions of major inorganic constituents in ground water in uncontaminated and contaminated areas are compared. Areal, vertical, and temporal changes in major-ion concentrations are also discussed. The ranges in concentrations of selected major constituents in ground water in the Canal Creek area are shown as boxplots in figures 27 and 28 for the data collected during the second sampling period (excluding the grout-affected samples). The boxplots represent only quantified concentrations; concentrations reported as less than the detection limit were not included.

Concentrations of major ions in samples from contaminated sites in the the surficial aquifer were generally similar to those in samples from contaminated sites in the Canal Creek aquifer. For example, median chloride concentrations were 30 and 37 mg/L in the contaminated samples collected from the Canal Creek and surficial aquifers, respectively (fig. 27). The similar major ion chemistry indicates that the two aquifers have similar lithology and have been affected by the same types of contaminants. In fact, the surficial and Canal Creek aquifers are connected hydrologically at many sites where the surficial aquifer is contaminated.

The median concentrations for many of the major constituents were higher for the contaminated ground-water samples collected from the Canal Creek and surficial aquifers than for the background or uncontaminated samples. The major ion concentrations in the four samples collected from the lower confined aquifer during the second sampling period were relatively low, generally falling within the range of concentrations in the uncontaminated samples from the Canal Creek and surficial aquifers (fig. 27). The four samples from the lower confined aquifer (6C, 28C, 139A, 140A) were not contaminated with organic compounds (fig. 18).

Median concentrations of calcium, magnesium, sodium, potassium, sulfate, and chloride in the contaminated samples were more than twice as high as their respective median concentrations in the background and uncontaminated samples from the Canal Creek and surficial aquifers. For example, median concentrations of sodium and chloride were about

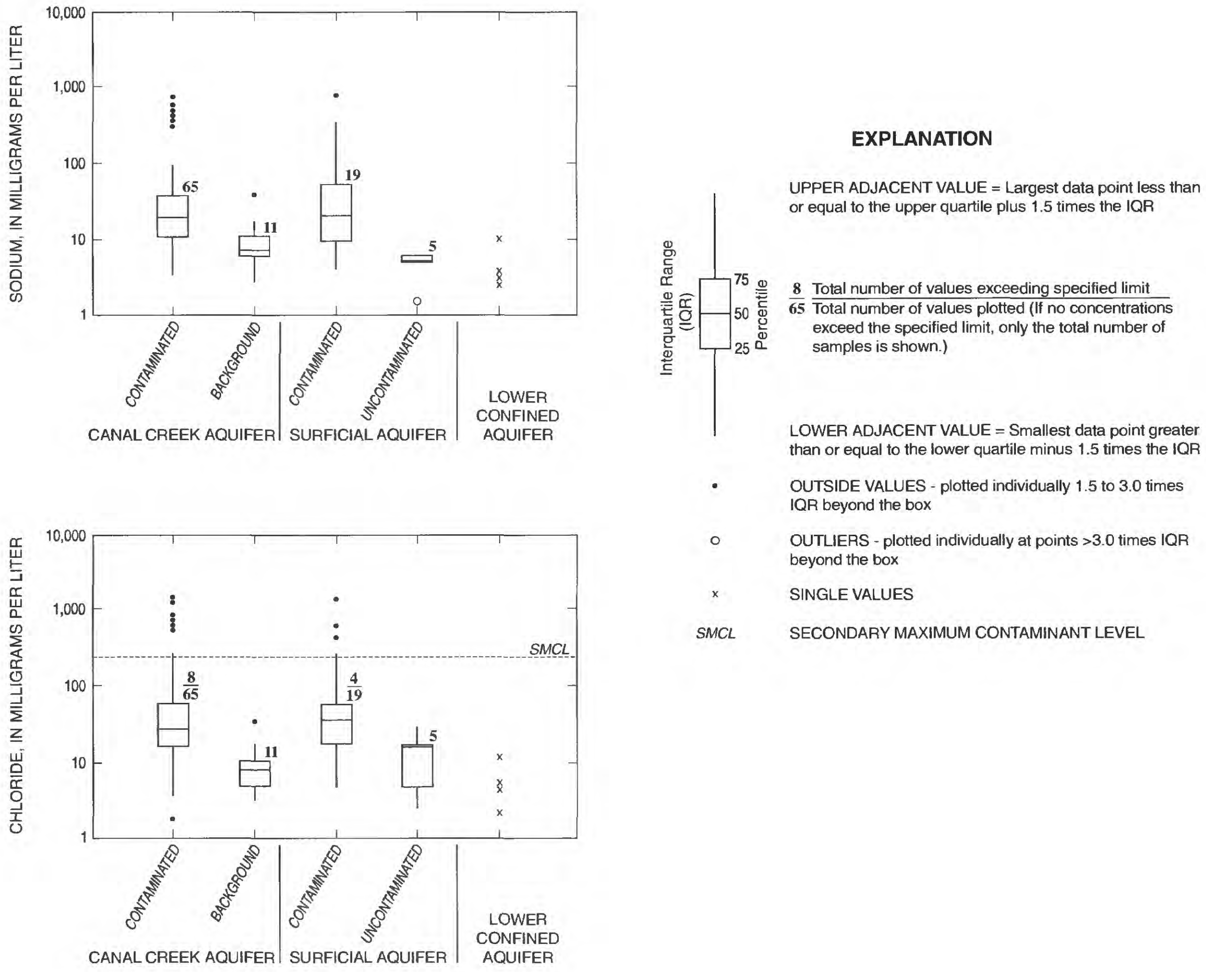


Figure 27. Ranges of sodium and chloride concentrations in the Canal Creek aquifer, surficial aquifer, and lower confined aquifer, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

20 and 30 mg/L, respectively, in the contaminated Canal Creek aquifer samples, whereas the median sodium and chloride concentrations were about 7.0 and 8.0 mg/L, respectively, in the background samples (fig. 27). Similar median concentrations were observed for the surficial aquifer samples. Median sodium and chloride concentrations were about 20 and 38 mg/L, respectively, in the contaminated samples from the surficial aquifer and about 5 and 15 mg/L, respectively, in the uncontaminated samples (fig. 27).

The pattern of elevated concentrations in the contaminated samples compared to those in the background samples is not evident for three major inorganic constituents--bicarbonate, silica, and iron. Median bicarbonate concentration was 35 mg/L for the contaminated samples collected from the Canal Creek aquifer and 39 mg/L for the background samples. Compared to the other major constituents, silica concentrations were the least variable in ground water in the Canal Creek area.

Silica concentrations in the three aquifers in the Canal Creek area ranged from about 0.40 to 24 mg/L, all within the range of silica concentrations commonly observed in natural ground water (1 to 30 mg/L) (Hem, 1985, p. 73). Iron concentrations were highly variable in the three aquifers and ranged from a minimum of 10 µg/L to a maximum of 50,000 µg/L during the second sampling period (fig. 28). Median iron concentrations were higher in the background and uncontaminated samples collected from the Canal Creek and surficial aquifers than in the contaminated samples from the two aquifers (fig. 28).

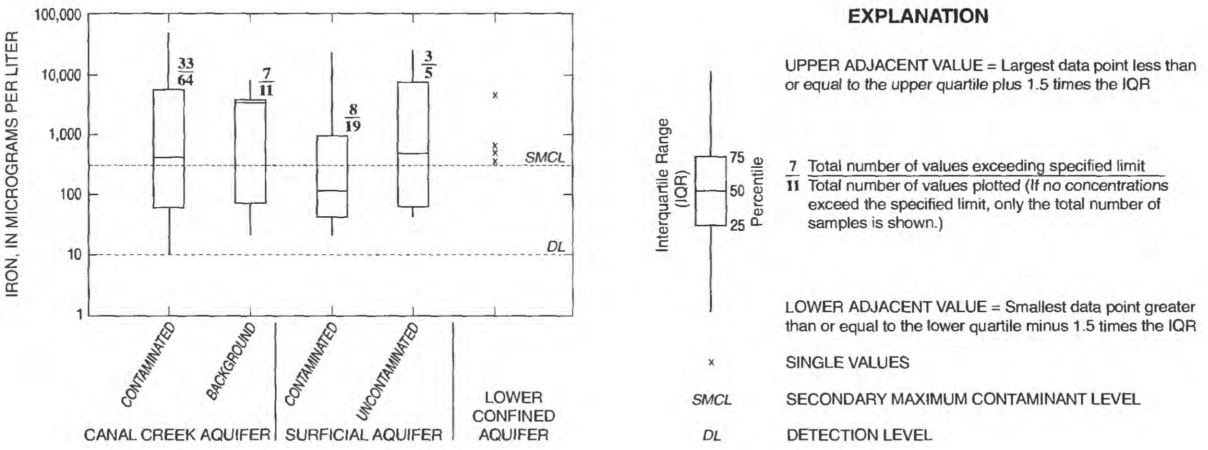


Figure 28. Range of iron concentrations in the Canal Creek aquifer, surficial aquifer, and lower confined aquifer, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

Chloride, sulfate, and iron are the only major inorganic constituents for which Federal drinking-water regulations have been established (table 11). Chloride and iron were found in concentrations that exceed the SMCL's, but sulfate concentrations were below the SMCL of 250 mg/L in all ground-water samples collected in the Canal Creek area. Chloride concentrations that exceed the SMCL were present in only the Canal Creek and surficial aquifers (fig. 27), but iron concentrations were elevated in all three aquifers (fig. 28).

Chloride concentrations exceeded the SMCL in eight samples collected at contaminated sites in the Canal Creek aquifer and in four samples collected at contaminated sites in the surficial aquifer (fig. 27). The eight samples from the Canal Creek aquifer were collected from wells 13A, 18A, 28A, 28B, 130B, 107B, 118A, and 118B. Except for wells 28A and 28B, all these wells are in contaminated area IB (fig. 19). The chloride concentrations in the eight samples ranged from 290 to 1,500 mg/L, which greatly exceed the median chloride concentration of 30 mg/L observed in the contaminated samples from the Canal Creek aquifer. In addition, one of the grout-affected samples, collected at well 107A in area IB, had a chloride concentration that equals the SMCL (Appendix B1).

The eight samples from the Canal Creek aquifer that had chloride concentrations exceeding the SMCL also had dissolved-solids concentrations that exceed the SMCL and sodium concentrations that are elevated with respect to background concentrations. Sodium concentrations for the eight samples ranged from 100 to 810 mg/L and plot as high outliers in the boxplot for the contaminated samples from the Canal Creek aquifer (fig. 27). In contrast, the maximum sodium concentration in the background samples from the Canal Creek aquifer was 41 mg/L (fig. 27).

The four samples from the surficial aquifer whose chloride concentrations exceeded the SMCL were collected from wells 32B, 33B, 33B.1, and 34A, which are in area IIID at Beach Point (fig. 19). Chloride concentrations ranged from 280 to 1,400 mg/L in the four samples during the second sampling period. These four samples were also characterized by dissolved-solids concentrations that exceeded the SMCL and by high sodium concentrations. Sodium concentrations ranged from 260 to 850 mg/L in the four samples (Appendix B1), whereas the median sodium concentration in contaminated samples from the surficial aquifer was only 20 mg/L.

Elevated iron concentrations were observed in background, uncontaminated, and contaminated ground-water samples. In fact, median iron concentrations for the background and the uncontaminated samples were greater than the SMCL of 300 μg/L iron (fig. 28), indicating that elevated iron concentrations occur naturally in the ground water. From the results of the second sampling period, iron concentrations exceeded the SMCL of 300 μg/L in 40 samples from the Canal Creek aquifer and 11 samples from the surficial aquifer (fig. 28). Iron concentrations in the four samples collected from the lower confined aquifer during the second sampling period also exceeded the SMCL (fig. 28).

The high degree of areal and vertical variability in major ion distribution is illustrated by means of Stiff diagrams plotted on hydrogeologic sections B-B' (fig. 29) and C-C' (fig. 30). Geochemical and microbial processes, changes in flow velocities and directions caused by aquifer heterogeneity, and variations in the types and concentrations of contaminants could all affect the major ion distribution.

Section B-B' trends west to east through contaminated areas IC, IB, and IA. All the wells along B-B' that were sampled during the second period are screened in the Canal Creek aquifer. Chloride is clearly the dominant anion in the ground water at wells 16A, 18A, 107B, 118A, 118B, and 130B; and sodium is the dominant cation at most of these wells. Water at the upgradient well sites 120 and 108 has substantially different major ion chemistry, characterized by mixed cation composition and low chloride concentration (fig. 29).

The high degree of vertical variability in distribution of the major ions is evident by comparing the shapes of the Stiff diagrams plotted at different depths in the Canal Creek aquifer at well sites 18, 130, and 16 (fig. 29). The sample from well 18B, screened below a thin clay layer in the Canal Creek aquifer, has much lower concentrations of major ions than water from well 18A and does not contain chloride and sodium as dominant ions. At sites 16 and 130, the similar shapes of the Stiff diagrams for both wells at each site indicate that the major ion composition does not change substantially with depth in the aquifer, although concentrations are substantially higher in the deeper part of the aquifer at each site.

Section C-C' (fig. 30) trends west to east through contaminated areas IIA and IIB (fig. 19); the sites shown on the section, except sites 3 and 11, have been designated as contaminated (figs. 17 and 18). Major ion concentrations decrease downgradient from site 20 to site 3, an uncontaminated site (fig. 30). At site 20, the major ion composition does not change significantly with depth in the aquifer, as seen by the similar shapes of the Stiff diagrams. However, the relative sizes of the Stiff diagrams show that water from the deepest well at site 20 had lower concentrations than observed at the shallower wells. Each well sampled at site 20 contained a higher proportion of calcium plus magnesium than sodium, and potassium was present in the lowest concentrations. The anion composition is mixed, consisting of approximately equal proportions of bicarbonate, sulfate, and chloride. At the other contaminated sites in section C-C', vertical variability in major ion composition was generally greater than was seen at site 20.

Moving downgradient from site 20 to site 3, the ground water generally seems to retain the same relative proportions of the major cations; however, sodium is more dominant than calcium plus magnesium at site 7 and at well 8C. A general downgradient decrease in sulfate concentrations is the most noticeable change in anion composition of the ground water (fig. 30).

The range of major ion concentrations in ground water in the Canal Creek area did not change substantially between the four sampling periods. Although some fluctuations in concentrations were noted at individual well sites, an overall seasonal trend in major ion concentrations was not noted. Seasonal changes in major ion concentrations would be expected to occur mainly in very shallow unconfined parts of the aquifer, where fluctuating water levels could cause variable dissolution rates of waste material and soil minerals. However, no distinct pattern was evident in the samples collected from the unconfined part of the Canal Creek aquifer. Seasonal trends could have been obscured because (1) only four sets of ground-water samples are available or (2) the sampling periods did not coincide with the optimum periods to observe seasonal ground-water-chemistry changes. In addition, during the last two sampling periods (Appendixes B1-B6), the laboratory reported some of the major ion concentrations as greater-than values, thus making seasonal trends difficult to discern.

Probable sources

The elevated concentrations of many of the major inorganic constituents in contaminated samples from the Canal Creek and surficial aquifers compared to concentrations in background or uncontaminated samples indicate that contamination has affected the major ion chemistry of the aquifer. The elevated concentrations could be caused by direct or indirect sources. To be a direct source, the major inorganic constituent must have been present in wastes disposed of in the Canal Creek area. Changes in the rate and occurence of natural geochemical reactions in the contaminated aquifers, such as mineral dissolution and ion exchange, could result in indirect sources of the major constituent. In the Canal Creek area, chloride and iron are the only major constituents that were measured in ground water in concentrations that exceeded their SMCL's. Specific probable sources will be discussed here for these two constituents.

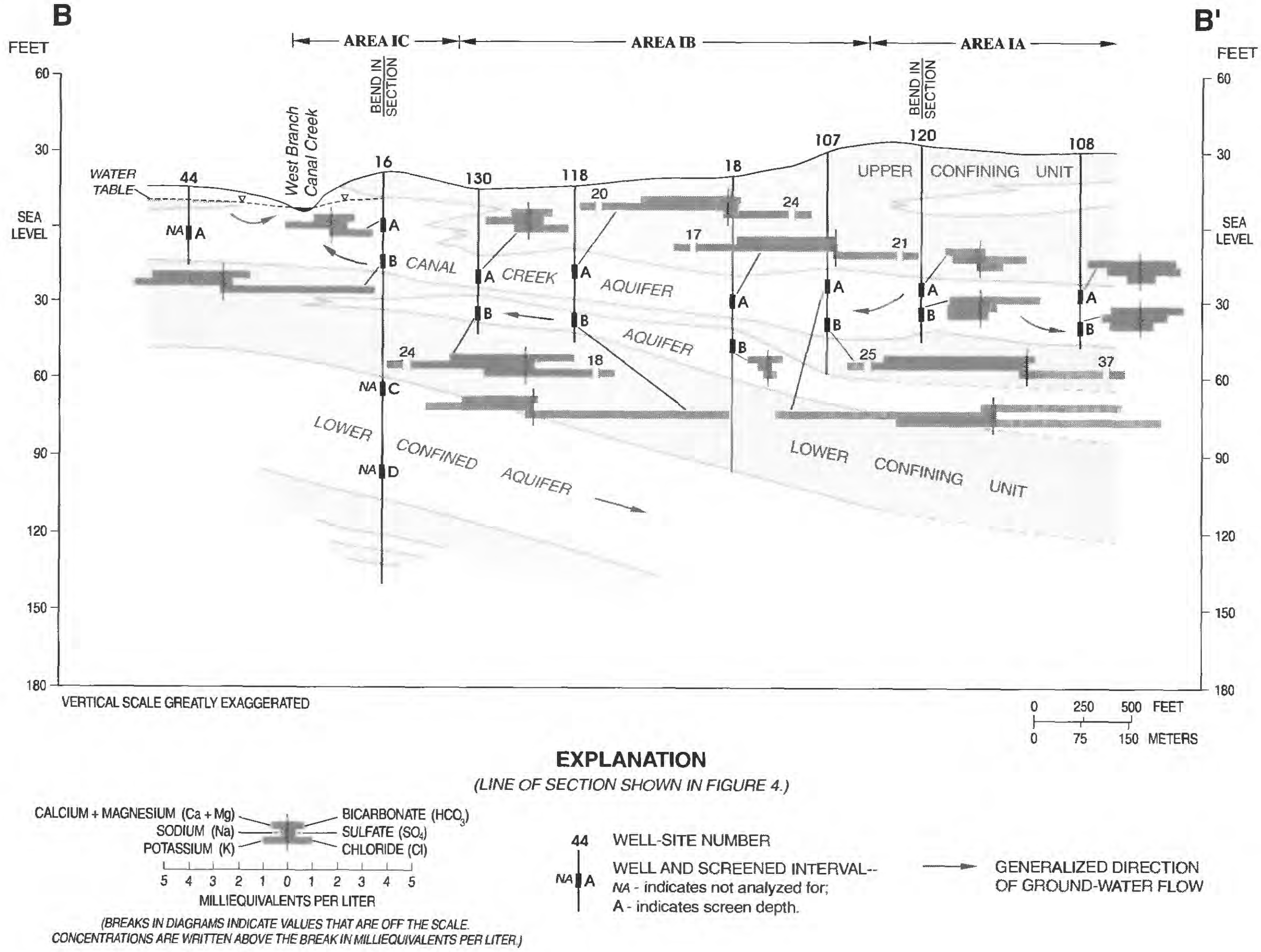


Figure 29. Distribution of major ions in ground water along hydrogeologic section B-B', second sampling period (July-September 1988).

Chloride

Sources of chloride in the ground water include brackish-water intrusion and disposal of wastewater and solid wastes containing chloride. Chloride and sodium were both components of wastes generated by many manufacturing processes in the Canal Creek area. At all the sites where chloride concentrations exceeded the SMCL, organic contaminants also were present, an indication that the sites were affected by manufacturing wastes.

Brackish-water intrusion is probably the major source of excessive chloride concentrations in wells in the surficial aquifer at Beach Point and could be a possible source of excessive chloride concentrations at site 28 along the West Branch Canal Creek (Lorah and Vroblesky, 1989, p. 44). The major-ion composition of surface-water samples collected from the Bush River and Kings Creek surrounding Beach Point is similar to the major-ion composition in ground-water samples collected at Beach Point (fig. 31). Sodium and chloride are the dominant ions in the ground water and surface water, indicating that brackish-water intrusion is the source of excessive chloride concentrations in the ground water at Beach Point (fig. 31). However, the major-ion composition of surface-water samples collected from the West Branch Canal Creek does not appear to be similar to the major-ion composition of ground-water samples collected at site 28 or at nearby site 27 (fig. 32). The ground water at site 28 has a distinct sodium-chloride composition, whereas nearby surface water generally has a mixed cation and mixed anion composition. Thus, the excessive chloride concentration at site 28 is probably not the result of brackish-water intrusion.

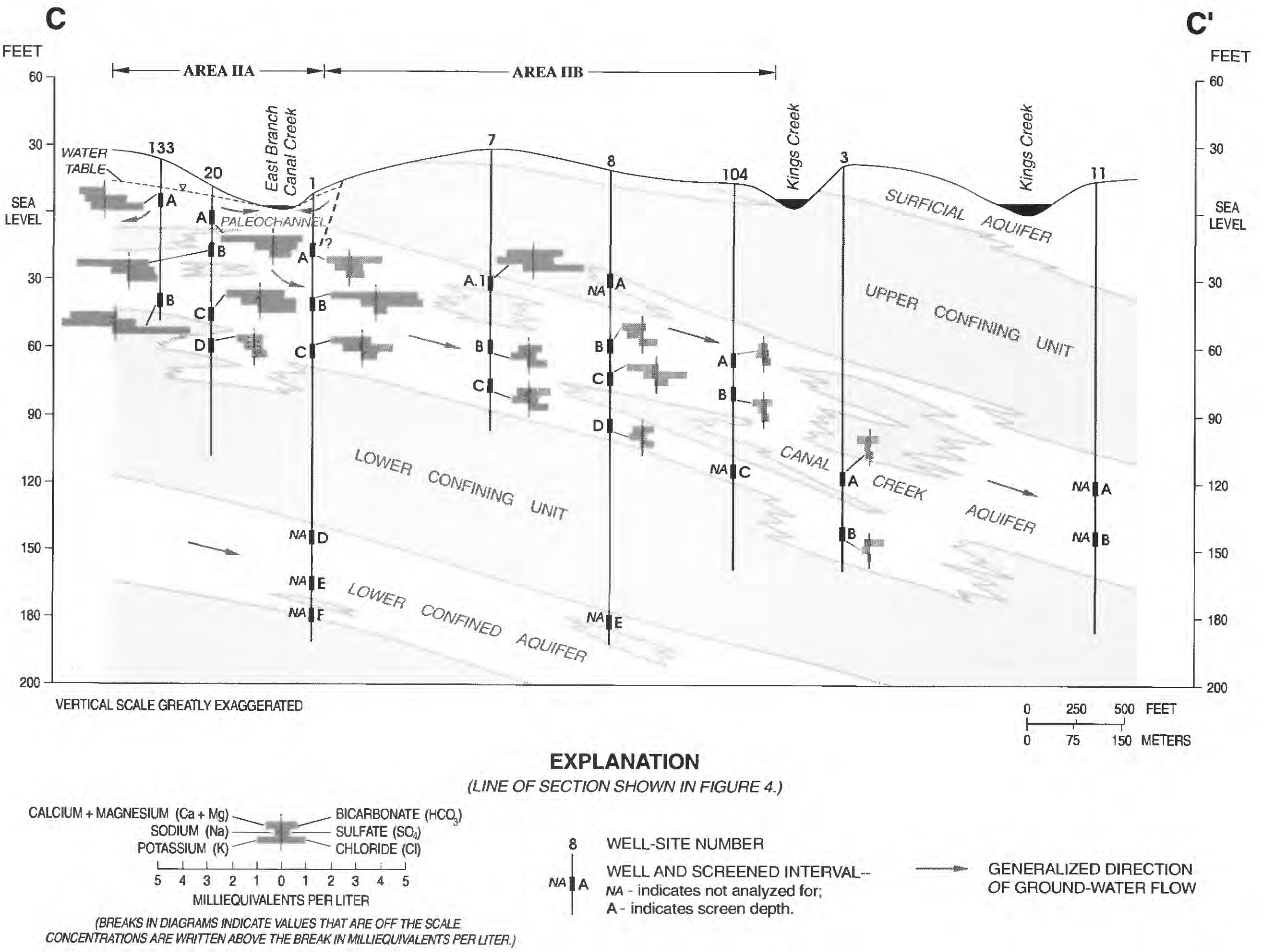


Figure 30. Distribution of major ions in ground water along hydrogeologic section C-C', second sampling period (July-September 1988).

The most likely source of chloride at site 28 (fig. 19) is past waste disposal associated with chlorine manufacturing in the WW2 chlorine plant (fig. 13), which was operated until 1968. Tanks for storing of rock salt and for storing, settling, and disposing of brine once surrounded site 28. Another possible source of choride in the ground water at site 28 is from salts in sludges and tars disposed of as wastes during the CN manufacturing that took place in building 58 during WW2 (fig. 13). Approximately 2,130 lb of aluminum chloride and 3 lb of zinc chloride were required in the manufacturing process to make one ton of CN (Nemeth, 1989, p. 41-45). Wastes containing these chloride compounds probably were disposed of in the marsh near site 28; elevated aluminum and zinc concentrations were also detected in the ground water at site 28. Because of the short ground-water residence time and the high mobility of chloride in water, excessive concentrations of chloride would be expected to be flushed quickly from the Canal Creek aquifer in this unconfined area near the West Branch Canal Creek. Thus, undissolved chloride compounds, which can be continuously dissolved and transported into the Canal Creek aquifer by recharge water, are probably still present in the soil near site 28.

The other ground-water samples that contained chloride concentrations exceeding the SMCL are from wells in contaminated area IB (fig. 19). High concentrations of organic contaminants were seen upgradient from area IB in ground water in area IA; however, the low dissolved-solids, chloride, and sodium concentrations in area IA (fig. 29) indicate that this contaminant plume is not the source of

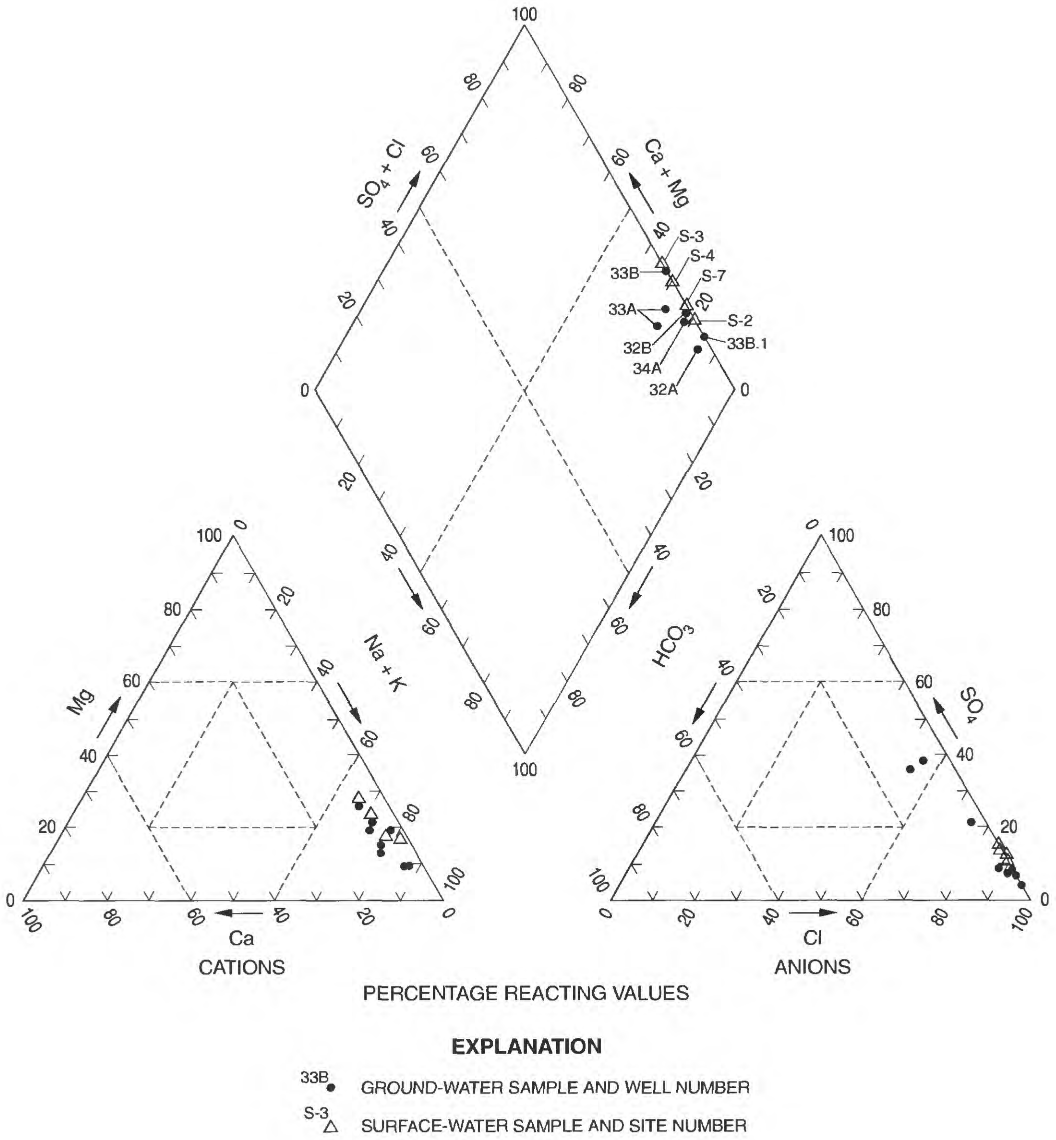


Figure 31. Major-ion composition of ground water at Beach Point and of nearby surface water, Aberdeen Proving Ground, Maryland.

excessive chloride in area IB. The phossy water ponds in area IB (figs. 13 and 19) could have been a source of the high dissolved-solids, sodium, and chloride concentrations in ground water in this area. Wastewater was discharged to one of the phossy water ponds until the 1980's (table 1). Loading of water on these ponds could have caused a reversal in ground-water-flow directions and movement of contaminants from site 118 toward site 107 in the Canal Creek aquifer. The phossy water ponds and well site 118 are located where the upper confining unit is thin or absent (figs. 2 and 6); thus, water leaking from the ponds could move directly into the Canal Creek aquifer. The phossy water ponds are also more likely source for this water than an older waste source, because chloride behaves as a conservative constituent and ground-water-flow velocity is relatively rapid in this region of the Canal Creek aquifer. How-

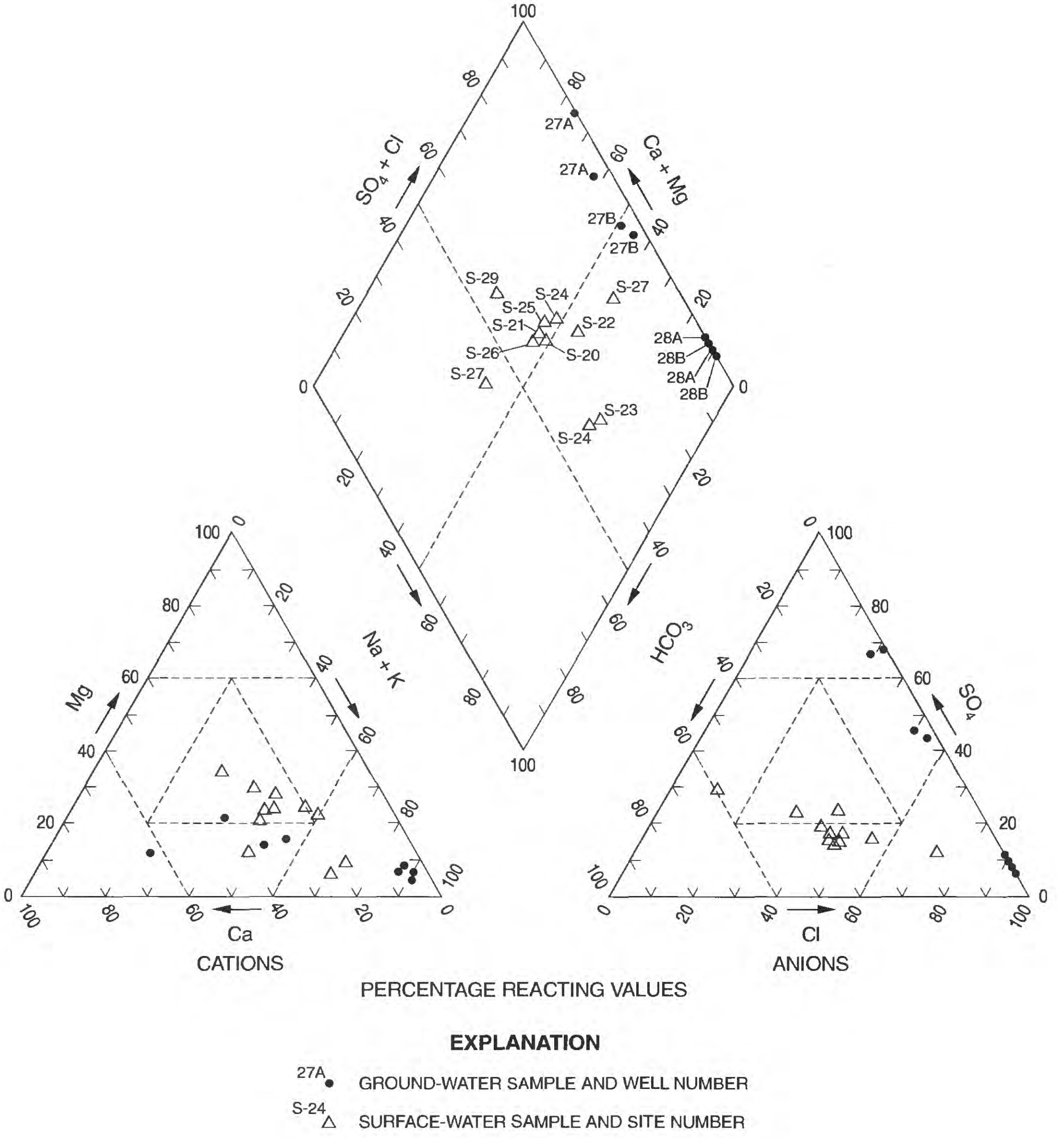


Figure 32. Major-ion composition of ground water at well sites 27 and 28 and of surface water in West Branch Canal Creek, Aberdeen Proving Ground, Maryland.

ever, no information has been found to date to indicate that elevated concentrations of chloride and sodium were present in the phossy water.

Iron

Because iron concentrations that exceed the SMCL were measured in uncontaminated and contaminated ground-water samples, iron seems to be derived mainly from a natural source of dissolution of iron-bearing minerals and iron oxide coatings on the aquifer sediments (Lorah and Vroblesky, 1989, p. 45). Hematite and goethite are two iron-bearing minerals that were identified in sediment samples from aquifers and confining units in the Canal Creek area (Appendix A4). At some sites, the ground water could also have been affected by anthropogenic sources of iron, although, overall, iron concentrations at contaminated sites were no greater than concentrations at uncontaminated sites in the Canal Creek area. Possible anthropogenic sources include disposal of scrap metal in landfilled areas and the use of ferric oxide in filling smoke and incendiary munitions.

Minor Constituents

Distribution

Ranges of concentrations of minor inorganic constituents measured in the Canal Creek, surficial, and lower confined aquifers during the second sampling period are listed in tables 15 through 17. The grout-affected samples from the Canal Creek aquifer are not included in the discussion of the minor inorganic constituents because the higher pH of these samples would affect the concentrations of most of the minor constituents. Many metals are less soluble at high pH and would be expected to be present at lower concentrations in the grout-affected water. The maximum concentrations of all the minor inorganic constituents were lower in the grout-affected samples than in the contaminated samples from the Canal Creek aquifer.

In general, concentrations of minor inorganic constituents were higher in the contaminated samples from the Canal Creek and surficial aquifers than in the background or uncontaminated samples, an indication that elevated concentrations of minor inorganic constituents in the aquifers could have resulted from anthropogenic sources. Concentrations of minor inorganic constituents measured in samples from the lower confined aquifer were generally similar to the low concentrations in background and uncontaminated samples from the Canal Creek and surficial aquifers.

The minor inorganic constituents that were most frequently detected in the three aquifers include manganese, nitrite plus nitrate, nickel, and zinc (tables 15-17). Concentrations of manganese and nickel exceeded Federal drinking-water regulations (table 11), but concentrations of nitrite plus nitrate and zinc were below Federal regulations in the ground-water samples collected for this study. The maximum nitrite plus nitrate concentrations in the contaminated samples from the Canal Creek and surficial aquifers were elevated compared to the concentrations in the background and uncontaminated samples. However, nitrite plus nitrate concentrations were well below the MCL of 10 mg/L (table 11) in all three aquifers (tables 15-17). Phosphorus concentrations were commonly 0.02 mg/L or less and indicate that white phosphorus has not affected the ground water in the Canal Creek area. Sulfide and cyanide were not detected in any samples collected from the three aquifers (tables 15-17). Barium, silver, and thallium were not determined for samples collected during the second sampling period, but were determined for the samples collected during the last two sampling periods (table 4). Barium and silver were not detected in concentrations that exceeded the Federal drinking-water regulations for these constituents, but thallium was detected in concentrations above the MCL (tables 11 and 18).

The remainder of this section will focus mainly on those constituents whose concentrations exceeded Federal drinking-water regulations (tables 11 and 18). Manganese (fig. 33), fluoride, aluminum, antimony, arsenic, beryllium, cadmium, lead, mercury, nickel, and thallium (table 18) were present in concentrations that exceeded Federal drinking-water regulations in the ground water of the Canal Creek area during one or more sampling periods. Although concentrations of zinc and copper did not exceed the SMCL's in any of the ground-water samples, these constituents will be discussed in detail because their distribution could help in defining sources of contamination.

Comparison of measured concentrations in ground-water samples to the Federal drinking-water regulations is difficult for many of the minor constituents because the analytical detection limits (table 4) are the same as, or close to, the MCL's or SMCL's for the constituents (table 11). Analyses of replicate water samples indicate that reproducibility can be low if concentrations for these constituents, which include aluminum, antimony, beryllium, cadmium, and thallium, are near the detection limit (tables 4 and 11). Consequently, confidence in the reported concentrations is low if they are near the detection limits, and confidence in stating that concentrations exceed Federal drinking-water regulations also is low.

In this report, comparisons of the analytical results from the four sampling periods are used to increase confidence in stating that concentrations of minor constituents exceed the Federal drinking-water regulations. If concentrations in samples from the same well exceed the Federal drinking-water regulation for a constituent during two or more sampling periods, the excessive concentration is referred to as "confirmed." Concentrations that slightly exceed the Federal drinking-water regulation during only one sampling period could have resulted from analytical error or cross-contamination. Replicate analyses, where available, also are used to increase confidence in the reported concentrations, but independent analyses from another sampling period provide better confirmation of excessive concentrations.

Table 15. *Minor inorganic constituents detected in ground-water samples collected from the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, at contaminated and background well sites during the second sampling period (July-September 1988)*

[Units are in milligrams per liter; replicate samples are not included; --, not available]

	CANAL CREEK AQUIFER (CONTAMINATED SAMPLES)				CANAL CREEK AQUIFER (BACKGROUND SAMPLES)			
Minor constituent	**Sample size**	**Number of samples in which constituent was detected**	**Maximum concentration**	**Minimum concentration**	**Sample size**	**Number of samples in which constituent was detected**	**Maximum concentration**	**Minimum concentration**
Ammonia (as N)	65	19	1.9	0.12	11	2	0.20	0.17
Nitrite (as N)	65	32	.20	.010	11	8	.06	.02
Ammonia + organic nitrogen (as N)	65	49	2.1	.18	11	9	.83	.12
Nitrite + nitrate (as N)	65	64	3.1	.030	11	11	.85	.03
Phosphorus	65	19	.10	.010	11	3	.010	.010
Sulfide	11	0	--	--	5	0	--	--
Fluoride	65	38	.90	.10	11	3	.10	.10
Bromide	25	5	.24	.10	1	0	--	--
Cyanide	37	0	--	--	9	0	--	--
Manganese	65	65	2.1	.004	11	11	2.4	.020
Antimony	65	13	.012	.003	11	1	.003	--
Arsenic	65	18	.049	.001	11	0	--	--
Beryllium	65	1	.002	--	11	0	--	--
Boron	65	45	.64	.010	11	8	.080	.010
Cadmium	65	34	.016	.001	11	4	.002	.001
Chromium	65	28	.007	.001	11	4	.002	.001
Copper	65	44	.18	.001	11	3	.003	.001
Lead	65	39	.065	.001	11	2	.002	.001
Mercury	65	14	.0009	.0005	11	0	--	--
Nickel	65	58	.25	.001	11	11	.052	.001
Selenium	65	6	.002	.001	11	0	--	--
Zinc	65	62	3.1	.011	11	11	2.4	.010

Table 16. *Minor inorganic constituents detected in ground-water samples collected from the surficial aquifer, Aberdeen Proving Ground, Maryland, at contaminated and uncontaminated well sites during the second sampling period (July-September 1988)*

[Units are in milligrams per liter; replicate samples are not included; --, not available]

	SURFICIAL AQUIFER (CONTAMINATED SAMPLES)				SURFICIAL AQUIFER (UNCONTAMINATED SAMPLES)			
Minor constituent	**Sample size**	**Number of samples in which constituent was detected**	**Maximum concentration**	**Minimum concentration**	**Sample size**	**Number of samples in which constituent was detected**	**Maximum concentration**	**Minimum concentration**
Ammonia (as N)	19	4	5.7	0.11	5	1	0.15	--
Nitrite (as N)	19	4	.12	.030	5	0	--	--
Ammonia + organic nitrogen (as N)	19	10	4.9	.20	5	4	.51	0.24
Nitrite + nitrate (as N)	19	18	2.7	.050	5	5	1.0	.090
Phosphorus	19	8	.020	.010	5	0	--	--
Sulfide	4	0	--	--	2	0	--	--
Fluoride	19	11	.26	.11	5	2	.15	.14
Bromide	11	9	1.4	.24	1	0	--	--
Cyanide	6	0	--	--	5	0	--	--
Manganese	19	18	3.1	.003	5	5	.68	.014
Antimony	19	3	.008	.006	5	1	.007	--
Arsenic	19	3	.033	.002	5	1	.003	--
Beryllium	19	0	--	--	5	0	--	--
Boron	19	10	.37	.020	5	3	.11	.030
Cadmium	19	6	.005	.003	5	3	.006	.001
Chromium	19	6	.002	.001	5	0	--	--
Copper	19	9	.010	.001	5	2	.004	.001
Lead	19	6	.008	.001	5	3	.004	.001
Mercury	19	1	.0008	--	5	0	--	--
Nickel	19	18	.18	.001	5	4	.015	.008
Selenium	19	3	.003	.002	5	0	--	--
Zinc	19	16	.51	.013	5	5	.071	.014

Table 17. *Minor inorganic constituents detected in ground-water samples collected from the lower confined aquifer, Aberdeen Proving Ground, Maryland, during the second sampling period (July-September 1988)*

[Units are in milligrams per liter; replicate samples are not included; --, not available]

Minor constituent	Sample size	Number of samples in which constituent was detected	Maximum concentration	Minimum concentration
Ammonia (as N)	4	0	--	--
Nitrite (as N)	4	1	0.020	--
Ammonia + organic nitrogen (as N)	4	4	.50	0.20
Nitrite + nitrate (as N)	4	4	.36	.040
Phosphorus	4	0	--	--
Sulfide	1	0	--	--
Fluoride	4	1	.10	--
Bromide	1	1	.14	--
Cyanide	4	0	--	--
Manganese	4	4	.12	.040
Antimony	4	0	--	--
Arsenic	4	0	--	--
Beryllium	4	0	--	--
Boron	4	3	.050	.020
Cadmium	4	2	.006	.001
Chromium	4	0	--	--
Copper	4	2	.017	.001
Lead	4	0	--	--
Mercury	5	1	.0008	--
Nickel	4	4	.027	.004
Selenium	4	0	--	--
Zinc	4	3	.073	.028

Most of the samples that had concentrations of minor constituents exceeding Federal regulations were collected from contaminated sites in the Canal Creek and surficial aquifers. However, mercury, aluminum, and cadmium were detected in the lower confined aquifer in concentrations that exceed Federal drinking-water regulations; and, antimony, cadmium, and thallium were detected in concentrations that exceeded Federal drinking-water regulations in samples from background wells over the course of the study (table 18). The excessive concentrations of these minor constituents in samples from the lower confined aquifer and the background wells were not confirmed by analytical results from the other sampling periods (table 18).

Manganese

Manganese was the most prevalent minor inorganic constituent; it was present in detectable concentrations in all except one of the samples collected during the second sampling period (tables 15-17). In most of the samples from the three aquifers, manganese concentrations exceeded the SMCL of 50 μg/L (fig. 33). The concentration range for manganese is not greatly different between the contaminated samples and the background or uncontaminated samples from the Canal Creek and surficial aquifers; thus, manganese, like iron, probably is derived from a natural source.

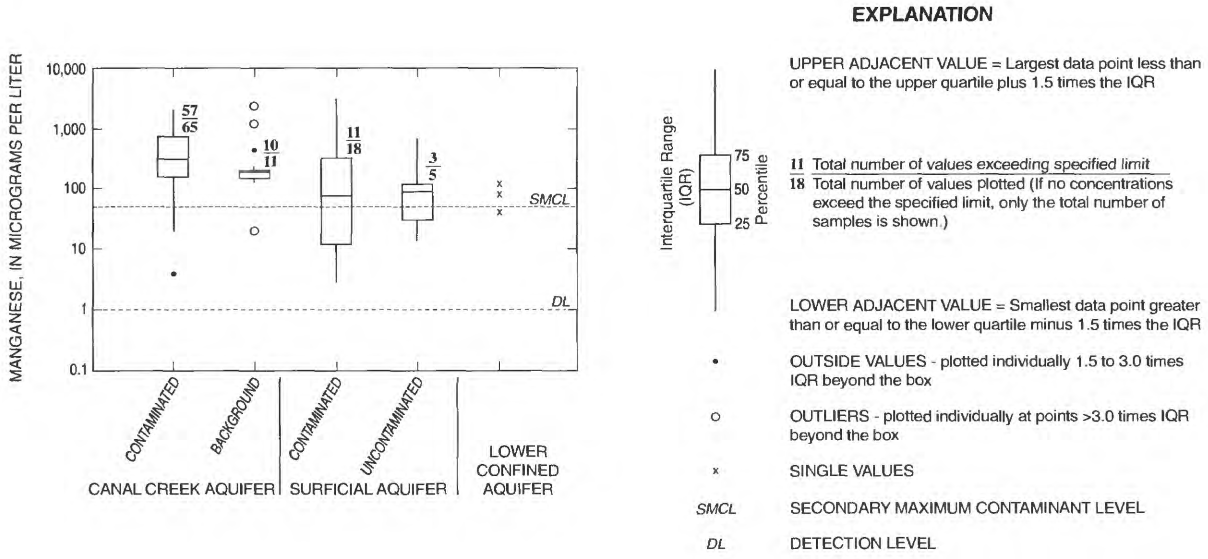


Figure 33. Range of manganese concentrations in the Canal Creek aquifer, surficial aquifer, and lower confined aquifer, Aberdeen Proving Ground, Maryland, second sampling period (July-September 1988).

Fluoride, beryllium, and mercury

Fluoride and beryllium were detected in concentrations that exceeded Federal drinking-water regulations only in samples collected during the first sampling period (table 18). Mercury was detected in concentrations exceeding the MCL of 0.002 mg/L (2 μg/L) in samples from only two wells throughout the study, and these excessive concentrations were not confirmed.

Fluoride concentrations exceeded the SMCL of 2.0 mg/L or the MCL of 4.0 mg/L in four samples that were collected during the first sampling period from wells 13A, 15A, 27B, and 28A in the Canal Creek aquifer (table 18). Although well 15A was sampled again during the second sampling period and wells 13A, 27B, and 28A were sampled during the next three sampling periods, fluoride concentrations exceeding the SMCL were not observed again. Samples from 13A, 27B, and 28A had fluoride concentrations ranging from 2.6 to 7.1 mg/L during the first sampling period (Lorah and Vroblesky, 1989, p. 33), whereas samples collected during subsequent periods had fluoride concentrations ranging from <0.071 to 0.90 mg/L (Appendixes B1, B3, and B5). The samples from wells 13A, 15A, 27B, and 28A collected in the second period (July-September 1988) had higher fluoride concentrations than the samples collected in April-May and September-October 1989, indicating a decrease in concentration with time. Fluoride is a fairly mobile constituent, and ground-water flow paths are short in the unconfined Canal Creek aquifer near West Branch Canal Creek where the four wells are located (fig. 20). Thus, fluoride could have left the unconfined flow system relatively quickly, and either the source does not continuously release fluoride into the ground water or it no longer exists.

The beryllium concentration in a sample from well 19B exceeded the MCL of 0.004 mg/L during the first sampling period (table 18). The excessive concentration 0.019 mg/L could not be confirmed because well 19B was not sampled again.

During the first sampling period, the mercury concentration in water from well 17C, which is screened in the lower confined aquifer, was 0.0046 mg/L (4.6 μg/L) (table 18). This well was sampled again during the second sampling period, and the mercury concentration in the sample (0.0008 mg/L) was less than the MCL. During the third sampling period, the mercury concentration in a sample from well 120A exceeded the MCL; however, concentrations in two replicate samples collected from this well were less than 0.0006 mg/L (0.6 μg/L) and less than 0.0001 mg/L (0.1 μg/L) (Appendix B3). Well 120A was also sampled during the second sampling period, and mercury was not detectable.

Aluminum

Aluminum was determined only for the samples collected during the third and fourth sampling periods, and the reported detection limits of 0.16 to 0.18 mg/L (table 4) were relatively high compared to the SMCL of 0.050 to 0.20 mg/L. A lower detection limit of 0.001 mg/L was reported only for those samples analyzed by the USGS laboratory during the third sampling period. Thus, most of the

Table 18. *Minor inorganic constituents whose concentrations exceeded Federal drinking-water regulations in ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland, for four sampling periods*

[No. samples that exceed, number of samples in which concentrations exceeded the lowest value of MCL or SMCL (see table 11); NA, not analyzed; NE, no exceeds found in samples from that aquifer; dashes indicate that no samples exceeded Federal drinking-water regulations; asterik (*) indicates that well is a background or uncontaminated well; replicate samples not included]

Minor inorganic constituent	No. samples that exceed	Concentration range (mg/L)	Well numbers for samples that exceeded--wells are listed by aquifer with semicolons separating aquifer: Canal Creek aquifer; surficial aquifer; lower confined aquifer
			First period (November 1986-1987)
Fluoride	4	2.6-8.5	13A, 15A, 27B, 28A; NE; NE
Aluminum	NA	NA	NA
Antimony[1]	0	--	--
Arsenic	0	--	--
Beryllium[2]	1	.019	19B; NE; NE
Cadmium	0	--	--
Lead[1]	0	--	--
Mercury	1	.0046	NE; NE; 17C
Nickel	4	.18-.61	13A, 18A, 40A; 33B; NE
Thallium	NA	NA	NA
			Second period (July-September 1988)
Fluoride	0	--	--
Aluminum	NA	NA	NA
Antimony	8	.007-.012	1B, 7B, 22B, 23B, 36B, 36C; 9A, *101A; NE
Arsenic	1	.053	1B; NE; NE
Berryllium[2]	0	--	NE; NE; NE
Cadmium	10	.006-016	1B, 22B, 23B, 28A, 28B, 36B, 36C, 114B; *101A; 139A
Lead	1	.065	28A; NE; NE
Mercury	0	--	--
Nickel	11	.11-.25	13A, 18A, 102A, 107B, 108A, 109A, 118A, 118B, 120A, 33B.1, 33B; NE
Thallium	NA	NA	NA

Table 18. *Minor inorganic constituents whose concentrations exceeded Federal drinking-water regulations in ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland, for four sampling periods--Continued*

Minor inorganic constituent	No. samples that exceed	Concentration range (mg/L)	Well numbers for samples that exceeded--wells are listed by aquifer with semicolons separating aquifer: Canal Creek aquifer; surficial aquifer; lower confined aquifer
			Third period (April-May 1989)
Fluoride	0	--	--
Aluminum [1]	16	0.090-14	7B, 8C, 13A, 18A, 27A, 27B, 28A, 28B, 102B, 110A, 118A, 118B, 120A,133B; NE; 1E, 16C
Antimony [1]	0	--	--
Arsenic	0	--	--
Beryllium	NA	NA	NA
Cadmium	3	.006-.022	36B, 36C, 114B; NE; NE
Lead	3	.020-.059	20C, 28A, 36B; NE
Mercury	1	.0030	120A; NE; NE
Nickel	10	.11-.22	13A, 18A, 102B, 107B, 108A, 118A, 120A, 130B; 33B; NE
Thallium [1]	2	.057-.18	1B, 102B; NE; NE
			Fourth period (September-October 1989)
Fluoride	0	--	--
Aluminum [1]	52	.17-29	see figure 34 for sites
Antimony [1]	0	--	--
Arsenic	2	.082-.087	1B; 1A; NE
Beryllium	NA	NA	NA
Cadmium	14	.007-.013	13A, 16A, 26A, 27A, 27B, 112A, 113A, 113B, 114B, 115A, 130A, 130B, *134A; 114A; NE
Lead	4	.019->.091	17B, 18A, 28A, 113B; NE
Mercury	NA	NA	NA
Nickel	10	.11-.25	13A, 18A, 102B, 107B, 108A, 109A, 118B, 120A, 130B; 33B; NE
Thallium [1]	8	.045-0.67	1B, 7B, 8B, *11A, 102B, 117A, *136A, *136B; NE; NE

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[1] Detection limits (see table 4) were higher than the Federal drinking-water regulations.

[2] Detection limits varied (see table 4) and were higher than the Federal drinking-water regulations for some samples.

measured aluminum concentrations exceed the SMCL of 0.050 mg/L.

During the third sampling period, samples from 16 wells had aluminum concentrations greater than 0.050 mg/L (table 18), and 12 of the 16 samples had concentrations exceeding the SMCL of 0.20 mg/L. Most of the samples collected during the third sampling period that had aluminum concentrations exceeding the SMCL were from contaminated sites in the Canal Creek aquifer, but two of the samples (1E and 16C) were from the lower confined aquifer. During the fourth sampling period, samples from 52 wells were found to exceed the SMCL of 0.050 mg/L for aluminum, and 34 of these samples had concentrations exceeding 0.20 mg/L.

Figure 34 shows the locations of well sites where aluminum was detected during the fourth sampling period. Most of the 31 well sites where aluminum concentrations exceed the SMCL of 0.050 mg/L are in contaminated areas (figs. 19 and 34), although samples from the Canal Creek aquifer at background sites 11 and 136 also had excessive aluminum concentrations during the fourth sampling period (fig. 34). Aluminum concentrations that exceeded the SMCL were confirmed at only 9 of these 31 sites (fig. 34), indicating that aluminum concentrations varied considerably. However, samples from well 28A consistently had the maximum aluminum concentrations. Aluminum concentrations in samples from 28A were 14 and 29 mg/L in the third and fourth sampling periods, respectively, and are an order of magnitude higher than aluminum concentrations measured elsewhere in the ground water.

Antimony

An MCL of 0.006 mg/L has been set for antimony (table 11). Antimony detection limits for the samples collected during the second sampling period (0.003 mg/L) were lower than those for the other three sampling periods (0.024 to 0.072 mg/L) (table 4). Consequently, antimony concentrations that exceeded the MCL were quantified only in samples collected during the second sampling period (table 18).

Samples collected from 8 wells during the second sampling period had antimony concentrations exceeding the MCL of 0.006 mg/L (table 18). Antimony concentrations in the 8 samples ranged from 0.007 to 0.012 mg/L. Seven of the samples were collected from wells screened in the Canal Creek aquifer or the surficial aquifer in contaminated areas IIA and IIB, and the other sample was collected from the surficial aquifer in area IIIA (table 18 and fig. 19). The maximum concentration was observed in the sample from well 36B, in area IIA (fig. 19).

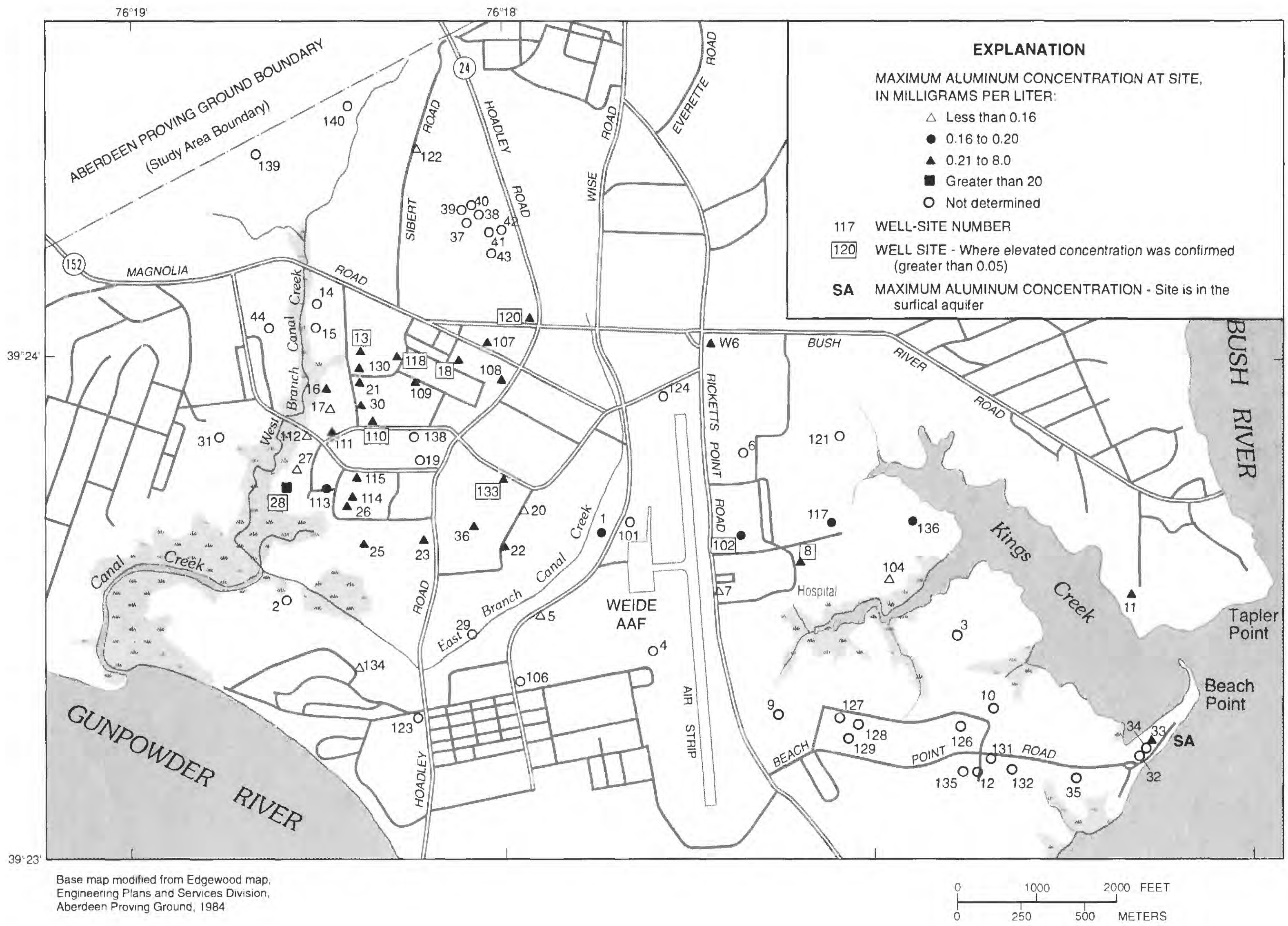
Replicate samples were collected at two wells, 1B and 7B, where antimony concentrations exceeded the MCL during the second sampling period. The concentration in the replicate sample from well 1B was consistent with an excessive antimony concentration of 0.008 mg/L at this site, but the replicate sample from well 7B had an antimony concentration below the MCL of 0.006 mg/L.

Arsenic

Samples collected from one well during the second sampling period and two wells during the fourth sampling period had arsenic concentrations that exceed the MCL of 0.05 mg/L (table 18). Water from well 1B, which is screened in the Canal Creek aquifer at a contaminated site (fig. 17), had arsenic concentrations exceeding the MCL during both of these sampling periods; and, the sample from well 1A, which is screened in the surficial aquifer at the same site, also had arsenic concentrations exceeding the MCL during the fourth sampling period. Replicate samples that were collected at well 1B during both sampling periods had arsenic concentrations that exceed or equal the MCL. The maximum arsenic concentration measured in ground water during this study was 0.087 mg/L, in a sample from well 1A during the fourth sampling period.

The background arsenic concentration in ground water in the Canal Creek area is probably less than 0.003 mg/L. The maximum arsenic concentration in the background and uncontaminated samples collected during the second sampling period was 0.003 mg/L (tables 15 and 16). In addition, a maximum arsenic concentration of 0.003 mg/L was measured in four ground-water samples that were collected outside the army base in Harford County in 1987. These four samples were collected from wells screened in the Potomac Group, and no anthropogenic source of arsenic was suspected near the wells (David Drummond, Maryland Geological Survey, and Joel Blomquist, U.S. Geological Survey, written commun., 1991).

In addition to site 1, where arsenic concentrations exceeded the MCL, relatively high arsenic concentrations were detected in samples from wells screened in the Canal Creek aquifer at sites 36, 23, and 25 (fig. 35). Arsenic concentrations at these sites were greater than 0.010 mg/L, or 10 μg/L, but less than the MCL of 0.05 mg/L (fig. 35). Except for site 25, the sites with arsenic concentrations greater than 0.010 mg/L are located in contaminated area IIA. Site 25 is nearby, in area ID (fig. 19).



Base map modified from Edgewood map,
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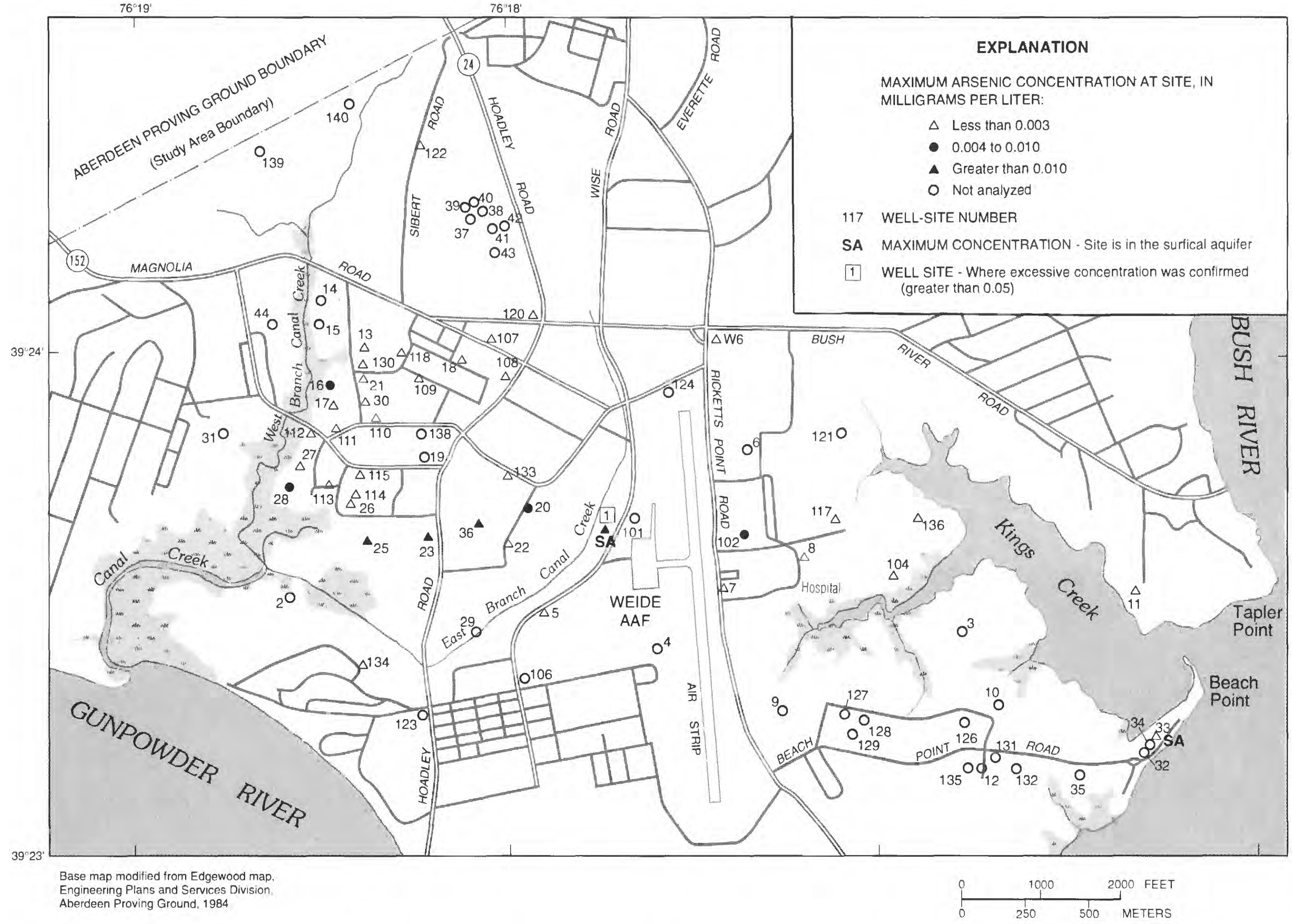
Aberdeen Proving Ground, 1984

Figure 34. Distribution of aluminum in the Canal Creek aquifer for the fourth sampling period (September-October 1989) and locations of well sites where elevated concentrations were confirmed.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984

Figure 35. Distribution of arsenic in the Canal Creek aquifer for the fourth sampling period (September-October 1989) and locations of well sites where excessive concentrations were confirmed.

Arsenic concentrations of greater than 0.010 mg/L were measured consistently in samples from well sites 1, 36, 23, and 25 during all four sampling periods. Samples from four other sites, two of which are also in contaminated areas IIA and ID, had arsenic concentrations that were elevated compared to background concentrations but were less than 0.010 mg/L (fig. 35).

Cadmium

The current MCL for cadmium is 0.005 mg/L. Cadmium concentrations that exceed 0.005 mg/L were measured in as many as 14 samples during the 4 sampling periods, but these excessive cadmium concentrations were confirmed only in samples from wells 36B, 36C, and 114B (table 18). During the first sampling period, cadmium concentrations were less than or equal to the MCL (0.005 mg/L) in all of the samples and less than 0.002 mg/L in most of these samples. Maximum cadmium concentrations ranged from 0.013 to 0.022 mg/L during the other three sampling periods; the maximum concentration was measured in well 114B during each of these sampling periods.

Samples from 10 wells had cadmium concentrations above the MCL during the second sampling period (table 18); samples from 3 of these wells, 23B, 36B, and 114B, had concentrations that were more than twice the MCL. The cadmium concentrations in wells 23B, 36B, and 114B ranged from 0.012 to 0.016 mg/L (Appendix B1). Wells 23B, 36B, and 114B are screened in the Canal Creek aquifer in contaminated areas IIA and ID (fig. 19). Two samples that had cadmium concentrations above the MCL during the second sampling period were collected from wells that were designated as uncontaminated on the basis of TOH concentrations--well 101A, screened in the surficial aquifer, and well 139A, screened in the lower confined aquifer (table 18). Cadmium concentrations in both of these samples (0.006 mg/L) were only slightly greater than the MCL; these concentrations could not be confirmed because the wells were sampled only during the second sampling period.

During the third sampling period, samples from wells 36B, 36C, and 114B had cadmium concentrations above the MCL (table 18). The concentrations in wells 36B and 114B (0.011 and 0.022 mg/L, respectively) were more than twice the MCL for cadmium, as observed during the second sampling period.

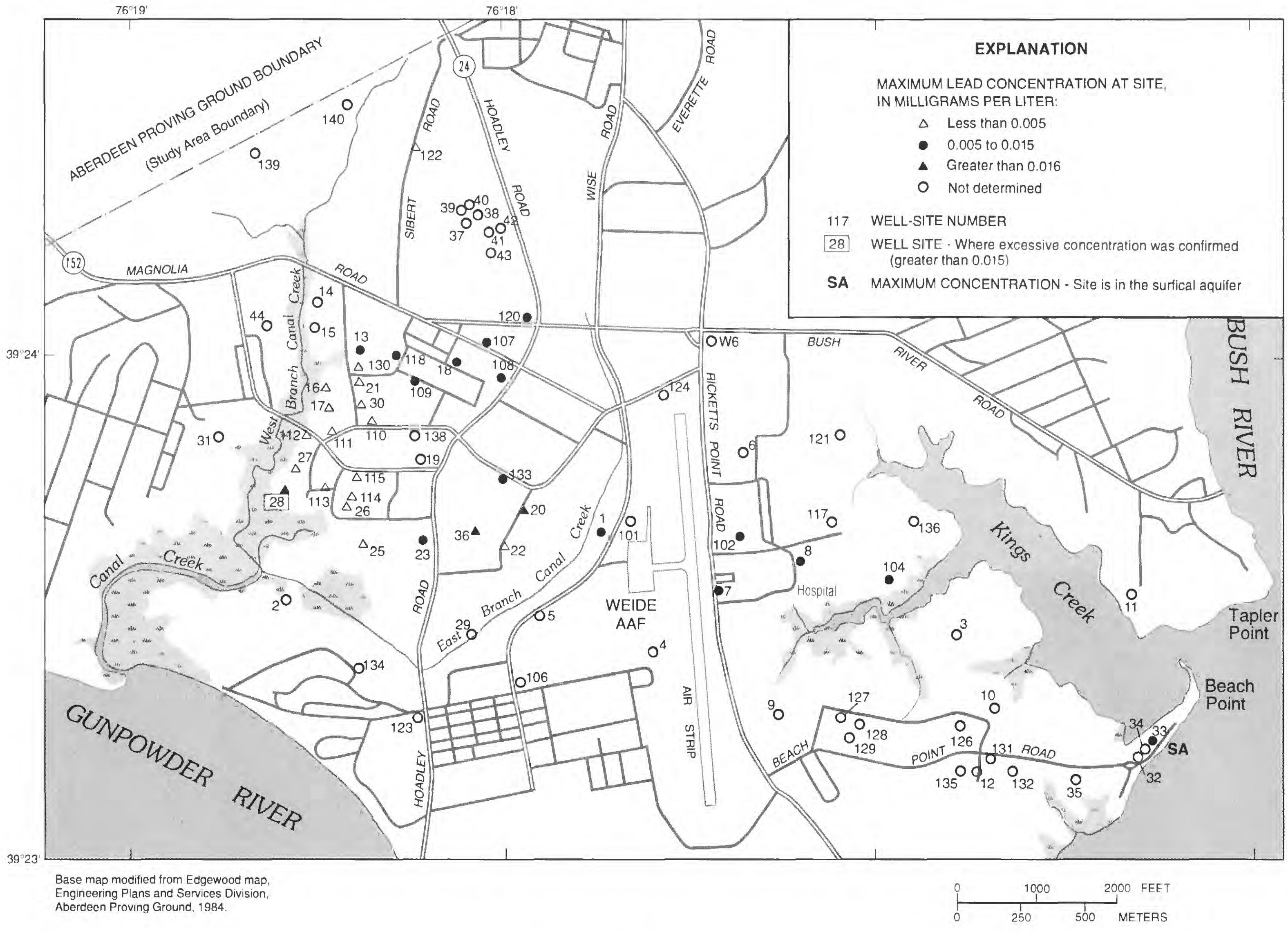
Samples from 14 wells, most of which are screened in the Canal Creek aquifer, had cadmium concentrations above the MCL during the fourth sampling period (table 18). Except for the sample from 114B, none of the samples that had cadmium concentrations above the MCL during the fourth sampling period had excessive concentrations during previous sampling periods. Replicate analyses indicate that reproducibility was low for concentrations near the detection limit, which was close to the MCL of 0.005 mg/L. For example, one set of replicate samples collected from wells 112A and 113A during the fourth sampling period had cadmium concentrations of 0.007 and 0.008 mg/L, whereas the corresponding replicate samples had cadmium concentrations of less than 0.003 mg/L (Appendix B5).

Lead, nickel, zinc, and copper

Lead concentrations exceeded the MCL of 0.015 mg/L in samples from only 1 to 4 wells during the four sampling periods (table 18), but concentrations commonly were elevated compared to a background lead concentration of less than 0.005 mg/L (tables 15-17) at other well sites (fig. 36). Nickel (fig. 37) concentrations exceeded the MCL of 0.10 mg/L in samples from many of the same well sites where elevated lead concentrations were observed, including sites 8, 13, 18, 28, 102, 107, 108, 109, 118, 120, and 33. All zinc and copper concentrations in ground water of the Canal Creek area were less than the SMCL's of 5.0 and 1.0 mg/L, respectively; however, elevated zinc (fig. 38) and copper (fig. 39) concentrations compared to background concentrations were observed at some of the same sites where nickel and lead concentrations were elevated (figs. 36 and 37). Thus, the distributions of zinc and copper could help in defining sources of the nickel and lead.

The lead distribution shown in figure 36 is for a different sampling period than distributions shown for the other trace metals (figs. 37 to 39). The data from the third sampling period, rather than the second sampling period, were used to show lead distribution because these data represent a worst-case scenario. Fewer samples were analyzed for lead during the third sampling period than during the second sampling period; however, more samples had elevated lead concentrations during the third sampling period than during the second sampling period (table 18). At all the sites where samples were not collected during the third sampling period (fig. 36), samples were collected during other sampling periods and were found to have lead concentrations less than 0.005 mg/L.

The sites where elevated lead was measured in the ground water during the third sampling period are grouped in contaminated areas IA and B and IIA and B, except for sites 28 and 33 (figs. 19 and 36). The maximum lead concentration during this



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 36. Distribution of lead in the Canal Creek aquifer for the third sampling period (April-May 1989) and locations of well sites where excessive concentrations were confirmed.

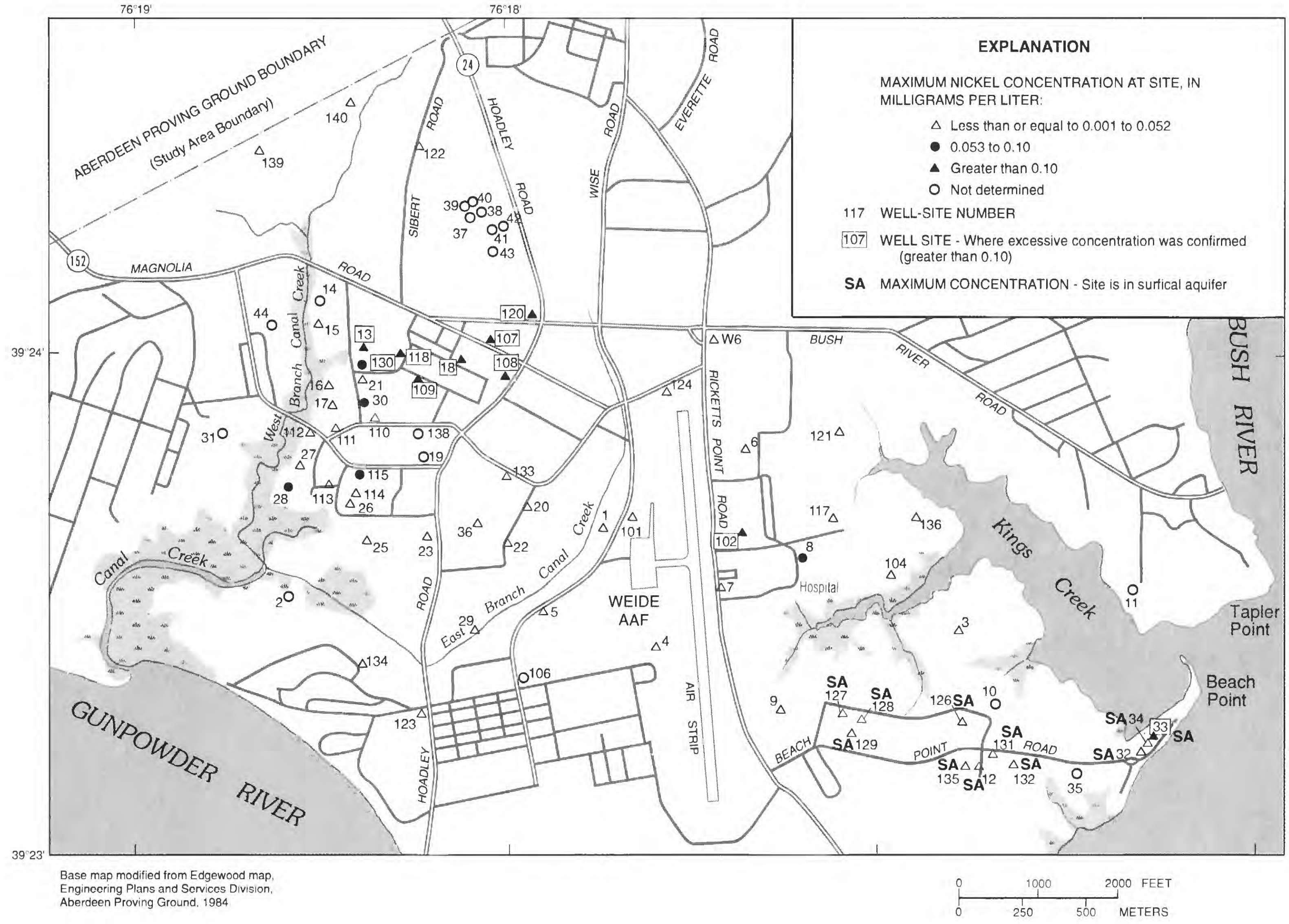
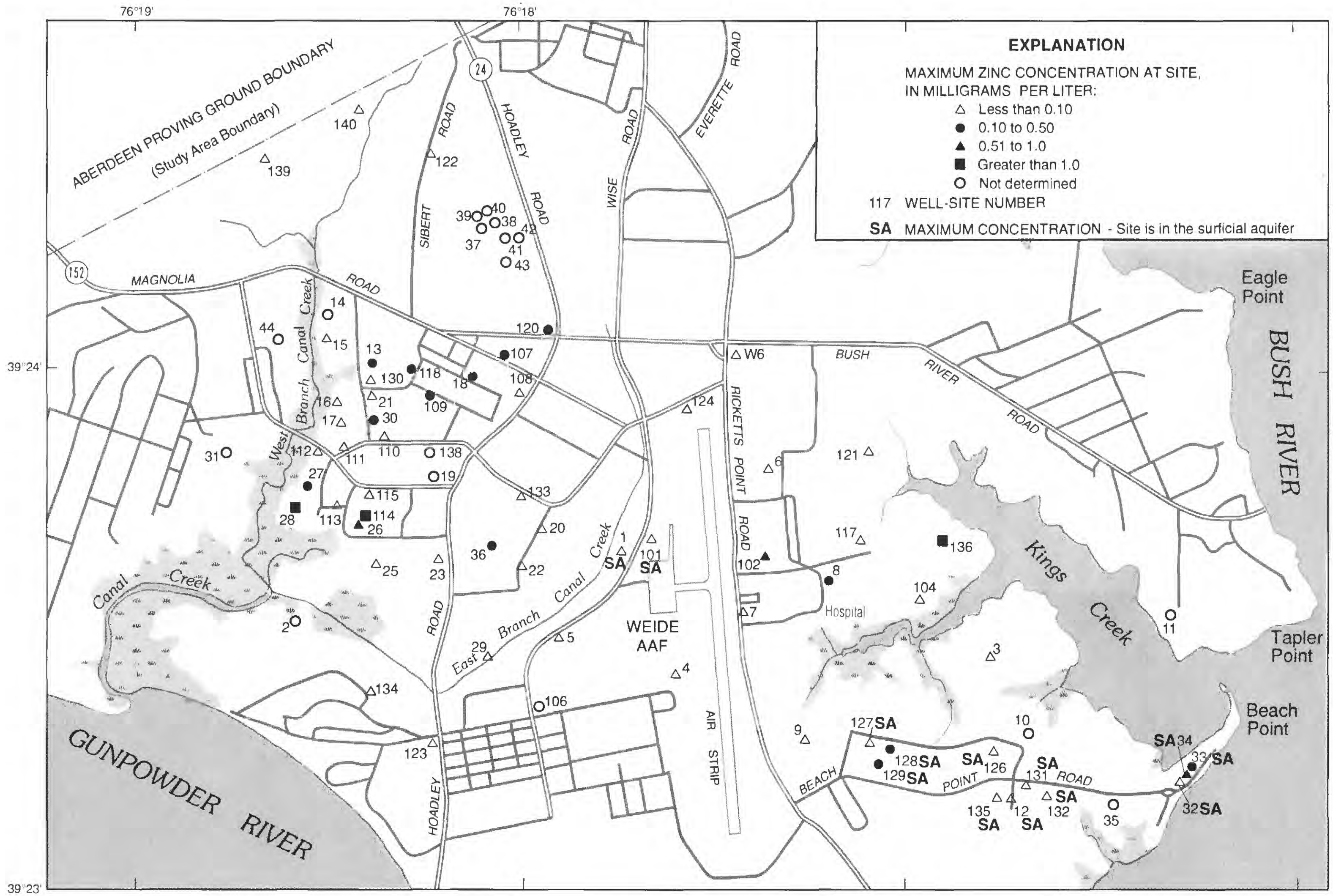
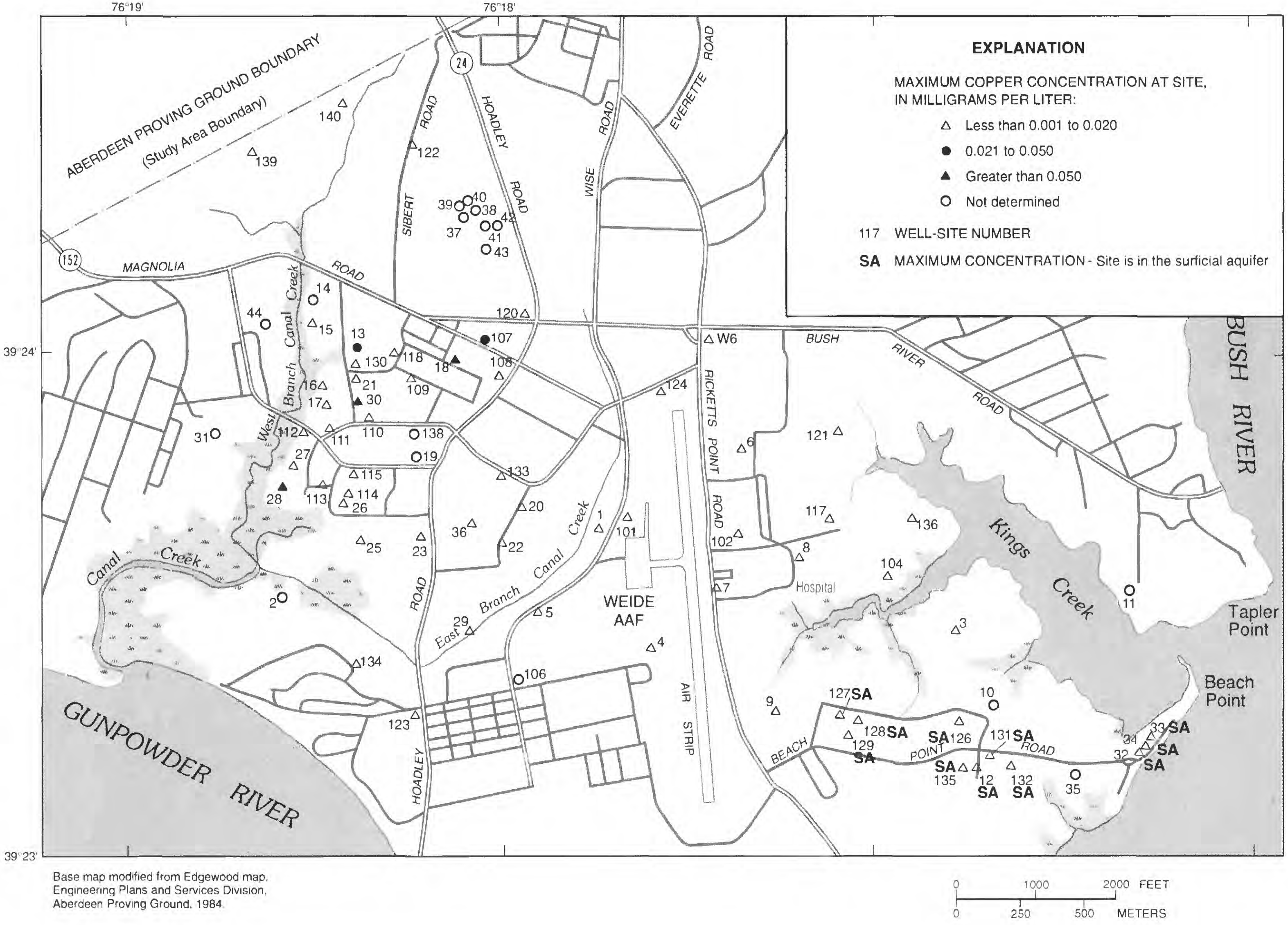


Figure 37. Distribution of nickel in the Canal Creek aquifer for the second sampling period (July-September 1988) and locations of well sites where excessive concentrations were confirmed.



Base map modified from Edgewood map. Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 38. Distribution of zinc in the Canal Creek aquifer, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 39. Distribution of copper in the Canal Creek aquifer, second sampling period (July-September 1988).

sampling period, 0.059 mg/L, was measured in the sample from well 36B (fig. 36). The sample from well 28A, screened in the Canal Creek aquifer in area ID (fig. 19), had the second highest lead concentration (0.045 mg/L) during the third sampling period and the maximum lead concentrations during two other sampling periods. Well 28A is the only well where lead concentrations exceeding the MCL of 0.015 mg/L were confirmed. During the second sampling period, the lead concentration in the sample from well 28A was 0.065 mg/L, which was corroborated with a replicate sample that had a concentration of 0.067 mg/L (Appendix B1). The lead concentration in the sample from well 28A was reported as greater than 0.091 mg/L for the fourth sampling period (table 18).

Excessive nickel concentrations ranged from 0.11 to 0.61 mg/L and were measured fairly consistently in samples from the same wells throughout the study (table 18). Most of the samples that had nickel concentrations exceeding the MCL of 0.1 mg/L were collected from wells screened in the Canal Creek aquifer in contaminated areas IA and IB (figs. 37 and 19). The exceptions are site 102, which is in area IIB, and site 33, which is in area IIID. In addition, nickel concentrations were above the background range of less than 0.001 to 0.052 mg/L (tables 15 and 17) in samples from several sites--sites 28, 115, 30, and 130 by the West Branch Canal Creek in areas IB, IC, and ID; and site 8 in area IIB (fig. 37). Ground-water samples at these sites, except site 130, did not have nickel concentrations above the MCL during any of the sampling periods but did consistently have concentrations that were elevated above background.

The background zinc concentration in ground water of the Canal Creek area is probably less than 0.10 mg/L, on the basis of zinc concentrations measured in samples from uncontaminated wells in all three aquifers (tables 15 to 17). The maximum zinc concentration in uncontaminated samples from the surficial aquifer was 0.071 mg/L (table 16), and a maxium concentration of 0.073 mg/L was observed in the lower confined aquifer (table 17). All background samples from the Canal Creek aquifer had zinc concentrations less than 0.10 mg/L, except for the sample from well 136B, which had a zinc concentration of 2.4 mg/L during the second sampling period (table 15). The anomalous zinc concentration of 2.4 mg/L could be an outlier caused by cross-contamination or analytical error.

The distribution of elevated zinc concentrations, compared to background concentrations (fig. 38), is similar to the distributions of lead and nickel (figs. 36 and 37). Samples from wells 28B and 114B, located in area ID (fig. 19), consistently had the maximum zinc concentrations measured in the Canal Creek aquifer during all sampling periods (Appendixes B1, B3, and B5). During the second sampling period, zinc concentrations were 3.1 and 1.4 mg/L in the samples from wells 114B and 28B, respectively. No other sample from the Canal Creek aquifer (except the sample from well 136B) had a zinc concentration greater than 1.0 mg/L (fig. 38).

The maximum copper concentrations observed in samples from background or uncontaminated wells during the second sampling period were 0.003 mg/L in the Canal Creek aquifer, 0.004 mg/L in the surficial aquifer, and 0.017 mg/L in the lower confined aquifer (tables 15 to 17). Thus, a concentration of 0.020 mg/L is probably conservative to use for the maximum background copper concentration. Elevated concentrations (fig. 39) were not as widespread for copper as for lead, nickel, and zinc (figs. 36 to 38) but were observed at some of the same sites in Region I in the Canal Creek aquifer. Unlike nickel and zinc, elevated copper concentrations were not observed in ground water in Region II or at Beach Point in Region III (figs. 19 and 39).

Copper concentrations were elevated above background concentrations in samples from sites 107, 18, 13, and 30 in areas IB and IC and from site 28 in area ID during the second sampling period (figs. 19 and 39). Samples from these five sites had elevated copper concentrations consistently during all four sampling periods; samples from nearby sites, including sites 118 and 27, occasionally had elevated copper concentrations (Appendixes B1, B3, and B5). Replicate samples collected from well 28A during the second sampling period had copper concentrations of 0.18 and 0.19 mg/L; these concentrations in samples from well 28A are an order of magnitude greater than background concentrations and were the maximum concentrations measured in the ground water.

Thallium

Thallium was determined only for samples collected during the third and fourth sampling periods. The reported detection limits for thallium (0.044-0.045 mg/L) are much greater than the MCL of 0.002 mg/L (table 11); thus, any detected thallium concentrations exceed the MCL.

During the third sampling period, samples from wells 1B and 102B had thallium concentrations of 0.18 and 0.057 mg/L, respectively (table 18). A replicate sample collected at well 1B did not have detectable thallium (Appendix B3); however, samples from well 1B and 102B had elevated concentrations again during the fourth sampling period. Samples from an additional six wells had thallium concentrations above the MCL during the fourth sampling period (table 18).

Of the eight samples that had thallium concentrations above the MCL during the fourth sampling period, five were from contaminated sites in the Canal Creek aquifer (1B, 7B, 8B, 102B, and 117A) and three were from background wells (11A, 136A, 136B). Thallium concentrations in these eight samples ranged from 0.045 to 0.067 mg/L and were only slightly above the detection limit. Thus, confidence in these analytical results is low. Most of the samples that had thallium concentrations exceeding the MCL were from wells in contaminated areas IIA and IIB (fig. 19). During the fourth sampling period, the maximum thallium concentration (0.067 mg/L) was detected in the sample from well 117A, which is in area IIB.

Probable Sources

The 11 minor constituents that were detected in concentrations exceeding Federal drinking-water regulations (fig. 33, table 18) could originate from natural or anthropogenic sources in the Canal Creek area. The particular sites at which minor constituents were present in excessive concentrations in the ground water were often different between each of the four sampling periods. This variability in concentrations could be caused by several factors, including changes in ground-water chemistry and reported detection limits (table 4) between the four sampling periods and low reproducibility of the determinations near the detection limits. Factors such as pH and dissolved-oxygen concentrations varied at individual sites among the four sampling periods (Appendixes B1 to B6) and would affect the solubility of many of the minor constituents. In addition, different wells were sampled during each period, and analyses were not done for all the inorganic constituents on each sampling run.

Despite these variabilities, excessive concentrations of many of the minor inorganic constituents were measured during two or more sampling periods at the same sites. For some of the minor constituents, the distribution of excessive concentrations does not appear to be random but instead appears to be associated with one or more of the defined contaminated areas (fig. 19). Probable sources for each of the minor inorganic constituents detected in excessive concentrations in the ground water are discussed here.

Manganese

Manganese distribution in samples collected from contaminated and uncontaminated sites (fig. 33) indicates that concentrations above the SMCL are derived mainly from a natural source. Manganese can substitute for iron, magnesium, or calcium in the silicate minerals that are abundant in the Coastal Plain sediments of the Canal Creek area. Manganese and iron commonly are present in oxide coatings on sediments and can be dissolved as pH and redox conditions change in ground water (Hem, 1985, p. 85). Analyses of sediments from the confining units and aquifers in the Canal Creek area show that manganese concentrations in the sediments range from 8 to 170 ppm (Appendix A5).

Fluoride, beryllium, and mercury

Fluoride and beryllium were detected in concentrations that exceed Federal drinking-water regulations only in samples collected during the first sampling period. Probable sources for fluoride, but not for beryllium, are discussed in Lorah and Vroblesky (1989, p. 49-52). No reference to the use of beryllium could be found in historical information on activities in the Canal Creek area. Beryllium is used in copper alloys to strengthen and stiffen the copper for use in electrical equipment and some machinery (Rochow, 1977, p. 49; Lucius and others, 1989, p. 142). Thus, activities at the machine and metal plating shops (fig. 13) could have been a source of beryllium. Well 19B, where the excessive concentration of beryllium in ground water was detected, is about 200 ft north of three buildings that were used as machine shops in the past (fig. 13).

Mercury concentrations exceeded the MCL of 0.002 mg/L in samples from only two wells throughout this study--wells 17C and 120A. Mercury was detected only once in excessive concentrations at these two wells and was not detected in replicate samples collected at 120A. The unconfirmed detections indicate that laboratory contamination or analytical error account for the excessive mercury concentrations. Some possible anthropogenic sources of mercury are also discussed in Lorah and Vroblesky (1989, p. 50).

Aluminum

Aluminum, which was determined in samples from the third and fourth sampling periods with reported detection limits between 0.16 and 0.18 mg/L (table 4), was measured in concentrations above the SMCL's of 0.050 and 0.20 mg/L in samples from 16 to 52 wells (table 18, fig. 34). Aluminum is abundant in the silicate minerals illite, kaolinite, montmorillonite, plagioclase, and potassium feldspar that were identified in sediment samples from the confining units and aquifers in the Canal Creek area (Appendix A4). Of the minor inorganic constituents determined in the sediment samples, aluminum commonly was present at the highest concentrations (0.27 to 16 percent) (Appendix A5). Despite its abundance in the Earth's crust, aluminum rarely occurs in solution in natural water in concentrations greater than a few tenths or hundredths of a milligram per liter (Hem, 1985, p. 73). Aluminum concentrations greater than 1.0 mg/L in water could sometimes be caused by the presence of natural polymeric colloidal material that can pass through most filter sizes commonly used (Hem, 1985, p.75). In ground water in the Canal Creek area, aluminum concentrations were as high as 29 mg/L, although a filter pore size of 0.1 µm was used instead of the more common 0.45 µm. These extremely high concentrations indicate that an anthropogenic source, in addition to natural sources, exists for aluminum in the Canal Creek area.

The highest aluminum concentrations in ground water in the Canal Creek area (14 and 29 mg/L) were measured in samples from well 28A, which is screened in the Canal Creek aquifer in contaminated area ID. Samples from other well sites near site 28 in area ID also had excessive aluminum concentrations (figs. 19 and 34). Anhydrous aluminum chloride, which is a solid, was used as a catalyst in the manufacturing process for CN (Nemeth, 1989, p. 41-46), and the most likely source of aluminum in area ID is the manufacturing of CN in building 58 (fig. 13) during WW2. Typically, about 2,130 lb of aluminum chloride were required to produce 1 ton of CN; the plant in building 58 produced more than 750 tons of CN. Wastewater contained aluminum salts, and sludges generated as waste were reported to consist mostly of aluminum oxide mixed with benzene and CN. To produce CN, purified chloracetylchloride was reacted with excess benzene, aluminum chloride was used as a catalyst. This mixture was then immersed in water to separate the CN and benzene solution from the aluminum sludge. Separation from the sludge sometimes was not possible because of the formation of emulsions, and the entire batch was then discharged as waste (Nemeth, 1989, p. 41-46). Sludge was probably dumped in the marshes near site 28. Wastewater was discharged through a sewer that extended southward from the building to the West Branch Canal Creek (fig. 14) and was later found to leak. In addition, spills could have occurred from drums of aluminum chloride that were stored in and around the plant.

Other manufacturing processes that took place in area ID also used aluminum chloride or aluminum oxide as catalysts, including manufacturing of chloropicrin and ethylene in building 103 and lewisite in the experimental plants area (fig. 13). CN manufacturing, however, probably used the most raw materials and generated the most waste.

Filling of incendiary, pyrotechnic, and smoke munitions are another probable source of aluminum in the Canal Creek area. Thermite, which contains approximately 27 percent fine granular aluminum (U.S. Departments of the Army and Air Force, 1975, p. 33), was used in incendiary mixtures during WW1 and WW2 (Nemeth, 1989, p. 131-136). Building 99 (fig. 13) was constructed during WW1 and was used from WW1 through the 1930's to fill incendiary bombs. Not much incendiary bomb filling took place during WW2 at APG. After WW2, a variety of experimental filling operations were done in building 99, including triethyl aluminum filling in the late 1960's through the early 1970's. Filling operations in this building could be a source of aluminum in the ground water in contaminated areas IA, IB, and IC, where samples collected at most of the well sites had aluminum concentrations exceeding the SMCL (figs. 19 and 34). In addition, thermite washout, or deactivation, took place in building 84 in the 1940's and 1950's and could be a source of aluminum in area IC (Nemeth, 1989, p. 897).

Activities with incendiary and smoke mixtures in the building 503 area (fig. 13) are a likely source of aluminum in ground water in areas IIA and IIB. Building 503, which is near well site 36, was first used for incendiary filling in 1942 and then was remodeled as a smoke filling unit, called the smoke pot plant (Nemeth, 1989, p. 880-884). The building 503 smoke pot plant consisted of building 503 and smaller surrounding buildings that were used for operations related to filling, such as preparation, storage, drying, and mixing of smoke and incendiary mixtures. A smoke mixture referred to as Type C HC was first developed during WW2 and has been the most commonly used smoke mixture since that time (Nemeth, 1989, p. 806). Type C HC mixture contains approximately 6.7 percent granular aluminum (U.S. Departments of the Army and Air Force, 1975, p. 3-36). After WW2, the building 503 area continued to be used for filling of smoke and incendiary munitions and for blending of experimental smoke mixtures (table 1); the research and development work continued through at least 1989 (Nemeth, 1989, p. 880-884).

Smoke mixtures were burned east of building 503 for testing and disposal purposes from WW2 until 1975 (Nemeth, 1989, p. 805-811) (fig. 13). Residue from burning smoke mixtures could have included aluminum oxide. Because the upper confining unit is not present in the area around building 503, contaminants could easily enter the Canal Creek aquifer in area IIA. Contaminants entering the Canal Creek aquifer near site 36 could have moved into area IIB when the former water-supply wells were pumped (fig. 21). In addition, dust and ash containing aluminum could have been transported to other sites by way of the atmosphere.

Testing and research and development with pyrotechnics also took place at Beach Point (fig. 13) near site 33 after WW2 until the 1970's (Nemeth, 1989, p. 734). Aluminum concentrations as high as 4.0 mg/L were measured in the ground water at site 33 during the fourth sampling period (fig. 34).

Another possible source of aluminum in areas IIA and IIB is the clothing-impregnating plant (building 73) that operated near site 133 in 1942 (figs. 13 and 34). The solvent-recovery system at the plant was constructed of aluminum and was known to have rapidly corroded. Failure of the solvent-recovery system caused the release of large amounts of solvent to the sewer that discharged to the East Branch Canal Creek. This plant is believed to be a large source of the organic contamination in areas IIA and IIB (Lorah and Vroblesky, 1989, p. 68), and it is possible that high aluminum concentrations from corrosion of aluminum pipes and tanks were associated with the wastes.

Antimony

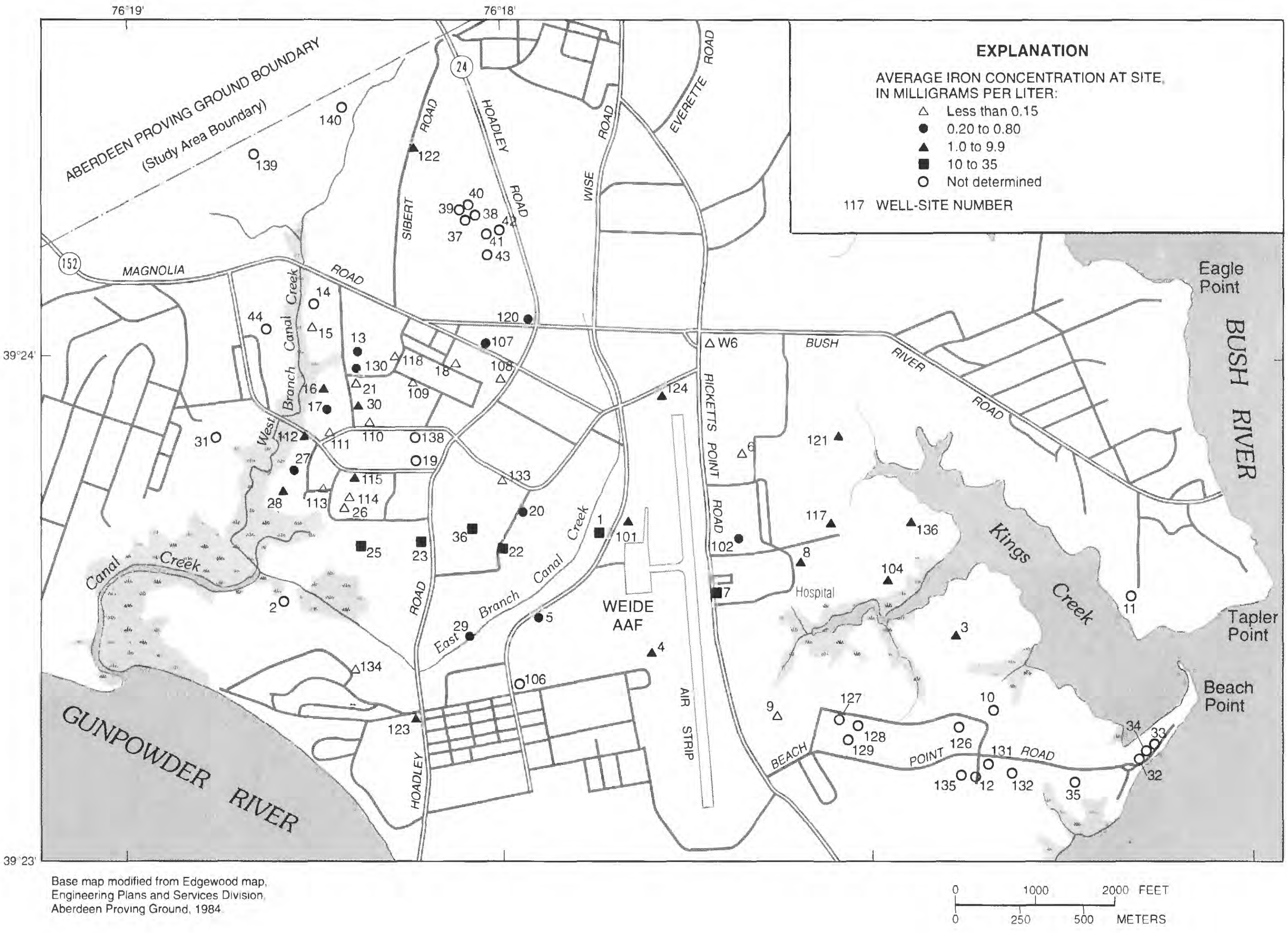
Antimony concentrations that exceed the MCL of 0.006 mg/L were measured mostly at well sites in areas IIA and IIB in the Canal Creek aquifer and also in the surficial aquifer in the semiconfined area IIA (table 18, fig. 19). Only one reference to antimony use in historical activities in the Edgewood area was found--antimony or ferric chloride could have been added to sulfur monochloride before it was used in producing mustard (Nemeth, 1989, p. 38). Even if antimony was used in mustard manufacturing, an effect on ground water in Region II is not likely because mustard manufacturing took place near the West Branch Canal Creek in and near the experimental plants area (fig. 13).

The maximum antimony concentration (0.012 mg/L) was present in a sample from well 36B, near the building 503 complex. Although antimony is not specifically mentioned as a component of the pyrotechnic and smoke mixtures used in this filling and research plant, antimony could have been a component of some experimental mixtures or an impurity associated with other metals that were widely used, including ferric and zinc oxides. The fact that antimony concentrations exceeded the MCL at well 12A.1, which is near another pyrotechnic plant (fig. 13), supports the hypothesis that antimony could be derived from pyrotechnic materials.

Iron distribution in the Canal Creek aquifer (fig. 40) indicates that a relation could exist between high iron concentrations and excessive antimony concentrations. The highest average iron concentrations were observed in the Canal Creek aquifer in Region II, not Region I (fig. 40). At many of these sites in Region II where iron concentrations were high, the MCL for antimony was exceeded, including sites 36, 1, 7, 22, 23 (fig. 40, table 18). During the second sampling period, the maximum iron concentration (51 mg/L) in the Canal Creek aquifer was observed in the sample from well 36B, which also contained the maximum antimony concentration. All of the samples collected from the Canal Creek aquifer that had excessive antimony concentrations also had iron concentrations greater than 10 mg/L (fig. 40).

Dissolved-iron concentrations are higher in the Canal Creek aquifer in areas IIA and IIB than in contaminated areas in Region I because the aquifer generally had the lowest dissolved-oxygen concentrations (less than 0.1 to 0.5 mg/L) in areas IIA and IIB (fig. 25). Iron, which is probably largely present in oxide coatings on the aquifer sediments, is more soluble and mobile under reducing conditions. Iron reduction is often microbially mediated, either indirectly or directly through enzymatic reduction by microorganisms (Lovley and others, 1991). Bacteria that can use iron as an alternate electron acceptor during the decomposition of organic contaminants can release reduced iron and other metals associated with the iron into solution (Francis and Dodge, 1990; Lovley and others, 1991). Thus, microbial activity in the contaminated anoxic ground water of Region II could help to increase the concentrations of dissolved iron and associated trace metals, such as antimony.

At least two explanations are possible for the apparent association between high antimony and iron concentrations: (1) antimony is naturally present in iron oxide coatings and minerals in the aquifer sediments, and it can reach concentrations higher than background in the ground water when the oxide coatings are dissolved under reducing conditions, and (2) antimony migrated into the ground water from an anthropogenic source, and its mobility in water is controlled by the mobility of iron in



Base map modified from Edgewood map,
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Figure 40. Distribution of iron in the Canal Creek aquifer, second sampling period (July-September 1988).

water. Although the ground-water-chemical data for the Canal Creek area indicates that antimony mobility is at least partially controlled by iron mobility, the data are not sufficient to define whether antimony is derived from a natural source, an anthropogenic source, or both.

Antimony was not determined in the aquifer sediments collected in the Canal Creek area, but the average composition in sandstones is 0.014 ppm (Hem, 1985, p. 6). The concentration of antimony in natural waters, although only rarely determined, is expected to be very low (Hem, 1985, p. 145). Iron oxides are known to scavenge trace metals, including arsenic, cobalt, nickel, copper, zinc, cadmium, and lead, through sorption or coprecipitation (Drever, 1988, p. 342-343; Buckley, 1989). In a study of the Coeur d'Alene River in northern Idaho (a river contaminated with various heavy metals from mining wastes), antimony and arsenic mobilities were controlled by coprecipitation with iron and manganese oxides and by subsequent dissolution of the oxides under reducing conditions in the bottom sediments (Mok and Wai, 1990). A relation between manganese and antimony concentrations was not observed in the Canal Creek area.

Arsenic

Arsenic concentrations exceeded the MCL of 0.05 mg/L in samples from wells 1A and 1B during the course of this study and were consistently above background concentrations (less than 0.003 mg/L) at well sites 1, 36, 23, and 25 in the Canal Creek aquifer (fig. 35). Sites 1, 36, and 23 are in area IIA, and site 25 is near site 23 in area ID (fig. 19).

Arsenic distribution is similar to the antimony distribution and also shows a relation to iron distribution. Arsenic solubility is largely controlled by redox processes and sorption/desorption or coprecipitation processes with metal oxides (Hem, 1985, p. 144; Seyler and Martin, 1989; Mok and Wai, 1990; Vroblesky and others, 1989, p. 60-61). Iron oxides have been shown to have a higher sorptive capacity for arsenic than for aluminum or manganese oxides. Thus, reduction of iron oxides and mobilization of iron in the anoxic region of the Canal Creek aquifer in area IIA could release arsenic into solution. Reduced forms of arsenic are more mobile and more toxic than oxidized forms (Vroblesky and others, 1989, p. 60). If redox conditions become sufficiently anoxic to allow sulfide formation, reduced arsenic and iron sulfide could subsequently coprecipitate, forming arsenopyrite (FeAsS) (Seyler and Martin, 1989, p. 1262). The lower concentrations of iron and arsenic in area IIB compared to those concentrations in area IIA could result from arsenopyrite precipitation.

As previously discussed for antimony, arsenic could result from a natural or anthropogenic source. Sandstones typically contain more arsenic (average composition, 1.0 ppm) than antimony (Hem, 1985, p. 6). Most of the samples of aquifer sediments in the Canal Creek area had arsenic concentrations of less than 10 ppm (Appendix A5). A maximum concentration of 30 ppm, however, was observed in a sediment sample collected from the Canal Creek aquifer at site 1, which is also the site where arsenic concentrations in water from the surficial and Canal Creek aquifers exceeded the MCL. This correspondence indicates that at least part of the arsenic present in the ground water and aquifer sediments is from an anthropogenic source. Unlike antimony, arsenic is known to have been present in compounds used and produced in the Canal Creek area.

Wastes from the manufacture and filling of munitions with arsenicals is the most probable anthropogenic source of arsenic in the Canal Creek area. Much of the pilot-scale manufacturing and research and development work that took place between 1920 and 1941 was with arsenical compounds, including lewisite, adamsite, diphenylchloroarsine, and methyldichloroarsine (Nemeth, 1989, p. 73). Arsenic trichloride, the raw material used in the production of many arsenic-containing chemical agents, was also produced. A total of about 16,600 lb of arsenic trichloride is known to have been produced during 1920-25, and more was produced at later dates to support manufacturing of the arsenicals (Nemeth, 1989, p. 74-75).

Manufacturing of these arsenic compounds resulted in wastewater and sludges containing arsenic. The agents adamsite and lewisite were produced in the largest quantities of all the arsenicals. During 1921-35, approximately 19,000 lb of adamsite was produced. About 1,800 lb of lewisite was produced in 1925 (Nemeth, 1989, p. 82), and more than 500,000 lb was probably produced during 1940-43 (Nemeth, 1989, p. 827). During lewisite production, which was a very inefficient process, as much as two-thirds of the arsenic trichloride used could be lost with the waste products (Nemeth, 1989, p. 82). Large amounts of sludge that consisted mainly of arsenic trioxide were formed as wastes.

Arsenical manufacturing and research took place mainly in the experimental plants area, which was located near well site 25 and is probably the source of elevated arsenic (compared to background concentrations) in the ground water at this site (figs. 13 and 35). Wastewater from buildings in the experimental-plants area was transported through open sewer ditches and closed sewers to the nearby Canal Creek (fig. 14), and sludge was most likely disposed of in the nearby marsh. In addition, wastes from spills and leaking storage containers could have released arsenic around the buildings.

Filling of munitions with arsenicals could be a source of arsenic in area IIA. Three filling plants were previously located in this area (fig. 13). The second and third filling units were built in WW1 and were designed to handle all toxic chemicals including mustard, whereas the first filling unit was designed to handle all toxic chemicals used in WW1 except mustard (Nemeth, 1989, p. 122). Building 503, which is near site 36 (figs. 13 and 35), was constructed adjacent to the second filling unit and could have originally been considered a part of that filling plant. Besides the production-scale munition filling during WW1 and WW2, small-scale filling was done in support of research and development work in the period between WW1 and WW2. One of the sewer-discharge points from the first and third filling units was near site 1 (figs. 2 and 14), where the highest arsenic concentrations were observed in the ground water. In addition, site 1 is in an area along the East Branch Canal Creek where landfilling took place. Arsenicals could have been disposed of in this landfill area.

Operations at the smoke pot plant in the building 503 area during the 1960's and 1970's are known to have included the use of the arsenical adamsite (Nemeth, 1989, p. 882). In addition, arsenic could have been a component or impurity in experimental smoke mixtures that were blended, tested, and disposed of in the building 503 area. Colored smoke mixtures were used (Nemeth, 1989, p. 882), and arsenic compounds have been used in pigment production (Lucius and others, 1989, p. 119). Throughout this study, arsenic concentrations in samples from site 36 were among the highest observed in the Canal Creek aquifer (fig. 35; Appendixes B1, B3, and B5).

Cadmium

Excessive cadmium concentrations were detected in samples from a varying number of wells during the course of this study (table 18), but the excessive concentrations were confirmed only in samples from wells 114B, 36B, and 36C. The dissolved-cadmium concentrations in the ground water at these three sites are most likely derived from an anthropogenic source, not a natural source.

The machine shops that operated in several buildings near site 114, including the building 101 complex, building 103, and building 88 (fig. 13), are a likely anthropogenic source of cadmium. Metal shavings commonly were placed in piles outside the buildings (Nemeth, 1989, p. 838), and cadmium was used in metal plating. The three machine shops were most active during WW2 in the manufacturing of metal parts for munitions. Metal-plating wastes are the most probable source of the excessive cadmium concentrations measured in the Canal Creek aquifer at well site 114 and also of the excessive concentrations detected on one sampling trip at other sites within area ID, including sites 27, 113, 115, and 26 (table 18, fig. 19).

The excessive cadmium concentrations in the Canal Creek aquifer at site 36 are probably the result of activities that took place in the building 503 complex. Trace amounts of cadmium chlorides have been measured in solid residue left from the burning of smoke mixtures outside the building 503 complex immediately west of site 36 (figs. 2 and 13). Cadmium was probably an impurity in the zinc oxide used as a major ingredient in HC smoke mixtures (Nemeth, 1989, p. 806). Zinc concentrations were above background concentrations in ground water at site 36 (fig. 38). Cadmium could have leached into the ground water as rainwater infiltrated through soils contaminated with cadmium from burning residues or spills of zinc oxide.

Lead, nickel, zinc, and copper

Lead, nickel, and zinc were measured in elevated (compared to background concentrations) or excessive concentrations (compared to Federal drinking-water regulations) in the ground water at the same sites; the sites include all or most of the sites in regions IA and IB, site 28 in ID, sites 102 and 8 in IIB, and site 33 in IIID (fig. 19 and figs. 36-38). Copper was also detected in elevated concentrations in area IB and at site 28 in area ID (figs. 19 and 39). The apparent association between high concentrations of lead, nickel, zinc, and copper could indicate that (1) these constituents are derived from the same or similar natural or anthropogenic sources, (2) the mobility of these constituents is controlled by similar geochemical factors, or (3) concentrations are derived from a combination of similar sources and mobility controls.

All four constituents occur naturally in the aquifer sediments and in the clay and silt of the confining units in the Canal Creek area (Appendix A5). The confining-unit sediments have much higher concentrations of these constituents than the sand samples from the aquifers. Much of the lead, nickel, zinc, and copper present in the aquifer sediments is likely associated with iron and manganese oxide minerals and coatings; clay- to silt-sized particles; and natural, solid organic matter, such as lignite. Trace metals are known to have a strong affinity for organic matter in soils and aquatic sediments. The sequence of affinities that has been found for organic matter is, in descending order, lead, copper, nickel, cobalt, zinc, cadmium, iron, manganese, and magnesium (Horowitz, 1985, p. 34-35). An empirical affinity sequence for some heavy metals to clay minerals is, in descending order, lead, nickel, copper, and zinc (Horowitz, 1985, p.34).

Although a natural source probably exists for lead, nickel, copper, and zinc in ground water of the Canal Creek area, the grouping of elevated concentrations of these constituents in certain contaminated areas or sites indicates that geochemical characteristics associated with the contaminant plumes cause an increase in their solubility above background concentrations or that there is also an anthropogenic source. In Region II where the contaminated ground water is generally anoxic and contains high dissolved-iron concentrations, elevated metal concentrations could be associated with the reduction and dissolution of iron oxide coatings and minerals. However, the high dissolved-oxygen and low iron concentrations in Region I (figs. 25 and 40) indicate that anoxic conditions could not be a cause of high metal concentrations in this region. Samples from contaminated ground water in area IB and at sites 28 and 33 (fig. 19) were the only samples to contain dissolved-solids and chloride concentrations exceeding their SMCL's. In brackish water, nickel, lead, zinc, and copper can form soluble chloride complexes that are highly mobile (Krauskopf, 1979, p. 417; Pucci and others, 1989). Thus, the formation of chloride complexes could result in the elevated metal concentrations in area IB and sites 28 and 33.

Except for water at site 16, the ground water in area IC, which is directly downgradient of IB, did not contain elevated chloride or elevated lead, nickel, zinc, or copper concentrations. The abrupt decrease in nickel, lead, zinc, and copper concentrations seen in this area of low dissolved-chloride concentration indicates that chloride complexes could play a large role in mobilizing trace metals in area IB, whether the trace metals are derived from a natural source or from an anthropogenic source. Coprecipitation with iron and manganese oxides is probably removing the trace metals from solution in area IC as their solubility decreases.

Ground water in area IA did not contain elevated chloride concentrations, but the four trace metals were observed in elevated concentrations. The metal solubility in area IA perhaps is increased because of the formation of dissolved organometallic complexes in the ground water (Drever, 1988, p. 332; Pucci and others, 1989). The ground water in area IA had some of the highest concentrations of organic contaminants observed in the Canal Creek area; the average concentrations of TOH in samples from sites 120 and 108 in area IA were 3 or more times greater than the average concentrations at sites in areas IB and IC.

Probable anthropogenic sources of lead, nickel, zinc, and copper in the Canal Creek area include the use of zinc oxide and zinc chloride in smoke mixtures and some manufacturing processes, machine-shop and metal-plating wastes, and leaching from reaction vessels and pipes in the manufacturing plants. Samples from wells 28A and 36B had the maximum lead concentrations throughout this study; thus, an anthropogenic source of lead is strongly indicated at wells 28A and 36B.

Zinc chloride was used in large amounts for CN manufacturing in building 58 near well site 28, and lead could have been an impurity in the zinc chloride. More than 2,200 lb of zinc chloride was needed to manufacture the amount of CN produced by the plant in building 58 (Nemeth, 1989, p. 42). Zinc chloride, along with other raw materials and the final products, was stored in drums in open areas around the plant, and sludges that were generated as wastes were probably disposed of in the marsh near site 28. Aluminum, which was probably derived from the use of aluminum chloride in CN manufacturing, was a major component of the sludges and was also detected in elevated concentrations in the ground water at this site.

Chloropicrin, which was used to make the CN mixture CNS, commonly contained lead as an impurity (Nemeth, 1989, p. 27). CNS consists of about 38 percent chloropicrin, and the total WW2 production of CNS in building 58 was about 3,258,500 lb (Nemeth, 1989, p. 43-46). In addition, the reaction vessels, stills, and pipes used in the CN plant were lead lined, and wastes probably contained small amounts of lead (Nemeth, 1989, p. 42). Lead and copper also were components of wastewater generated by chlorine manufacturing that took place until 1968 in the WW2 chlorine plant (fig. 13) near site 28 (Nemeth, 1989, p. 13). The elevated lead, nickel, zinc, and copper concentrations observed in the ground water at site 28 could also have resulted from alloys used in the machine shops and from metal-plating wastes.

Activities with smoke mixtures in the building 503 complex are the most likely source of the elevated zinc, lead, and cadmium that were measured in the Canal Creek aquifer at well site 36. Lead is known to be an impurity in the zinc oxide that was a major component of the various HC smoke mixtures. HC smoke mixtures have been used in pyrotechnic and smoke munitions from the mid-1920's until the present. Type C HC smoke mixture consists of approximately 46.7 percent zinc oxide (U.S. Departments of the Army and Air Force, 1975, p. 36). Lead and cadmium have been detected in trace amounts in the residue left from burning smoke mixtures (Nemeth, 1989, p. 806). Rainwater infiltrating through soils contaminated with metals from burning residues or spills of zinc oxide could transport the metals into the Canal Creek aquifer at well site 36.

Probable anthropogenic sources of lead, nickel, zinc, and copper in contaminated areas IA and IB include filling operations in building 99 and activities in the machine and metal-plating shop in building 60 (fig. 13; table 1). Although no specific reference could be found to the use of these four metals in the filling plants in areas IA and IB, these metals could have been used directly or could have been present as impurities in other materials. Most of the experimental work in the building 99 filling plant involved pilot studies of the WP filling process, but many other filling materials also were used (Nemeth, 1989, p. 901). Various metal oxides were ingredients in experimental incendiary mixtures made between WW1 and WW2 (Nemeth, 1989, p. 132).

Nickel and copper have been used in metal plating, and all four of the metals are common constituents in alloys. From the mid-1960's until 1975, building 60 was used for raw-material machining, plating, and other production-type shop activities (Nemeth, 1989, p. 894). A chemical sewer, which also served building 90, discharged to a ditch about 500 ft west of building 60 and carried wastewater to the West Branch Canal Creek (fig. 14). The chemical sewer later included a concrete neutralization sump that was adjacent to the north side of building 60 near well site 18. This sump was constructed to receive wastewater from metal-plating operations (Nemeth, 1989, p. 895). Trace metals from filling or machine-shop wastes could have been transported to ground water in areas IA and IB through several routes that include leaking sewer systems, overflowing or leaky sumps, infiltrating rainwater through contaminated soils in recharge areas (fig. 9), and direct flow of contaminated wastewater into the Canal Creek aquifer in areas where the upper confining unit is thin or absent (fig. 6).

The elevated or excessive concentrations of zinc, nickel, and lead that were measured in ground water in Region IIB, especially at sites 102 and 8, could have resulted from clothing-impregnating operations in building 73 during 1942. During WW2, experiments were conducted with a water-suspension process that involved addition of zinc oxide to the impregnating material to protect the impregnite from acids in body perspiration. Although the clothing-impregnating plant in building 73 primarily used a solvent process that did not permit addition of zinc oxide, the plant did experiment with the water-suspension process for 19 days. Approximately 100,000 lb of clothing was impregnated during the 19 days, requiring the use of about 1,230 lb of zinc oxide (Nemeth, 1989, p. 60). Lead is known to be an impurity in zinc oxide, and other metals also could be present. Wastes from building 73 were discharged through the sewer to the East Branch Canal Creek near site 1 (fig. 14), where the upper confining unit is absent and the surficial and Canal Creek aquifers are connected. Heavy pumping of the standby water-supply wells during this period caused the ground water to flow eastward toward sites 8 and 102 (figs. 19 and 21).

Clothing impregnating also occurred at Beach Point near site 33 in area IIID and could account for the elevated zinc, nickel, and lead concentrations measured in the surficial aquifer at site 33. Two mobile impregnating plants, one for the solvent-suspension process and one for the water-suspension process that used zinc oxide, were operated at Beach Point in 1943 for about 1,000 hours (Nemeth, 1989, p. 56-57). A semipermanent clothing-impregnating plant that used the water-suspension process was then set up at Beach Point and operated until at least 1947 (Nemeth, 1989, p. 731). The plant was adjacent to site 33; waste-disposal practices are unknown for this plant. Wastes from the mobile plants were discharged to open pits dug several feet deep next to the laboratories, where the wastes could easily migrate into the surficial aquifer. In addition to zinc, nickel, and lead, organic solvents associated with the clothing-impregnating tests were measured in the ground water at site 33.

Another possible source of the trace metal contamination in ground water at Beach Point is the pyrotechnic materials that were tested outside of and in buildings after WW2 until about 1970. Most of the outside tests and all of the inside tests were done at the extreme southern end of Beach Point (fig. 13) (Nemeth, 1989, p. 734). Thus, the clothing impregnating-operations at Beach Point are a more likely source of the trace metals than pyrotechnic testing.

The PVC casings that were used to construct the observation wells could cause increased lead concentrations in well-water samples. Lead and cadmium have both been shown to leach from PVC casings in laboratory experiments (Hewitt, 1989; Parker and others, 1990). However, the leached lead and cadmium were resorbed onto the casing with time during an exposure period of as long as 40 days. Thus, the overall effect of PVC casings on metal concentrations is believed to be small (Hewitt, 1989).

Thallium

Thallium concentrations that exceeded the MCL were measured in samples from a total of five wells in the Canal Creek aquifer in contaminated areas IIA and IIB and in samples from three background wells in the Canal Creek aquifer. The excessive thallium concentrations in samples from the three background wells indicate that thallium could be derived from a natural source or from analytical errors. The thallium concentrations commonly were not much greater than the detection limit (0.044-0.045 mg/L); thus, confidence in the reported concentrations is low.

Thallium was detected in sediment samples collected from the confining units in the Canal Creek area in concentrations ranging from 9 to 20 ppm (Appendix A5); most of the sediment samples from the aquifers had thallium concentrations of less than 4 ppm, but one sample had a concentration of 7 ppm. In aqueous solution, thallium is more stable in reduced form and resembles iron in behavior by forming a brown oxide precipitate, Tl_2O_3, under oxidizing conditions (Rochow, 1977, p. 134). Thallium concentrations could be relatively high in ground water in areas IIA and IIB because thallium that dissolves from the aquifer sediments would be stable in the anoxic conditions present in these two areas (fig. 25).

No reference could be found to the use of thallium in historical activities in the Canal Creek area. However, thallium could have been an impurity in other materials, such as zinc oxide. Lead is an impurity in zinc oxide, which was used for various activities in the Canal Creek area, and thallium is a heavy metal similar to lead (Rochow, 1977, p. 134). Thallium is concentrated in sulfide ores along with lead and other metals (Krauskopf, 1979, p. 470 and 479).

Organic Constituents

As mentioned previously, the organic groundwater chemistry in the Canal Creek area was characterized primarily by non-compound-specific analyses for TOH and total phenols and by analyses for specific volatile and semivolatile organic compounds (tables 5 and 6). The division between volatile and semivolatile compounds is based on the analytical technique used. Halogenated VOC's that are common industrial solvents are the major contaminants observed in ground water of the Canal Creek area, and TOH is used to describe the overall distribution of contamination. Organic contaminants were detected in the Canal Creek and surficial aquifers, but the contamination is most widespread in the Canal Creek aquifer. Low concentrations of organic compounds that were sporadically detected in some samples from the lower confined aquifer are most likely caused by laboratory contamination.

The total number of wells sampled for organic consituents include 87 wells during the first sampling period (Lorah and Vroblesky, 1989), 122 wells during the second sampling period, 80 wells during the third sampling period, and 73 wells during the fourth sampling period (table 3). The chemical data for TOH, total phenols, and quantitated VOC's for the last three sampling periods are presented in Appendixes B2, B4, and B6 at the end of the report.

TOH concentrations calculated from the quantitated concentrations of individual VOC's agreed fairly closely with the TOH concentrations measured during the first sampling period (Lorah and Vroblesky, 1989); thus, TOH concentrations for samples collected during the second sampling period were calculated rather than measured analytically (Appendix B2). TOH was measured analytically for samples collected during the last two sampling periods (Appendixes B4 and B6). Total phenols were determined only for samples collected during the third sampling period (Appendix B4). TOC, a non-compound-specific measurement of dissolved and particulate carbon attributed to organic substances, also was determined but is not discussed in this report (Appendixes B4 and B6). TOC was not a good indicator of organic contamination in ground water of the Canal Creek area because the volatile organic fraction is lost from the sample during sample preparation and analysis.

Other organic chemical data presented in tables throughout this section of the report include quantitated semivolatile organic compounds, tentatively identified organic compounds (TIOC's) and unknown compounds reported during GC/MS library search of volatile and semivolatile compounds, and quality-control data. Concentrations of TIOC's and unknowns are estimated because they are not quantitated by comparison to standards of known concentrations. Volatile and semivolatile compounds for which quantitative analyses were done are listed in tables 5 and 6 in the Methods section. The distribution of organic contamination is described mainly by use of the chemical data from the second sampling period, as was done for the inorganic constituents.

Total Organic Halogen and Total Phenols

Distribution

The approximate distribution of TOH in the Canal Creek aquifer is shown in figures 41 and 42, which divide the study area into Region I and Region II. TOH distribution did not change significantly during the course of this study. The TOH concentrations observed during the second sampling period in all the wells screened in the Canal Creek aquifer at a site were averaged (figs. 41 and 42). For example, the TOH concentrations in samples from wells 1B and 1C, which are screened in the Canal Creek aquifer in Region II (table 2; fig. 19), were averaged; the average was used as the TOH concentration in the Canal Creek aquifer at this site (fig. 42).

In Region I, TOH distribution indicates that contamination is widespread in the Canal Creek aquifer along the middle reach of the West Branch Canal Creek (fig. 41). The highest TOH concentrations in Region I (more than 3,000 µg/L) were measured in ground water at sites 120 and 108 in area IA (figs. 19 and 41). The extent of contamination to the north and west of these two sites in area IA cannot be defined because of the lack of observation wells in this area. TOH concentrations equaled or were greater than 1,000 µg/L in two areas adjacent to the West Branch Canal Creek--in area IC at several well sites surrounding the pilot plant and in area ID at site 27 (figs. 19 and 41).

Two smaller and hydrologically unconnected areas of ground-water contamination were found north of contaminated areas IA-D. Samples from wells at site 14 near the West Branch Canal Creek had a low average TOH concentration of 18 µg/L during the second sampling period (figs. 19 and 41). Relatively high average TOH concentrations (410 µg/L) were observed in samples from wells at site 39 in the salvage yard (figs. 19 and 41). Low TOH concentrations (33 µg/L or less) were observed at a few of the surrounding well sites in the salvage yard during the first sampling period; however, only site 39, where samples had TOH concentrations that were an order of magnitude higher than those detected at surrounding sites, was sampled during the second sampling period.

TOH distribution in Region II (fig. 42) shows a large contaminated area that trends to the east in the center of the region and a smaller contaminated area that seems to trend to the southeast in the northern part of the region. The extent of the large east-trending plume (divided into areas IIA and IIB in fig. 19) was determined fairly well by the installation and sampling of well sites 106, 123, and 136 during the second phase of the study. The average TOH concentrations in the Canal Creek aquifer in samples from well sites 106, 123, and 136 and well sites 3, 9, and 11 (installed during the first phase of drilling (Lorah and Vroblesky, 1989) generally were less than 5 µg/L. Thus, the southern and eastern extent of the plume is fairly well defined (fig. 42).

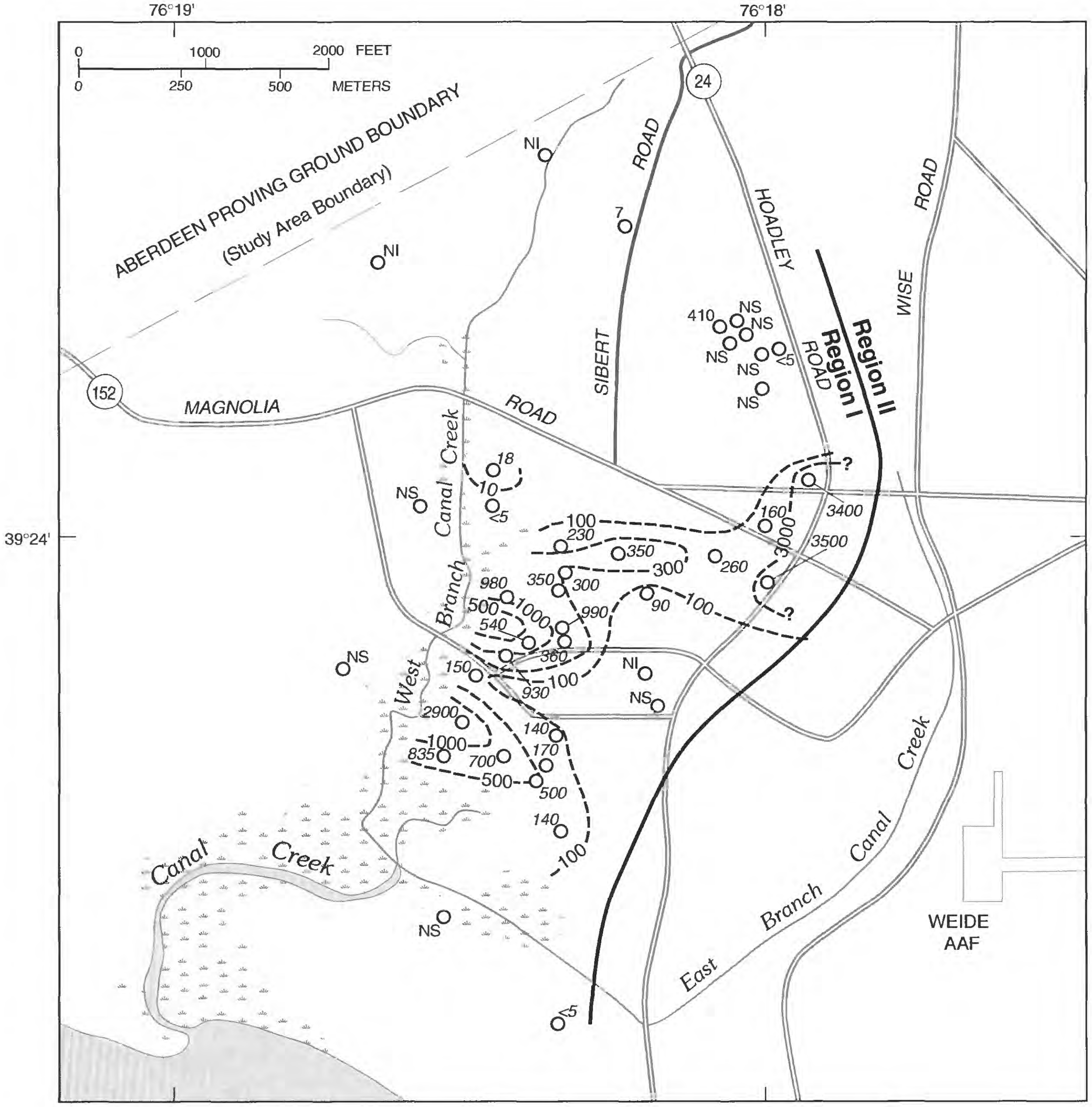
The extent of the smaller contaminated area to the north, called area IIC (figs. 19 and 42), is not as well defined as areas IIA and IIB because only three well sites are in area IIC. Samples from the three well sites indicate that water in the Canal Creek aquifer in area IIC has a TOH concentration between approximately 30 and 50 µg/L.

The highest TOH concentrations in Region II were measured in samples from the Canal Creek aquifer at well site 1 (figs. 19 and 42), adjacent to the East Branch Canal Creek in area IIA. During the second sampling period, the average TOH concentration in the aquifer at site 1 was 1,100 µg/L (fig. 42). Samples from the Canal Creek aquifer at site 5, which is south of site 1, had the second highest TOH concentrations of about 500 µg/L (figs. 19 and 42).

TOH distribution in the surficial aquifer during the second sampling period is shown in figure 43. The maximum TOH concentration observed in the surficial aquifer (6,900 µg/L) was measured in samples from site 33 (fig. 43), which is in area IIID at Beach Point (fig. 19). Excluding area IIID at Beach Point, the TOH distribution indicates that water in the surficial aquifer generally has lower concentrations of halogenated VOC's and less extensive contamination than are found in the Canal Creek aquifer.

Except for area IIID, TOH concentrations in the surficial aquifer ranged from 6 to 60 µg/L (fig. 43). In Regions I and II, the TOH concentrations in the surficial aquifer generally were lower than in the Canal Creek aquifer (figs. 41-43). At the well sites shown as not sampled in fig. 43, calculated TOH concentrations for samples from the surficial aquifer were less than or equal to 10 µg/L during the first sampling period (Lorah and Vroblesky, 1989, p. 57).

Of the 60 wells sampled for total phenols in April-May 1989, samples from 11 wells in the Canal Creek aquifer contained detectable concentra-

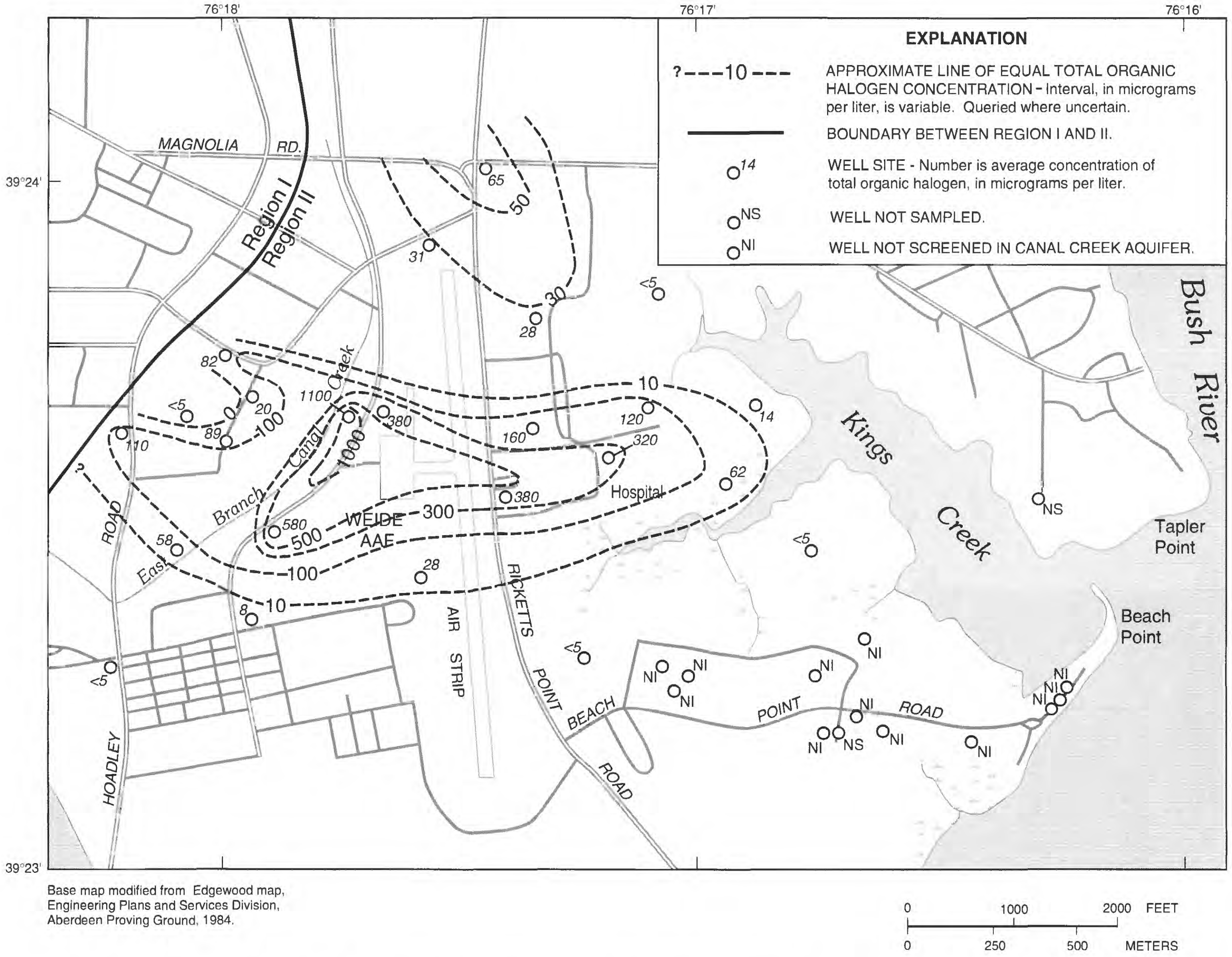


Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

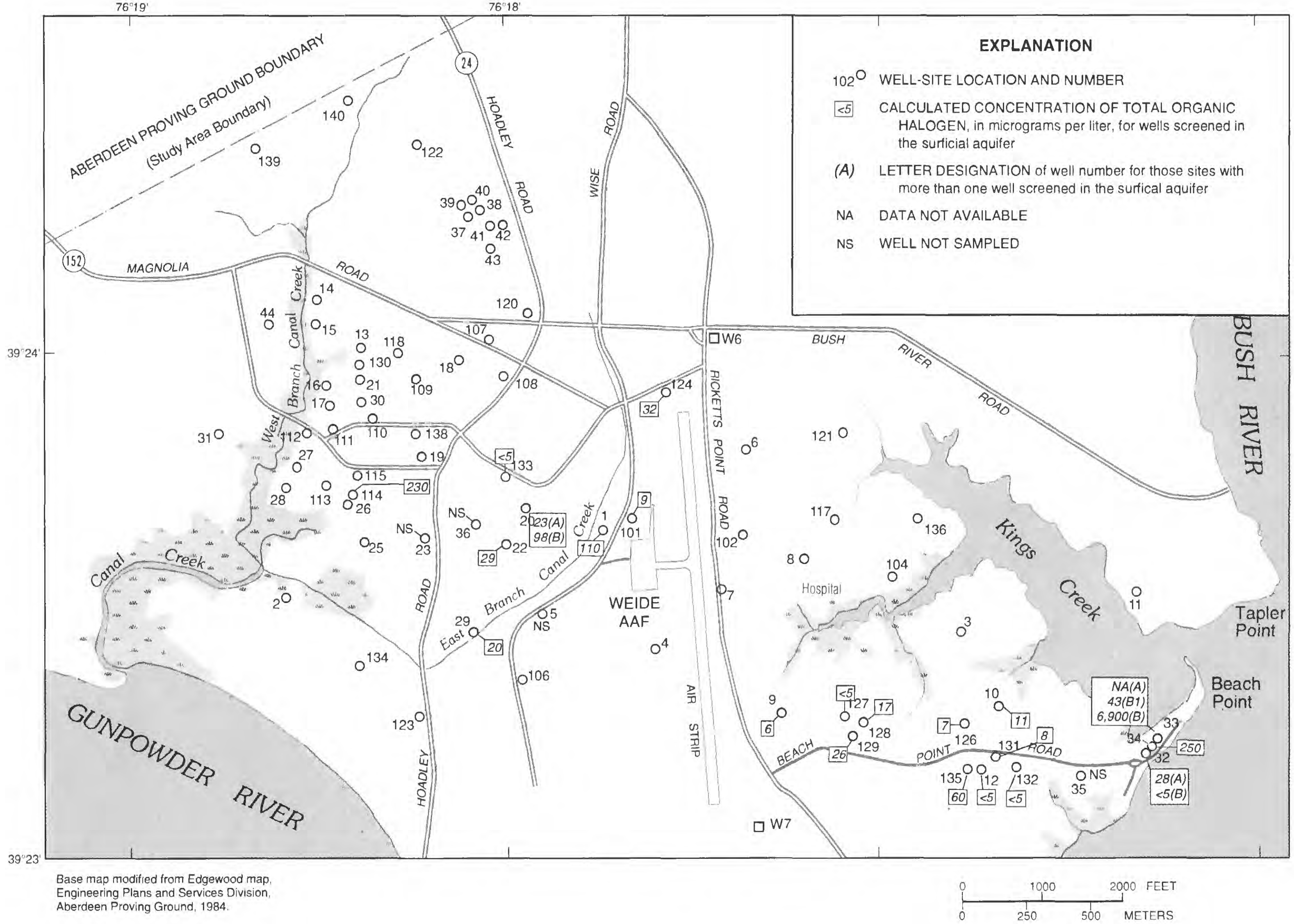
?---10---	APPROXIMATE LINE OF EQUAL TOTAL ORGANIC HALOGEN CONCENTRATION - Interval in micrograms per liter, is variable. Queried where uncertain
———	BOUNDARY BETWEEN REGION I AND II.
O 18	WELL SITE - Number is average calculated concentration of total organic halogen, in micrograms per liter.
O NS	WELL NOT SAMPLED.
O NI	WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 41. Approximate distribution of total organic halogen in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 42. Approximate distribution of total organic halogen in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 43. Distribution of total organic halogen in the surficial aquifer, second sampling period (July-September 1988).

tions that ranged from 2 to 32 μg/L; the median was 4 μg/L (Appendix B4). The maximum concentration was detected in the sample from well 122A; the water at this well has been designated as representative of background water-quality conditions in the Canal Creek aquifer on the basis of TOH concentrations (fig. 17). Samples from four other background wells in the Canal Creek aquifer had total phenol concentrations of 5 μg/L or less. The highest phenols concentrations measured in samples from contaminated sites in the Canal Creek aquifer were 25 and 22 μg/L in wells 26A and 113A, respectively. Total phenols were also detected in all eight samples collected from the lower confined aquifer, which is otherwise considered to be uncontaminated; concentrations ranged from 1 to 3 μg/L. Total phenols were not detected in samples from the surficial aquifer.

Probable sources

Probable sources for TOH in ground water of the Canal Creek area are included in the discussion of probable sources of the individual VOC's because TOH indicates the total amount of halogenated VOC's in a water sample. Probable sources of total phenols are discussed here.

The source of low concentrations of total phenols measured in samples from the Canal Creek and lower confined aquifers could be the natural occurence of phenols in water. Phenols are present naturally in water at concentrations that are usually less than 1 μg/L (Thurman, 1986, p. 143). Laboratory or field contamination is a probable source of the relatively high total phenols concentrations measured in samples from background well 122A and from wells 26A and 113A. Analyses of replicate samples indicated low reproducibility for total phenols; thus, confidence in the reported concentrations is low. For example, one of the replicate samples from well 113A did not contain detectable phenols, whereas the corresponding sample had a total phenols concentration of 22 μg/L (Appendix B4). Phenols are present in common chemicals, such as general disinfectants, that are used in laboratories; thus, samples could have been contaminated during handling and analysis in the laboratory. Phenols also are present in gasoline engine exhaust (Lucius and others, 1989, p. 402), and sample contamination could have occurred during collection as a result of exhaust from the engines used to run the purge and sample pumps or from automobiles in the study area. Because no other inorganic or organic contaminants were detected in samples from background well 122A, the anomalous total phenols concentration measured in one sample from this well (Appendix B4) most likely resulted from contamination during sample collection or analysis.

Volatile Organic Compounds

Quality control and data validation

Quality-control data for the volatile analyses include replicate ground-water samples (Appendixes B2, B4, and B6), laboratory method blanks (tables 19 and 20), and blanks that were collected in the field (tables 21 to 23). Most of the quality-control analyses shown in tables 19 through 23 include both quantitated and library-search data for VOC's.

Few replicate analyses are available for the library-search compounds, but the replicate analyses for the quantitated VOC's (Appendixs B2, B4, and B6) will be used to evaluate possible variability in the data that could result from analytical and sampling variabilities. Some differences in concentrations in the replicate samples could have resulted from different volatilization losses from one sample compared to its replicate during sample collection and analysis. Many of the replicate analyses agree remarkably closely, however, considering the volatility of these constituents. The percent difference between most of the replicate analyses for the volatile compounds was less than 10 percent, but concentrations in some of the replicate samples differ by as much as an order of magnitude.

Bar diagrams are used in figures 44 and 45 to show the differences observed in VOC concentrations for some of the replicate analyses collected during the third and fourth sampling periods. During the third sampling period, several replicate samples were collected for analysis by both the halocarbon method (USEPA Method 601) and the USEPA Method 624 for VOC's. In addition, several split samples were collected and sent to the USGS National Water-Quality Laboratory for analysis by USEPA Method 624. The analytical results for these replicate samples are shown in figure 44 for well 120A. Split samples for analysis by different laboratories were not collected during the fourth sampling period, but replicate samples were collected for halocarbon analysis and for determination of VOC's by USEPA Method 624 (fig. 45).

In general, the differences between concentrations determined by the two different analytical methods or between those determined by the two different laboratories are not greater than the differences between concentrations of replicate samples analyzed by the same method or by the same laboratory (figs. 44 and 45). However, the frequency of reported greater-than values and high less-than values (such as less than 270 μg/L of 1,2-*trans*-dichloroethylene) (Appendix B4) makes it difficult to quantify the precision of replicate analyses. The concentration of one of the VOC's measured in a

Table 19. *Volatile organic compounds detected in laboratory method blanks during the analysis of ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[**Analysis type codes:** V, volatile organic compounds by gas chromotagraphy/mass spectrometry; VL, library search for volatile organic compounds; library search compounds are tentatively identified organic compounds, and their concentrations are estimated; (1.55), retention time in minutes; µg/L, micrograms per liter]

Sample number	Analysis type	Analysis date	Compound	Concentration (µg/L)
A2874	V	07-18-88	Methylene chloride	19
A2889	V	07-20-88	Methylene chloride	5
A2889	VL	07-20-88	Unknown (1.55)	4
A2897	V	07-20-88	Methylene chloride	10
A2949	V	07-22-88	Methylene chloride	12
A2949	V	07-22-88	Ethylbenzene	4
A2957	V	07-23-88	Methylene chloride	10
A2957	V	07-23-88	Ethylbenzene	2
A2957	VL	07-23-88	Unknown (1.41)	5
A2957	VL	07-23-88	Unknown alkane (22.7)	2
A2967	V	07-24-88	Methylene chloride	6
A3117	V	08-01-88	Methylene chloride	7
A3117	VL	08-01-88	Unknown (1.41)	4
A3117	VL	08-01-88	Unknown (2.85)	2
A3131	V	08-02-88	Methylene chloride	6
A3131	V	08-02-88	1,1,1-Trichloroethane	2
A3193	V	08-08-88	Methylene chloride	10
A3691	V	09-21-88	Methylene chloride	4
A3853	V	09-30-88	Methylene chloride	7
B0158	V	10-11-88	Methylene chloride	10
B0166	V	10-12-88	Methylene chloride	13
B0173	V	10-13-88	Methylene chloride	7
B9562	V	08-03-88	Methylene chloride	4
B9570	V	08-04-88	Methylene chloride	9
B9581	V	08-05-88	Methylene chloride	10
B9594	V	08-06-88	Methylene chloride	8
B9594	VL	08-06-88	Unknown (21.3)	6
B9604	V	08-07-88	Methylene chloride	7
B9604	VL	08-08-88	Unknown (1.55)	6
B9613	V	08-09-88	Methylene chloride	11
B9625	V	08-10-88	Methylene chloride	7
B9636	V	08-11-88	Methylene chloride	9
B9648	V	08-12-88	Methylene chloride	11
B9658	V	08-13-88	Methylene chloride	12
B9674	V	08-14-88	Methylene chloride	8
B9687	V	08-15-88	Methylene chloride	11
B9695	V	08-16-88	Methylene chloride	12
B9745	V	08-22-88	Methylene chloride	12
B9751	V	08-23-88	Methylene chloride	11
B9776	V	08-25-88	Methylene chloride	12
B9809	V	08-27-88	Methylene chloride	12
B9824	V	08-28-88	Methylene chloride	11
B9824	VL	08-28-88	4-Methyl-2-pentanone	5
B9824	VL	08-28-88	2-Hexanone	5
B9837	V	08-29-88	Methylene chloride	12
B9847	V	08-30-88	Methylene chloride	5
B9847	V	08-30-88	*trans*-1,2-Dichloroethene	2
B9866	V	08-31-88	Methylene chloride	8
B9874	V	09-01-88	Methylene chloride	9
B9890	V	09-03-88	Methylene chloride	4
B9899	V	09-05-88	Methylene chloride	5
B9906	V	09-06-88	Methylene chloride	5

Table 20. *Volatile organic compounds detected in laboratory method blanks during the analysis of ground-water samples collected during the third (April-May 1989) and fourth (September-October 1989) sampling periods, Aberdeen Proving Ground, Maryland*

[**Analysis type codes:** H, halocarbons by gas chromatography; V, volatile organic compounds by gas chromatography/mass spectrometry; VL, library search for volatile organic compounds; library-search compounds are tentatively identified organic compounds, and their concentrations are estimated; (11.2), retention time in minutes; µg/L, micrograms per liter]

Sample number	Analysis type	Analysis date	Concentration (µg/L)
		April-May 1989	
HAC005	H	1,3-Dichlorobenzene	0.24
HAD001	H	1,3-Dichlorobenzene	0.24
		September-October 1989	
VBH005	V	Chlorobenzene	1.5
VBJ012	V	Methylene chloride	9.0
VBJ012	VL	Unknown (11.2)	3
VBJ012	VL	Unknown (11.9)	4
VBJ012	VL	Unknown (12.2)	20
VBJ012	VL	Unknown (12.4)	3
VBJ012	VL	Unknown (12.8)	2
VBJ012	VL	Unknown (13.1)	5
VBJ012	VL	Unknown (13.7)	10
VBL006	V	Carbon tetrachloride	7.3
VBL006	V	Chloroform	2.2
VBR008	V	1,2-*trans*-Dichloroethylene	1.3
VBT002	V	Acetone	12
VBT002	V	Chloroform	1.0
VBT002	V	1,1-Dichloroethane	1.2
VBT002	V	1,2-*trans*-Dichloroethylene	1.2
VBT002	VL	Unknown (09.3)	3
VBM007	VL	Unknown (07.1)	30
VBM007	VL	Unknown (11.2)	3
VBP007	VL	Unknown (02.0)	15
VBP007	VL	Unknown (02.3)	4
VBP006	VL	Unknown (01.2)	7
VBP006	VL	Unknown (01.4)	4
VBP006	VL	Unknown (02.0)	27
VBP006	VL	Unknown (02.4)	7
VBP006	VL	Unknown (02.8)	8
VBP006	VL	Unknown (02.9)	4
VBP006	VL	Unknown (03.0)	3
VBP006	VL	Unknown (03.5)	3
VBP006	VL	Unknown (03.8)	14
VBP006	VL	Unknown (04.2)	3
VBP006	VL	Unknown (05.5)	7
VBP006	VL	Unknown (06.0)	4
VBP006	VL	Unknown (06.5)	26
VBP006	VL	Unknown (06.8)	3
VBP006	VL	Unknown (07.8)	16
VBP006	VL	Unknown (08.2)	4
VBP006	VL	Unknown (09.3)	17

sample often differed greatly between replicate analyses, whereas concentrations measured for the other VOC's agreed closely. This pattern indicates that analytical error, rather than loss of volatile compounds from one sample during field collection, is the cause of the difference in concentration.

Anomalous replicate analyses include the low 1,2-*trans*-dichloroethylene concentrations that were reported in a few of the replicate samples. For example, the three replicate samples collected from well 16A during the fourth sampling period have 1,2-*trans*-dichloroethylene concentrations of less than 13 µg/L, 160 µg/L, and 2,200 µg/L (fig. 45). The high 1,2-*trans*-dichloroethylene concentration of 2,200 µg/L (figs. 45) agrees closely with previously measured concentrations at well 16A (Appendix B2). The reported concentrations of 1,2-*trans*-dichloroethylene should actually be the total

Table 21. *Volatile-organic-chemical data for quality-control blanks collected in the field during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[All concentration units are in micrograms per liter; in the sample number, the "-T" or "-F" indicates a trip blank or equipment blank, respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; *, below laboratory method blank concentration; J, estimated concentration, peak present but concentration below reported detection limit]

Sample number	Sampling date	Analysis date	Toluene, total	Ethylbenzene, total	Benzene, total	Chloro-benzene, total	Carbon tetrachloride, total	Chloroform, total	Methylene chloride, total
CC-1B-F	8-18-88	8-30-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.0*J
CC-1B-T	8-18-88	8-30-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.0J
CC-7B-F	8-15-88	8-27-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	12*
CC-7B-T	8-15-88	8-27-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	21
CC-8B-F	8-11-88	8-23-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0*
CC-8B-T	8-11-88	8-23-88	1.0J	<5.0	<5.0	<5.0	<5.0	<5.0	20
CC-13A-F	7-20-88	8-03-88	<5.0	3.0J	<5.0	<5.0	<5.0	<5.0	4.0*J
CC-13A-T	7-20-88	8-02-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-16B-F	7-25-88	8-06-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-16B-T	7-25-88	8-06-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	16
CC-17B-F	7-26-88	8-08-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	11
CC-17B-T	7-26-88	8-07-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0
CC-18A-F	7-18-88	8-02-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	10
CC-18A-T	7-18-88	8-01-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0*
CC-22B-F	8-22-88	9-03-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.0*J
CC-22B-T	8-22-88	9-01-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-25A-F	8-01-88	8-13-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	14
CC-25A-T	8-01-88	8-13-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.0*J
CC-26B-F	7-27-88	8-10-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-26B-T	7-27-88	8-10-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	10 8
CC-28A-F	7-28-88	8-11-88	<5.0	<5.0	<5.0	<5.0	2.0J	1.0J	12
CC-28A-T	7-28-88	8-11-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0*
CC-33B-F	9-07-88	9-21-88	11	1.0J	2.0J	<5.0	<5.0	<5.0	10
CC-36D-F	8-23-88	9-06-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-36D-T	8-23-88	9-06-88	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.0*J

Table 21. *Volatile-organic-chemical data for quality-control blanks collected in the field during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland--Continued*

Sample number	1,1,2,2-Tetrachloroethane, total	1,1,2-Trichloroethane, total	1,2-Dichloroethane, total	1,1-Dichloroethane, total	Tetrachloroethylene, total	Trichlorethylene, total	1,1-Dicholoro-ethylene total	1,2-*trans*-Dichloro-ethylene, total	Vinyl chloride, total
CC-1B-F	<10	<5.0	<10	<5.0	<5.0	1.0J	<5.0	3.0J	<10
CC-1B-T	<10	<5.0	<10	<5.0	<5.0	2.0J	<5.0	5.0	<10
CC-7B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-7B-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-8B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-8B-T	1.0J	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-13A-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-13A-T	4.0J	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-16B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-16B-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-17B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-17B-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-18A-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-18A-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-22B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	1.0J	<10
CC-22B-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-25A-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-25A-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-26B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-26B-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-28A-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-28A-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-33B-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-36D-F	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10
CC-36D-T	<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10

Table 22. *Volatile-organic-chemical data for quality-control blanks collected in the field during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

[In the sample number, the "-T" or "-F" indicates a trip blank or equipment blank, respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; analysis type codes: H,halocarbon analysis by gas chromotagraphy; VL, library search for volatile organic compounds; dashes indicate data not available; unknown compound concentrations are estimated; (17.7), retention time in minutes; µg/L, micrograms per liter]

Sample number	Sampling date	Constituent	Analysis type	Concentration (µg/L)
CC-1B-T	05-22-89	Tetrachloroethylene	H	0.07
CC-1B-F	05-22-89	None detected	--	--
CC-8B-T	05-25-89	None detected	--	--
CC-8B-F	05-25-89	None detected	--	--
CC-17C-F	06-02-89	None detected	--	--
CC-21A-T	05-04-89	None detected	--	--
CC-21A-F	05-04-89	None detected	--	--
CC-25A-T	05-17-89	None detected	--	--
CC-25A-F	05-17-89	None detected	--	--
CC-33B-F	04-26-89	None detected	--	--
CC-111B-T	05-03-89	None detected	--	--
CC-111B-F	05-03-89	None detected	--	--
CC-113A-T	04-28-89	None detected	--	--
CC-113A-F	04-28-89	Total organic halogen	--	80
CC-120A-T	05-15-89	Unknown (17.7)	VL	3.0
CC-120A-T	05-15-89	Unknown (22.6)	VL	4.0
CC-120A-F	05-15-89	None detected	--	--

concentration of the *trans* and *cis* isomers; the anomalously low concentrations indicate that only one of the isomers was sometimes reported instead of the total 1,2-dichloroethylene concentration.

Anomalous differences also are seen in the concentrations of carbon tetrachloride, 1,1,2,2-tetrachloroethane, and trichloroethylene that were measured in replicate samples collected at well 120A during the third sampling period (fig. 44). For the three replicate samples analyzed by USEPA Method 624, concentrations in two of the samples (one of which was analyzed by the USGS laboratory) were within about 10 percent, whereas the concentrations in a third sample differed by an order of magnitude. The concentrations of 1,100 µg/L of carbon tetrachloride, 3,200 µg/L of 1,1,2,2-tetrachloroethane, and 470 µg/L of trichloroethylene agree relatively closely with the concentrations observed during the second sampling period (Appendix B2).

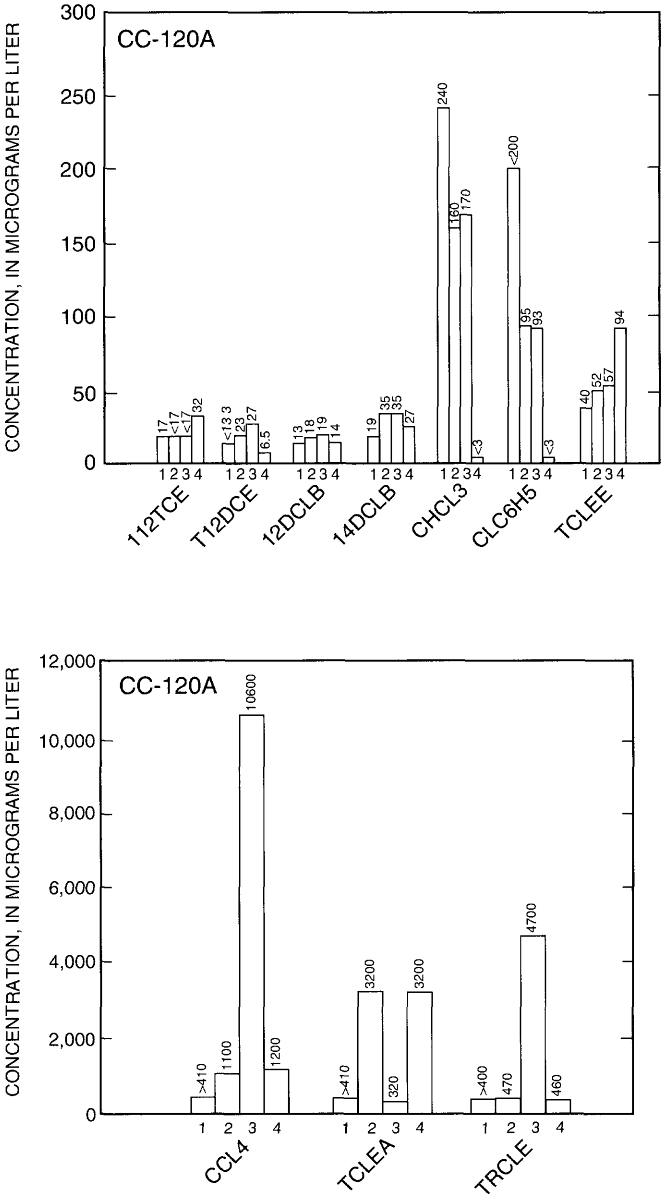
Table 23. *Volatile-organic-chemical data for quality-control blanks collected in the field during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

[In the sample number, the "-T" or "-F" indicates a trip blank or equipment blank, respectively, and the number preceded by "CC-" indicates the well site at which the sample was collected; analysis type codes: V, volatile organic compounds by gas chromotagraphy/mass spectrometry; VL, library search for volatile organic compounds; dashes indicate data not available; unknown compound concentrations are estimated; (11.2), retention time in minutes; µg/L, micrograms per liter]

Sample number	Sampling date	Constituent	Analysis type	Concentration (µg/L)
CC-1B-F	10-13-89	None detected	--	--
CC-8B-T	10-16-89	1,1,2,2-Tetrachloroethane	V	5.7
CC-8B-T	10-16-89	Unknown (1.2)	VL	8
CC-8B-T	10-16-89	Unknown (1.4)	VL	4
CC-8B-T	10-16-89	Unknown (2.0)	VL	12
CC-8B-T	10-16-89	Unknown (2.3)	VL	3
CC-8B-F	10-16-89	None detected	--	--
CC-16A-T	09-15-89	None detected	--	--
CC-16A-F	09-15-89	Unknown (13.1)	VL	10
CC-33B-F	10-11-89	1,1,2,2-Tetrachloroethane	V	100
CC-33B-F	10-11-89	Unknown (1.2)	VL	7
CC-112A-T	09-18-89	Unknown (11.2)	VL	7
CC-112A-F	09-18-89	Unknown (11.2)	VL	7
CC-112A-F	09-18-89	Unknown (12.1)	VL	20
CC-112A-F	09-18-89	Unknown (12.3)	VL	4
CC-113A-F	09-27-89	Unknown (1.9)	VL	2
CC-113A-F	09-27-89	Unknown (2.2)	VL	20
CC-113A-F	09-27-89	Unknown (2.5)	VL	3
CC-120A-T	09-29-89	None detected	--	--
CC-120A-F	09-29-89	1,1,2,2-Tetrachloroethane	V	16
CC-120A-F	09-29-89	Unknown (7.0)	VL	10

The concentrations measured by the halocarbon analysis cannot be compared to those of the EPA Method 624 analysis because greater-than values were reported (fig. 44).

The analytical results for quality-control blanks collected in the field during the three sampling periods are shown in tables 21 to 23. Library-search compounds were not reported for the blanks collected during the second sampling period (table 21), but they were reported for the blanks collected during the third and fourth sampling periods (tables 22 and 23). Methylene chloride was the most commonly detected VOC in the blanks collected in the field during the second sampling period. Because



EXPLANATION

ANALYTICAL METHOD

1 HALOCARBON METHOD (EPA METHOD 601)
2 EPA METHOD 624 - FIRST REPLICATE SAMPLE
3 EPA METHOD 624 - SECOND REPLICATE SAMPLE
4 EPA METHOD 624 - ANALYSES BY U.S. GEOLOGICAL SURVEY NATIONAL WATER QUALITY LABORATORY

VOLATILE ORGANIC COMPOUNDS

112TCE	1,1,2 - TRICHLOROETHANE
T12DCE	1,2 - TRANS - DICHLOROETHYLENE
12DCLB	1,2 - DICHLOROBENZENE
14DCLB	1,4 - DICHLOROBENZENE
CHCL3	CHLOROFORM
CLC6H5	CHLOROBENZENE
TCLEE	TETRACHLOROETHYLENE
CCL4	CARBON TETRACHLORIDE
TCLEA	1,1,2,2 - TETRACHLOROETHANE
TRCLE	TRICHLOROETHYLENE

Figure 44. Concentrations of selected volatile organic compounds in replicate samples collected from well CC-120A, third sampling period (April-May 1989).

methylene chloride was also commonly detected in laboratory method blanks (table 19), the presence of this compound in quality-control blanks probably indicates laboratory contamination. Methylene chloride concentrations in the laboratory method blanks commonly ranged from about 10 to 20 µg/L (tables 19 and 20). The low concentrations of toluene and ethylbenzene measured in several of the quality-control blanks during the second sampling period are also most likely caused by laboratory contamination, because these compounds are commonly used in laboratory procedures.

In addition to these common laboratory contaminants, low concentrations (5 µg/L or less) of benzene, carbon tetrachloride, chloroform, 1,1,2,2-tetrachloroethane, trichloroethylene, and 1,2-*trans*-dichloroethylene were measured in some of the quality-control blanks collected in the field during the second sampling period (table 21). The

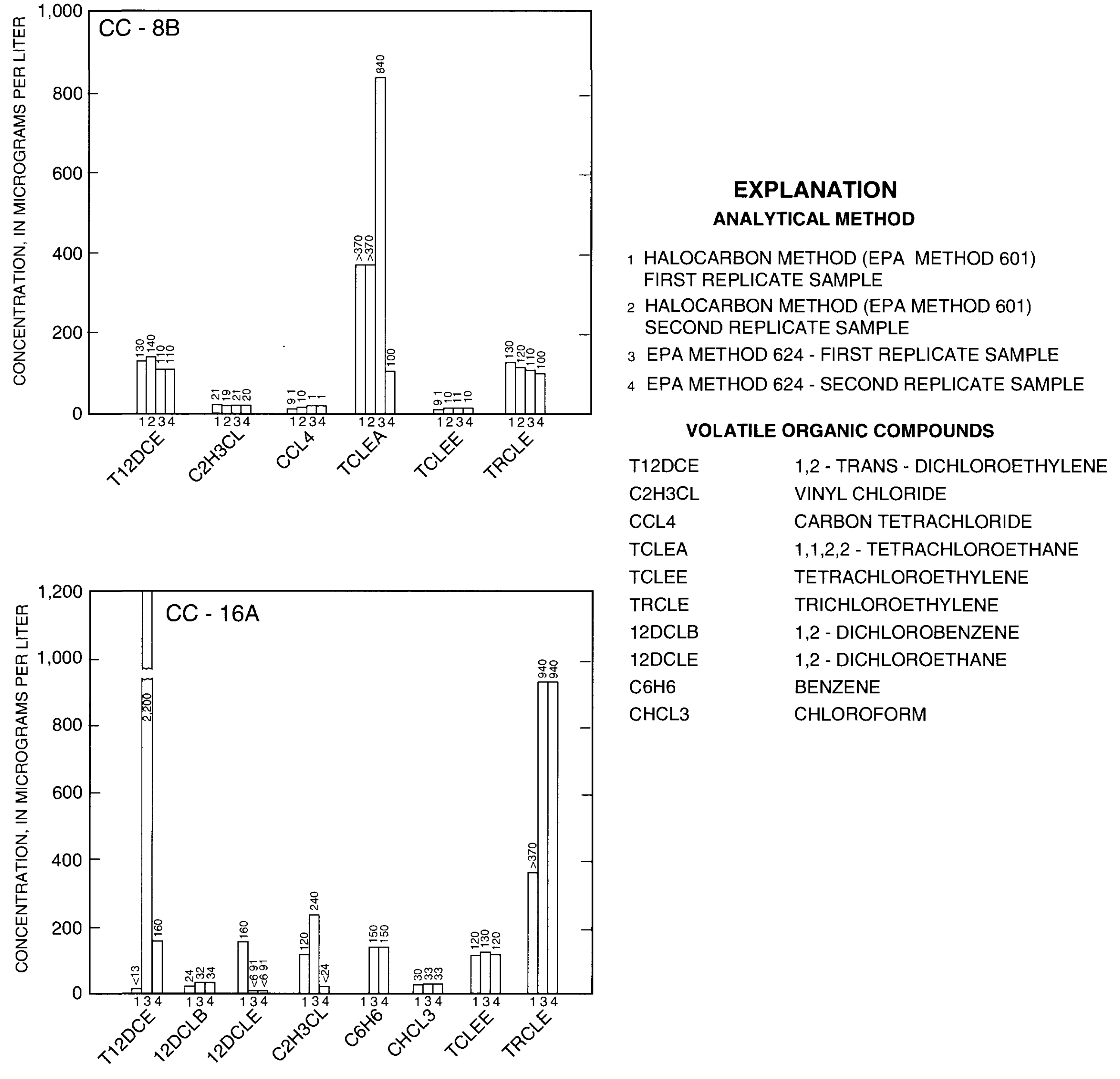


Figure 45. Concentrations of selected volatile organic compounds in replicate samples collected from well CC-8B and CC-16A, fourth sampling period (September-October 1989).

concentrations of the same volatile compounds commonly were much higher in the ground-water samples (Appendixes B2 to B6) than in the blanks. Thus, cross-contamination from the sampling equipment probably did not cause a substantial increase in the measured concentrations in the ground-water samples.

A high concentration (100 µg/L) of 1,1,2,2-tetrachloroethane was detected in one equipment blank collected after the sampling of well 33B during the fourth sampling period (table 23). Well 33A was sampled after well 33B was sampled and the quality-control blanks were collected. A 1,1,2,2-tetrachloroethane concentration of 840 µg/L was detected in the sample from well 33A during the fourth sampling period (Appendix B6), but this concentration is not significantly different from the concentrations of 730 to 1,300 μg/L that were detected in samples from well 33A on previous sampling trips (Appendix B4; Lorah and Vroblesky, 1989, p. 55). Thus, the sample collected from well 33A during the fourth sampling period probably was not affected by cross-contamination.

Unknown compounds were the most commonly detected VOC's in quality-control blanks collected in the field during the third and fourth sampling periods (tables 22 and 23). In addition, unknown compounds often were detected in laboratory method blanks, indicating that laboratory contamination could be a source of these compounds. Concentrations of individual volatile unknowns in the method blanks ranged from 3 to 30 μg/L (tables 19 and 20), and the total concentration of unknowns in one method blank was about 160 μg/L (sample number VBP006 in table 20).

Distribution

In this section, the general occurrence of VOC's in the Canal Creek and surficial aquifers is discussed first, and then the distribution of the major contaminants in the three regions (fig. 19) is described in separate subsections. Tables 24 to 26 summarize the VOC's that were quantitatively detected in the Canal Creek aquifer, giving the frequency of detection and the medians and ranges of concentrations. Concentrations of these quantitated VOC's in the Canal Creek aquifer are compared to Federal drinking-water regulations for those compounds for which regulations have been established (U.S. Environmental Protection Agency, 1989; 1990a-e; 1991a-c). Table 27 summarizes the maximum concentrations of VOC's that were quantitatively measured in the surficial aquifer during the study.

Of the 41 total VOC's for which quantitative analyses were done (table 5), 10 compounds were not detected in ground-water samples collected from the Canal Creek area. These 10 compounds (and their reported detection limits) are as follows: bromomethane (10 μg/L); carbon disulfide (5 μg/L); 2-chloroethylvinyl ether (10 μg/L); 1,3-dichloropropane (3.8 μg/L); 1,2-dimethylbenzene (3.0 μg/L); 2-hexanone (10 μg/L); 4-methyl-2-pentanone (10 μg/L); styrene (5 μg/L); trichlorofluoromethane (5 μg/L); and vinyl acetate (10 μg/L).

Sixteen VOC's were quantitatively detected in samples from the Canal Creek aquifer during the second sampling period (table 24). Many of these VOC's were also contaminants in the surficial aquifer (table 27). Three of the 16 compounds--methylene chloride, toluene, and ethylbenzene--are common laboratory contaminants (see preceding section on quality control and data validation), and their distribution will not be discussed further.

VOC's can be divided into three classes of compounds: (1) chlorinated alkanes, which are saturated aliphatic compounds characterized by single bonds, (2) chlorinated alkenes, which are unsaturated aliphatic compounds characterized by double bonds, and (3) aromatic compounds, which contain the benzene ring structure (Lorah and Vroblesky, 1989, p. 61). Chlorinated alkanes and alkenes were generally detected more frequently and at higher concentrations in the Canal Creek aquifer than were the aromatic compounds (table 24). The five major VOC's in the ground water, identified on the basis of their high detection frequencies (greater than 40 percent) and relatively high median concentrations (greater than about 10 μg/L), were 1,1,2,2-tetrachloroethane, trichloroethylene, chloroform, 1,2-*trans*-dichloroethylene, and carbon tetrachloride (table 24). The most prevalent VOC's, 1,1,2,2-tetrachloroethane and trichloroethylene, were detected in about 70 percent of the 93 samples collected from the Canal Creek aquifer during the second sampling period (table 24).

MCL's have not been established for 1,1,2,2-tetrachloroethane, but MCL's for trichloroethylene and carbon tetrachloride are 5 μg/L. Trichloroethylene concentrations in the Canal Creek aquifer exceeded the MCL in samples from 61 wells (out of 93 wells sampled) during the second sampling period (table 24). Trichloroetheylene concentrations exceeded Federal drinking-water regulations in more samples than any of the other VOC's, except methylene chloride. Samples from 29 wells screened in the Canal Creek aquifer exceeded the current MCL for carbon tetrachloride during the second sampling period.

The MCL of 100 μg/L for 1,2-*trans*-dichloroethylene (table 24) was exceeded in 10 samples. The concentrations given for 1,2-*trans*-dichloroethylene in this report actually represent the total concentrations of the *trans* and *cis* isomers of 1,2-dichloro-ethylene (Appendixes B2, B4, and B6). If the two isomers could be separately identified, the concentration for each isomer was reported by the laboratory (table 28). An MCL of 70 μg/L has been established for 1,2-*cis*-dichloroethylene. Samples that had total 1,2-dichloroethylene concentrations that exceeded the MCL of 100 μg/L for 1,2-*trans*-dichloroethylene also had 1,2-*cis*-dichloroethylene concentrations that exceeded the MCL of 70 μg/L (table 28).

Table 24. *Volatile organic compounds quantitated in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, during the second sampling period (July-September 1988), their ranges of concentrations, and relation of observed concentrations to Federal drinking-water regulations*

[Units are in micrograms per liter; frequency of detection, in percent, is the number of samples in which the constituent was detected divided by the total number of samples that were collected (93 samples total) and multiplied by 100; replicate samples are not included; dashes indicate that value is not known]

Volatile organic compound	Frequency of detection (percent)	Median concentration	Minimum concentration	Maximum concentration	Well no. (for maximum concentration)	Current MCL [1]	Current MCLG [2]	Proposed MCLG [3]	No. of samples exceeding MCL
Chlorinated alkanes									
Carbon tetrachloride	45	24	1.0	3,100	CC-108A	5	0	--	29
Chloroform	58	9.5	1.0	650	CC-113A	--	--	--	--
Methylene chloride	98	8.0	2.0	62	CC-111B	5	--	0	68
1,1,2,2-Tetrachloroethane	70	79	1.0	5,800	CC-27A	--	--	--	--
1,1,2-Trichloroethane	38	4.0	1.0	31	CC-27A	5	--	3	12
1,2-Dichloroethane	32	5.5	1.0	260	CC-16A	5	0	--	15
1,1-Dichloroethane	54	3.0	2.0	4.0	CC-104C	--	--	--	--
Chlorinated alkenes									
Tetrachloroethylene	25	7.0	1.0	200	CC-16A	5	0	--	15
Trichloroethylene	72	47	3.0	760	CC-27A	5	0	--	61
1,1-Dichloroethylene	12	2.0	1.0	9.0	CC-16A	7	7	--	1
1,2-*trans*-Dichloroethylene	53	15	1.0	1,100	CC-1B	[a]100	[a]100	--	10
Vinyl chloride	20	20	4.0	210	CC-16A	2	0	--	19
Aromatics									
Benzene	22	3.0	1.0	140	CC-16A	5	0	--	6
Chlorobenzene	14	4.0	1.0	100	CC-120A	--	--	--	--
Toluene	6.4	2.0	1.0	4.0	CC-106A	1,000	1,000	--	0
Ethylbenzene	8.6	1.5	1.0	3.0	CC-124B, CC-36B	700	700	--	0

[a] Values reported as 1,2-*trans*-dichloroethylene actually represent the total of 1,2-*trans*-dichloroethylene and 1,2-*cis*-dichloroethylene; the MCL and MCLG for 1,2-*cis*-dichloroethylene are both 70 mg/L.

[1] MCL, Maximum Contaminant Level--Enforceable, health-based regulation that is to be set as close to the Maximum Contaminant Level Goal (MCLG) as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of U.S. Environmental Protection Agency finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration).

[2] MCLG, Maximum Contaminant Level Goal--Nonenforceable health goal that is to be set at the level at which no known or anticipated adverse effects on the health of person occur and that allows an adequate margin of safety. Formerly called Recommended Maximum Contaminant Level (RMCL).

[3] Proposed MCLG, Proposed Maximum Contaminant Level Goal.

Table 25. *Additional volatile organic contaminants quantitated in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, during the third sampling period (April-May 1989), their ranges of concentrations, and relation of observed concentrations to Federal drinking-water regulations*

[Principal set of volatile organic compounds is listed in table 24. Units are in micrograms per liter; frequency of detection,in percent, is the number of samples in which the constituent was detected divided by the total number of samples that were collected (80 samples total) and multiplied by 100; replicate samples are not included; dashes indicate that value is not known]

Volatile organic compound	Frequency of detection (percent)	Median concentration	Minimum concentration	Maximum concentration	Well no. (for maximum concentration)	Current MCL [1]	Current MCLG [2]	Proposed MCLG [3]	No. of samples exceeding MCL
Chlorinated alkanes									
Methyl chloride	10	1.5	1.1	2.7	CC-18A	--	--	--	--
1,1,1-Trichloroethane	5	.44	.24	1.9	CC-21A	200	200	--	0
Bromoform	1.2	--	--	1.7	CC-120A	--	--	--	--
Bromodichloromethane	2.5	--	1.5	2.5	CC-113A	--	--	--	--
Chlorodibromomethane	1.2	--	--	150	CC-120A	--	--	--	--
Chloroethane	3.8	1.4	1.0	1.7	CC-17A	--	--	--	--
1,2-Dichloropropane	1.2	--	--	.07	CC-130A	5	0	--	0
Chlorinated alkenes									
trans-1,3-Dichloropropene	1.2	--	--	.90	CC-110A	--	--	--	--
cis-1,3-Dichloropropene	3.8	1.4	1.1	2.2	CC-102C	--	--	--	--
Aromatics									
1,2-Dichlorobenzene	2.5	--	18	28	CC-16A	600	600	--	0
1,3-Dichlorobenzene	19	.40	.30	1.6	CC-113A	--	--	--	--
1,4-Dichlorobenzene	3.8	1.3	.48	35	CC-120A	75	75	--	0
1,3-Dimethylbenzene	1.2	--	--	3.0	CC-16A	--	--	--	--

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[1] MCL, Maximum Contaminant Level--Enforceable, health-based regulation that is to be set as close to the Maximum Contaminant Level Goal (MCLG) as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of U.S. Environmental Protection Agency finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration).

[2] MCLG, Maximum Contaminant Level Goal--Nonenforceable health goal that is to be set at the level at which no known or anticipated adverse effects on the health of person occur and that allows an adequate margin of safety. Formerly called Recommended Maximum Contaminant Level (RMCL).

[3] Proposed MCLG, Proposed Maximum Contaminant Level Goal.

Table 26. *Additional volatile organic contaminants quantitated in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, during the fourth sampling period (September-October 1989), their ranges of concentrations, and relation of observed concentrations to Federal drinking-water regulations*

[Principal set of volatile organic compounds is listed in table 24. Units are in micrograms per liter; frequency of detection, in percent, is the number of samples in which the constituent was detected divided by the total number of samples that were collected (73 samples total) and multiplied by 100; replicate samples are not included; dashes indicate that value is not known]

Volatile organic compound	Frequency of detection (percent)	Median concentration	Minimum concentration	Maximum concentration	Well no. (for maximum concentration)	Current MCL [1]	Current MCLG [2]	Proposed MCLG [3]	No. of samples exceeding MCL
Chlorinated alkanes									
Methyl chloride	4.1	1.3	1.2	2.1	CC-W6	--	--	--	--
1,2-Dichloropropane	2.7	--	.18	.48	CC-112A	5	0	--	0
1,3-Dichloropropane	1.4	--	--	5.3	CC-22B	--	--	--	--
Chlorinated alkenes									
Acetone	1.4	--	--	7.0	CC-27A	--	--	--	--
2-Butanone	1.4	--	--	12	CC-18B	--	--	--	--
Aromatics									
1,2-Dichlorobenzene	2.7	--	32	43	CC-21A	600	600	--	0
1,3-Dichlorobenzene	9.6	.52	.38	1.2	CC-16A, CC-27A	--	--	--	--
1,4-Dichlorobenzene	4.1	2.6	.45	47	CC-120A	75	75	--	0

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[1] MCL, Maximum Contaminant Level--Enforceable, health-based regulation that is to be set as close to the Maximum Contaminant Level Goal (MCLG) as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of U.S. Environmental Protection Agency finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration).

[2] MCLG, Maximum Contaminant Level Goal--Nonenforceable health goal that is to be set at the level at which no known or anticipated adverse effects on the health of person occur and that allows an adequate margin of safety. Formerly called Recommended Maximum Contaminant Level (RMCL).

[3] Proposed MCLG, Proposed Maximum Contaminant Level Goal.

Table 27. *Volatile organic compounds quantitated over the four sampling periods in the surficial aquifer, Aberdeen Proving Ground, Maryland, and their maximum concentrations*

[Area refers to contaminated areas defined in figure 19; µg/L, micrograms per liter; CT, carbon tetrachloride; CF, chloroform; PCA,1,1,2,2-tetrachloroethane; TCA, 1,1,2-trichloroethane; 1,2-DCA, 1,2-dichloroethane; 1,1-DCA, 1,1-dichloroethane; PCE, tetrachloroethylene; TCE, trichloroethylene; tDCE, 1,2-*trans*-dichloroethylene; VC, vinyl chloride. Detection of constituent confirmed by occurrences on two or more sampling dates unless otherwise noted. Uncontaminated surficial aquifer wells (CC-5A, CC-101A, CC-127A, CC-126A, CC-131A, CC-132A) are not included in this table]

Well no.	Area	Volatile organic compounds (maximum concentration, in µg/L)	Comments
CC-114A	ID	CT (230^b); CF (15^b)	Confirmed
CC-1A	IIA	PCA (87^c); TCE (61^c); tDCE (19^b); TCA (3.0^b); VC (2.4^d)	Confirmed
CC-20A	IIA	TCE (100^d); PCA (10^a); CF (3.4^d)	Confirmed
CC-20B	IIA	TCE (280^d); PCA (18^d); CT (9.9^d); CF (7.6^d)	Confirmed
CC-22A	IIA	TCE (12^b); tDCE (8.0^b); CF (5.5^a); PCE (4.0^b); PCA (2.1^a)	Confirmed
CC-23A	IIA	TCE (11^d); tDCE (9.7^a)	Unconfirmed
CC-29A	IIA	Chlorobenzene (21^b); VC (9.0^b); CF (8.0^b)	Confirmed
CC-36A	IIA	TCE (3.4^a); PCE (1.7^a)	Unconfirmed
CC-133A	IIA	CF (9.5^c)	Confirmed
CC-124A	IIC	Methylene chloride (48^b)	Unconfirmed
CC-9A	IIIA	Chlorobenzene (19^b)	Confirmed
CC-128A	IIIB	CF (8.2^c)	Unconfirmed
CC-129A	IIIB	1,2-DCA (20 b); tDCE (7.0^b)	Confirmed
CC-10A	IIIC	CT (88^a); CF (20^a)	Concentrations much lower during later sampling periods, except one reported concentration of >2.0 chloroform
CC-12A.1	IIIC	Chloroethane (5.5^c); 1,1-DCA (3.2^c)	Chloroethane unconfirmed
CC-135A	IIIC	TCE (47^b); tDCE (8.0^b)	tDCE unconfirmed
CC-32A	IIID	CF (66a)	
CC-32B	IIID	None	Sampled twice
CC-33A	IIID	PCA (840^d); TCE (250^a); PCE (64^a); TCA (47^c)	Confirmed
CC-33B.1	IIID	PCA (38^b); TCE (8.0^b)	Unconfirmed
CC-33B	IIID	PCA (9,500^d); TCE (940^a); tDCE (520^a); PCE (200^c); TCA (71^b)	Confirmed
CC-34A	IIID	TCE (380^a); PCA (130^b); CF (8.0^b)	Confirmed
CC-35A	IIID	tDCE (4.9^a); TCE (1.9^a); CF (1.4^a)	Unconfirmed

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[a] Concentration measured during first sampling period (November 1986-April 1987) (Lorah and Vroblesky, 1989).

[b] Concentration measured during second sampling period (July-September 1988).

[c] Concentration measured during third sampling period (April-May 1989).

[d] Concentration measured during fourth sampling period (September-October 1989).

Table 28. *Concentrations of cis and trans isomers of 1,2-dichloroethylene in ground-water samples collected during the third (April-May 1989)and fourth (September-October 1989) sampling periods, Aberdeen Proving Ground, Maryland*

["(N)" indicates that sample was analyzed by the U.S. Geological Survey National Water Quality Laboratory; "-R" indicates a replicate sample; µg/L, micrograms per liter; concentrations of the two isomers do not always exactly add to the total concentration owing to precision and rounding]

Sample number	Sampling date	*cis*-1,2-dichloro-ethylene (µg/L)	*trans*-1,2-dichloro-ethylene (µg/L)	total 1,2-dichloro-ethylene (µg/L)
		April-May 1989		
CC-1B(N)	05-22-89	990	81	1,100
CC-7B(N)	05-24-89	200	120	320
CC-8B(N)	05-25-89	48	73	120
CC-16A	05-03-89	3,000	190	3,200
CC-16B	05-03-89	30	3.1	33
CC-26B	04-27-89	5.0	<1.1	5.0
CC-27A	05-01-89	40	<1.1	40
CC-28B	04-28-89	3.0	1.9	4.9
CC-108A	05-09-89	8.0	42	50
CC-108B	05-09-89	6.0	40	46
CC-113B	04-28-89	10	<1.1	10
CC-120A	05-15-89	20	3.3	23
CC-120A-R	05-15-89	20	7.0	27
CC-120B	05-09-89	4.0	<1.1	4.0
		September-October 1989		
CC-16A	09-15-89	2,000	160	2,200
CC-17A	09-15-89	5.0	8.3	13
CC-107A	09-29-89	3.0	<1.1	3.0
CC-117A	10-18-89	10	1.8	12
CC-118A	09-28-89	2.0	<1.1	2.0
CC-120A	09-29-89	30	<1.1	30
CC-120A	09-29-89	20	<1.1	20

MCL's have not been established for chloroform, although the current MCL for total trihalomethanes, of which chloroform is one, is 100 µg/L. Chloroform concentrations were greater than the MCL for total trihalomethanes in eight samples from the Canal Creek aquifer.

Although vinyl chloride was detected at a frequency of only 20 percent in samples from the Canal Creek aquifer, the median and maximum concentrations were high--20 and 210 µg/L, respectively (table 24). During the second sampling period, 19 samples from the Canal Creek aquifer had concentrations that exceeded the MCL of 2 µg/L for vinyl chloride. A high detection frequency of 54 percent was found for 1,1-dichloroethane in the Canal Creek aquifer, but the median and maximum concentrations were low (3.0 and 4.0 µg/L, respectively).

The remaining VOC's--1,1,2-trichloroethane, 1,2-dichloroethane, tetrachloroethylene, 1,1-dichloroethylene, benzene, and chlorobenzene--were detected in less than 40 percent of the samples and had median concentrations below 8 µg/L (table 24). Samples from 12 to 15 wells in the Canal Creek aquifer had concentrations that exceeded the MCL's (5 µg/L) for 1,1,2-trichloroethane, 1,2-dichloroethane, and tetrachloroethylene (table 24). Only one sample had a 1,1-dichloroethylene concentration that exceeded the MCL of 7 µg/L, and six samples had benzene concentrations that exceeded the MCL of 5 µg/L.

Concentrations of the major VOC's in ground water did not change substantially during the period of study. The ranges in concentrations of four VOC's that were observed during each sampling period are shown in figures 46 to 49. The analytical results from 33 wells that were sampled during each sampling period were used to construct the boxplots shown in the figures. The number beside each box indicates the number of samples, of the 33 total samples, that had concentrations above the detection limit for the compound. Less-than or greater-than values were not included in the data sets used to construct the boxplots. The number of detected concentrations for a particular compound varies over the four sampling periods mainly because different detection limits were often reported and because greater-than values or anomalously high less-than values were often reported during the third and fourth sampling periods.

Temporal changes in concentrations of the VOC's sometimes are difficult to discern because of differences in the manner in which analyses were reported during the four sampling periods. The range in concentrations of chloroform and the median concentrations of chloroform show the least difference between the four sampling periods compared to the differences seen in concentrations of 1,1,2,2-tetrachloroethane, trichloroethylene, and 1,2-*trans*-dichloroethylene (figs. 46 to 49). Median concentrations of chloroform ranged from about 12 to 18 µg/L for the 33 samples collected during the four sampling periods (fig. 47). The fact that chloroform concentrations change so slightly is probably largely because only one greater-than value was reported for the chloroform concentrations for these

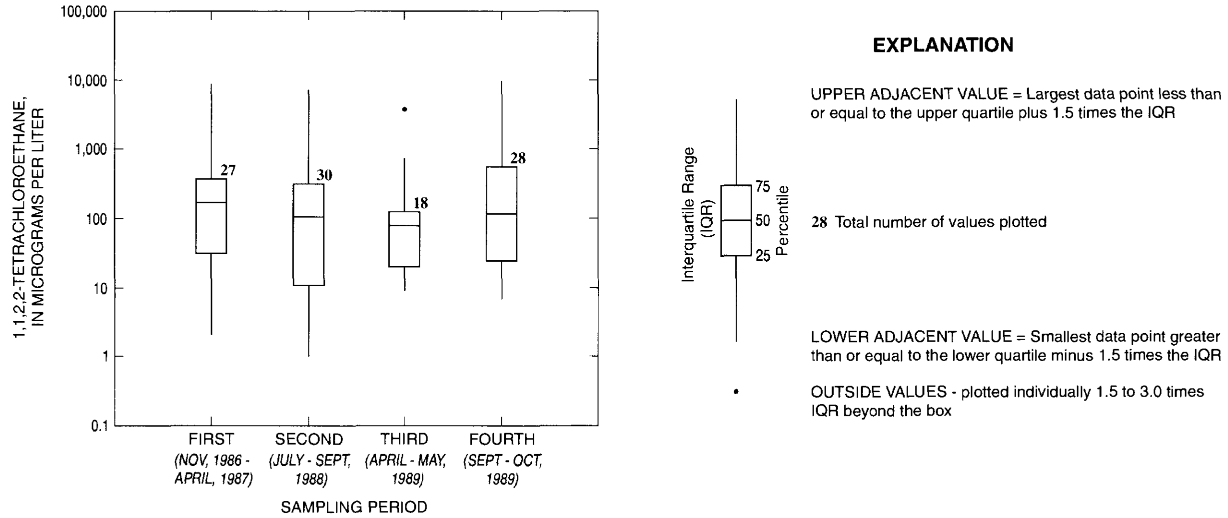


Figure 46. 1,1,2,2-Tetrachloroethane concentrations observed at 33 wells sampled during each of the four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland.

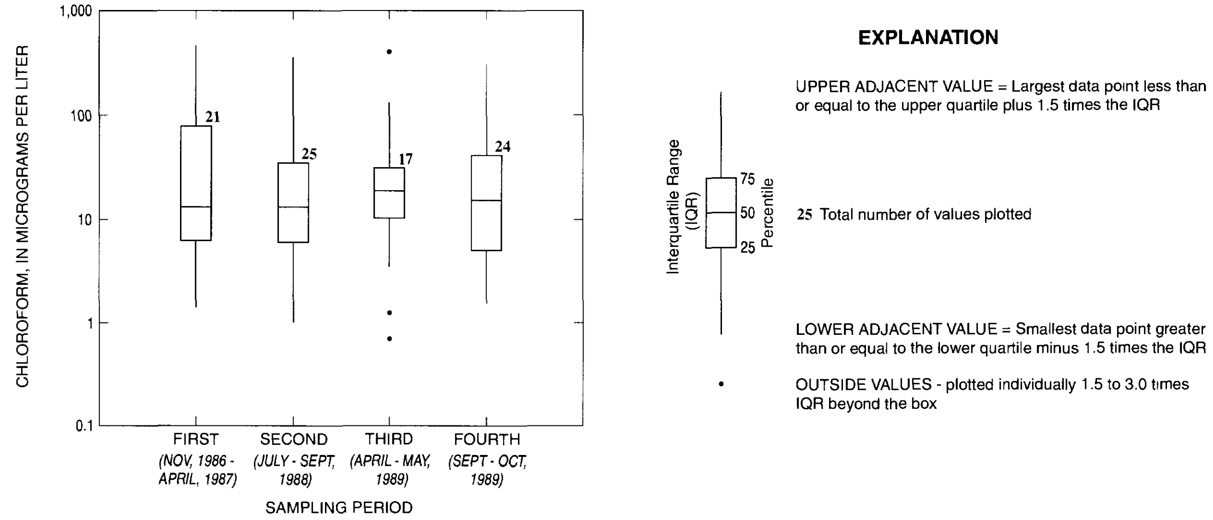


Figure 47. Chloroform concentrations observed at 33 wells sampled during each of the four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland.

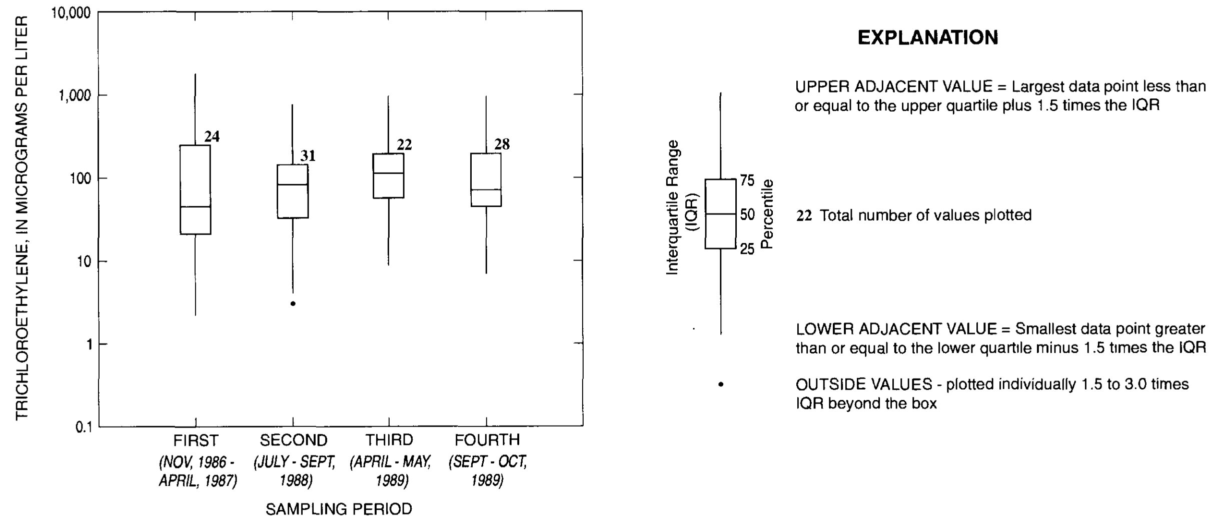


Figure 48. Trichloroethylene concentrations observed at 33 wells sampled during each of the four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland.

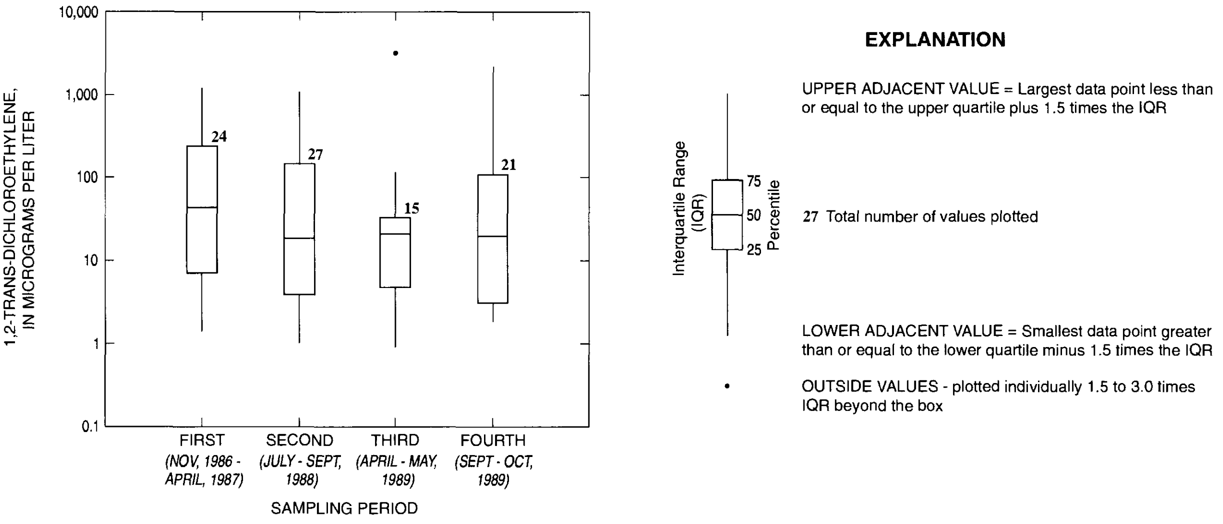


Figure 49. 1,2-*trans*-Dichloroethylene concentrations observed at 33 wells sampled during each of the four sampling periods in the Canal Creek area, Aberdeen Proving Ground, Maryland.

33 samples. In contrast, as many as six greater-than values or high less-than values were reported for the other three VOC's (figs. 46, 48, and 49) during the third and fourth sampling periods (Appendixes B4 and B6).

Additional VOC's that were quantitatively measured in samples from the Canal Creek aquifer during the third and fourth sampling periods are shown in tables 25 and 26. Except for methyl chloride and 1,2-dichlorobenzene, these additional VOC's were detected only by the USEPA Method 601 of halocarbon analysis, which gives lower detection limits for the VOC's than does USEPA Method 624. Methyl chloride and 1,2-dichlorobenzene were detected by both analytical methods.

Of the additional VOC's, 1,3-dichlorobenzene and methyl chloride were detected most frequently, but their maximum concentrations were less than 3 µg/L (tables 25 and 26). Because 1,3-dichlorobenzene was also detected in two laboratory method blanks (table 20), the 1,3-dichlorobenzene concentrations measured in the ground-water samples could be attributed to laboratory contamination. Methyl chloride could be a laboratory contaminant associated with methylene chloride. Of these additional VOC's (tables 25 and 26), the highest concentration (150 µg/L) was found for chlorodibromomethane. The maximum chlorodibromomethane concentration was measured in a sample from well 120A (table 25); however, two replicate samples collected from well 120A on the same date did not contain chlorodibromomethane, an indication that the measured concentration of 150 µg/L is an analytical or reporting error.

During the third and fourth sampling periods, 1,2-dichlorobenzene and 1,4-dichlorobenzene were not detected frequently in ground-water samples; however, their concentrations were high compared to concentrations of the other additional VOC's (except chlorodibromomethane) (tables 25 and 26). The maximum concentrations of 1,2-dichlorobenzene were 28 and 43 µg/L during the third and fourth sampling periods, respectively, and the maximum concentrations of 1,4-dichlorobenzene were 35 and 47 µg/L (tables 25 and 26). The other additional VOC's were detected in 5 percent or less of the samples collected from the Canal Creek aquifer and in low concentrations of less than 3 µg/L (tables 25 and 26). MCL's have been set for several of these VOC's, but measured concentrations did not exceed the MCL's in any of the ground-water samples (tables 25 and 26).

Additional VOC's were tentatively identified by library search in ground-water samples collected during the last three sampling periods (tables 29-31). Library searches for VOC's were done for samples collected from a total of 62 wells during the second sampling period, 32 wells during the third sampling period, and 73 wells during the fourth sampling period (table 3). TIOC's were detected in samples from only 4 to 10 wells during these three sampling periods, and the detected TIOC's generally had estimated concentrations below 50 µg/L (tables 29-31).

Pentachloroethane, which was detected in samples from well 120A, was the only confirmed occurrence of volatile TIOC's (tables 29 to 31). Pentachloroethane was detected consistently in replicate samples collected from well 120A during the third and fourth sampling periods, and the estimated concentrations were consistently between 30 and 40 µg/L (tables 30 and 31). Total xylenes is the only TIOC for which Federal drinking-water regulations have been established, and the single measured xylene concentration of 2 µg/L (table 31) is well below the MCL of 10,000 µg/L.

VOC's that could not be identified by library search were reported as unknowns (tables 32-34). Estimated concentrations of the unknowns were usually less than 50 µg/L, but concentrations as high as 2,000 µg/L were reported (table 33). Concentrations of unknowns were extremely variable between the different sampling periods. For example, samples collected from well 111A during the second and fourth sampling periods did not contain unknowns, whereas the sample collected during the third sampling period contained the maximum of about 2,000 µg/L of unknowns (table 33). Volatile unknowns were also detected in laboratory method blanks analyzed during the three sampling periods (tables 19 and 20), indicating that the presence of unknown compounds in the ground-water samples is at least partly due to laboratory contamination.

Region I

The areal distributions of the major VOC's in the Canal Creek aquifer are shown in figures 50 through 54 for Region I. In the construction of these figures, the data from the second sampling period were used to calculate an average concentration in the Canal Creek aquifer at each well site. Only one well in Region I, 114A, is screened in the surficial aquifer; at the other well sites in Region I, the surficial aquifer either is not present or is directly connected to the Canal Creek aquifer. The VOC's detected in samples from well 114A are listed in table 27.

Table 29. *Estimated concentrations of tentatively identified organic compounds detected by library search for volatile organic compounds in ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[TIOC's, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample number	Sampling date	Analysis date	Volatile TIOC's	Estimated concentration (µg/L)
			Canal Creek aquifer	
CC-4B	7-13-88	7-23-88	Ethyl ether	33
CC-5C	7-13-88	7-23-88	Ethyl ether	6
CC-16A	7-25-88	8-05-88	Dichlorobenzene isomer	7
CC-30A	7-21-88	8-04-88	Substituted benzene compound	.2
CC-36B	8-22-88	9-03-88	Substituted benzene isomer	16
CC-107B	7-15-88	7-24-88	Pentachloroethane	3
CC-111A	7-26-88	8-08-88	Ethyl ether	5
CC-111B	7-26-88	8-08-88	Acetone	22
CC-111B	7-26-88	8-08-88	1,2-Dibromoethene	11
CC-115A	7-26-88	8-08-88	3,5-Dimethyloctane	3
			Surficial aquifer	
CC-135A	8-09-88	8-16-88	1,4-Dioxane	3

Table 30. *Estimated concentrations of tentatively identified organic compounds detected by library search for volatile organic compounds in ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["-R" indicates a replicate sample; dashes indicate complete laboratory number not available; TIOC'S, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample no.	Sampling date	Laboratory number	Volatile TIOC's	Estimated concentration (µg/L)
			Canal Creek aquifer	
CC-27A	05-01-89	VAU001	Pentachloroethane	20
CC-112A	05-15-89	VAW---	Nitrobenzene	3
CC-113A	04-28-89	VAT005	Alcohols (high molecular weight)	20
CC-120A	05-15-89	VAW---	Pentachloroethane	30
CC-120A-R	05-15-89	VAW---	Pentachloroethane	30
CC-120B	05-09-89	VAV002	Pentachloroethane	2

Table 31. *Estimated concentrations of tentatively identified organic compounds detected by library search for volatile organic compounds in ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

["-R" indicates a replicate sample; TIOC's, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample no.	Sampling date	Laboratory number	Volatile TIOC's	Estimated concentration (µg/L)
			Canal Creek aquifer	
CC-16A	09-15-89	VBH003	Xylenes, total	2
CC-107A	09-29-89	VBM014	2-Propanol	30
CC-120A	09-29-89	VBM008	2-Propanol	200
CC-120A	09-29-89	VBM008	Pentachloroethane	40
CC-120A-R	09-29-89	VBM009	Pentachloroethane	30
CC-120B	09-29-89	VBM012	Pentachloroethane	3

The chlorinated alkane 1,1,2,2-tetrachloroethane was a widespread contaminant in Region I (fig. 50). In Region I, concentrations of 1,1,2,2-tetrachloroethane were highest (greater than 1,000 µg/L) in area IA at sites 120 and 108 and in area ID at site 27 adjacent to the West Branch Canal Creek (figs. 19 and 50). The sample from well 27A had the maximum 1,1,2,2-tetrachloroethane concentration, 5,800 µg/L, during the second sampling period (table 24). These high concentrations of 1,1,2,2-tetrachloroethane seem to be fairly localized, as average concentrations in the Canal Creek aquifer decreased to around 100 to 300 µg/L a short distance from sites 27 and 120 (figs. 19 and 50). A relatively high 1,1,2,2-tetrachloroethane concentration of about 500 µg/L was also observed at two well sites, sites 111 and 30, in area IC by the pilot plant (figs. 19 and 50).

High concentrations of carbon tetrachloride and chloroform occurred in the Canal Creek aquifer in Region I at some of the same well sites where concentrations of 1,1,2,2-tetrachloroethane were also high--site 120 and 108 in area IA, sites 111 and 30 in area IC, and sites 28 and 113, which are near site 27 in area ID (figs. 19, 51, 52). At site 114, which is directly upgradient from site 113 (fig. 20), a higher concentration of carbon tetrachloride was measured in the surficial aquifer than in the Canal Creek aquifer. The sample from well 114A in the surficial aquifer had a carbon tetrachloride concentration of 230 µg/L during the second sampling period (table 27), whereas the average concentration

Table 32. *Estimated concentrations of unknown compounds detected by library search for volatile organic compounds in ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[µg/L, micrograms per liter]

Sample no.	Sampling date	Analysis date	Unknown volatiles	Retention time (minutes)	Estimated concentration (µg/L)
		Canal Creek aquifer			
CC-4B	7-13-88	7-23-88	Unknown	4.34	24
CC-4B	7-13-88	7-23-88	Unknown octane	22.7	4
CC-18B	7-18-88	8-01-88	Unknown	1.37	4
CC-36B	8-22-88	9-03-88	Unknown	19.87	2
CC-36B	8-22-88	9-03-88	Unknown	25.7	4
CC-36B	8-22-88	9-03-88	Unknown	30.7	4
CC-36B	8-22-88	9-03-88	Unknown	32.7	8
CC-36B	8-22-88	9-03-88	Unknown	34.2	6
CC-101B	8-17-88	8-28-88	Unknown	23.3	.3
CC-107B	7-15-88	7-24-88	Unknown	1.57	5
CC-111B	7-26-88	8-08-88	Unknown	1.52	37
CC-112A	7-26-88	8-08-88	Unknown	1.51	5
CC-120A	7-12-88	7-20-88	Unknown	24.9	6
CC-120B	7-12-88	7-20-88	Unknown	2.31	42
CC-120B	7-12-88	7-20-88	Unknown	10.4	100
CC-120B	7-12-88	7-20-88	Unknown	22.7	18
CC-120B	7-12-88	7-20-88	Unknown	24.8	260
		Surficial aquifer			
CC-33B	9-07-88	9-21-88	Unknown	4.85	3
CC-101A	8-17-88	8-28-88	Unknown	23.3	10
CC-101A	8-17-88	8-28-88	Unknown	24.0	3

Table 33. *Estimated concentrations of unknown compounds detected by library search for volatile organic compounds in ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["R" in the sample number indicates a replicate sample; µg/L, micrograms per liter.]

Sample no.	Sampling date	Unknown volatiles	Retention time	Estimated concentration (µg/L)
		Canal Creek aquifer		
CC-16A	05-03-89	Unknown	12.6	20
CC-16A	05-03-89	Unknown	20.3	2
CC-16A	05-03-89	Unknown	22.2	4
CC-16A	05-03-89	Unknown	23.1	5
CC-16A	05-03-89	Unknown	24.0	3
CC-16A	05-03-89	Unknown	26.4	6
CC-16A	05-03-89	Unknown	27.1	2
CC-16A	05-03-89	Unknown	27.4	10
CC-28B	04-28-89	Unknown	11.7	700
CC-28B	04-28-89	Unknown	12.9	100
CC-28B	04-28-89	Unknown	31.4	40
CC-108A	05-09-89	Unknown	13.6	2
CC-108A	05-09-89	Unknown	15.4	8
CC-108A	05-09-89	Unknown	22.1	20
CC-108B	05-09-89	Unknown	13.5	3
CC-108B	05-09-89	Unknown	15.4	7
CC-108B	05-09-89	Unknown	22.0	10
CC-111A	05-01-89	Unknown	1.0	2,000
CC-111A	05-01-89	Unknown	15.3	3
CC-113A	04-28-89	Unknown	11.7	600
CC-113A	04-28-89	Unknown	12.1	200
CC-113A	04-28-89	Unknown	31.4	30
CC-113A-R	04-28-89	Unknown	11.8	300
CC-113A-R	04-28-89	Unknown	12.6	80
CC-113A-R	04-28-89	Unknown	12.9	100
CC-113A-R	04-28-89	Unknown	31.5	40
CC-120A	05-15-89	Unknown	17.7	2
CC-120A	05-15-89	Unknown	23.5	40
CC-120A	05-15-89	Unknown	25.4	50
CC-120A	05-15-89	Unknown	28.1	3
CC-120A	05-15-89	Unknown	32.1	800
CC-120A-R	05-15-89	Unknown	14.5	900
CC-120A-R	05-15-89	Unknown	15.3	6
CC-120A-R	05-15-89	Unknown	16.5	50
CC-120A-R	05-15-89	Unknown	17.4	40
CC-120A-R	05-15-89	Unknown	28.7	2
CC-120B	05-09-89	Unknown	13.6	30
CC-120B	05-09-89	Unknown	15.4	20
CC-120B	05-09-89	Unknown	22.1	300

in the Canal Creek aquifer at this site was 83 µg/L (fig. 51). Chloroform concentrations in the Canal Creek aquifer (fig. 52) generally were lower than those observed for 1,1,2,2-tetrachloroethane and carbon tetrachloride (figs. 50 and 51). In the Canal Creek aquifer, the maximum carbon tetrachloride concentration (3,100 µg/L) was in a sample from well 108A (table 24), and the maximum chloroform concentration (650 µg/L) was in a sample from well 113A (table 24).

One major difference is apparent when the distribution of 1,1,2,2-tetrachloroethane (fig. 50) is compared to the distributions of carbon tetrachloride and chloroform in Region I (figs. 51 and 52). The average carbon tetrachloride and chloroform concentrations in area IB, which is directly downgradient from area IA, were very low (less than

Table 34. *Estimated concentrations of unknown compounds detected by library search for volatile organic compounds in ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

["-R" in the sample number indicates a replicate sample; µg/L, micrograms per liter]

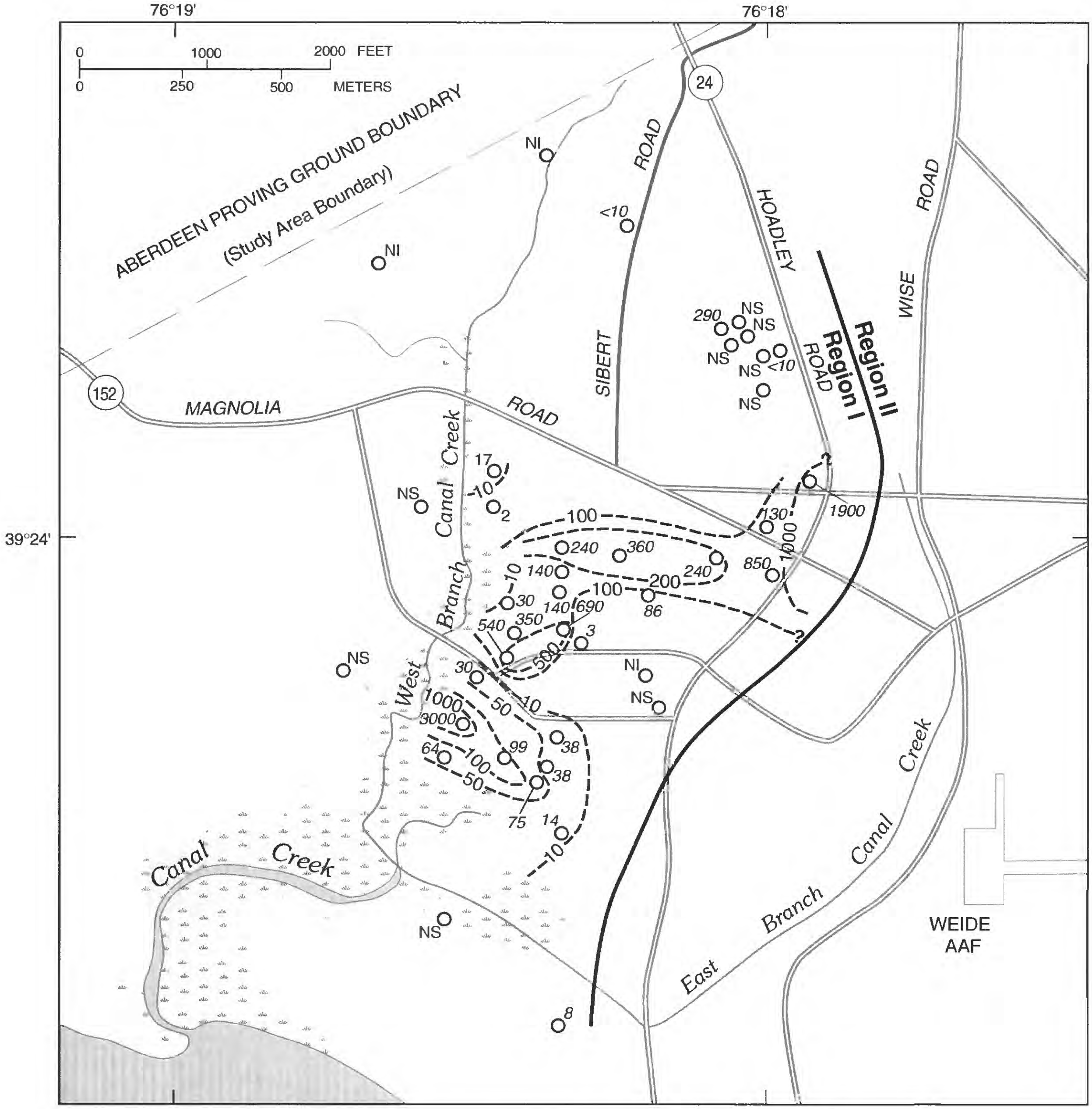
Sample no.	Sampling date	Unknown volatiles	Retention time (minutes)	Estimated concentration (µg/L)
CANAL CREEK AQUIFER				
CC-5C	10-10-89	Unknown	2.0	42
CC-5C	10-10-89	Unknown	2.5	9
CC-5C	10-10-89	Unknown	2.6	13
CC-5C	10-10-89	Unknown	2.7	18
CC-5C	10-10-89	Unknown	3.8	22
CC-5C	10-10-89	Unknown	4.2	4
CC-5C	10-10-89	Unknown	4.4	6
CC-5C	10-10-89	Unknown	7.0	5
CC-5C	10-10-89	Unknown	7.4	6
CC-5C	10-10-89	Unknown	7.8	19
CC-5C	10-10-89	Unknown	9.3	14
CC-5C	10-10-89	Unknown	9.6	15
CC-5C	10-10-89	Unknown	10.4	8
CC-5C	10-10-89	Unknown	10.8	6
CC-5C	10-10-89	Unknown	11.7	13
CC-7A	10-16-89	Unknown	2.0	9
CC-7B	10-16-89	Unknown	2.0	12
CC-7B	10-16-89	Unknown	3.2	140
CC-7B	10-16-89	Unknown	9.3	4
CC-8B	10-16-89	Unknown	2.1	8
CC-8B	10-16-89	Unknown	3.2	92
CC-8B	10-16-89	Unknown	9.3	4
CC-8B-R	10-16-89	Unknown	2.1	9
CC-8B-R	10-16-89	Unknown	3.2	85
CC-8B-R	10-16-89	Unknown	9.3	3
CC-8B-R	10-16-89	Unknown	16.0	4
CC-8C	10-16-89	Unknown	2.0	6
CC-8C	10-16-89	Unknown	2.1	6
CC-8D	10-16-89	Unknown	1.9	11
CC-8D	10-16-89	Unknown	3.1	47
CC-11A	10-20-89	Unknown	2.3	2
CC-11A	10-20-89	Unknown	9.3	3
CC-11B	10-20-89	Unknown	2.1	20
CC-11B	10-20-89	Unknown	5.6	3
CC-11B	10-20-89	Unknown	6.4	5
CC-11B	10-20-89	Unknown	6.8	2
CC-11B	10-20-89	Unknown	9.3	5
CANAL CREEK AQUIFER				
CC-13A	09-14-89	Unknown	11.2	3
CC-13A	09-14-89	Unknown	11.9	8
CC-13A	09-14-89	Unknown	12.2	30
CC-13A	09-14-89	Unknown	12.4	2
CC-13A	09-14-89	Unknown	12.5	5
CC-13A	09-14-89	Unknown	12.6	8
CC-13A	09-14-89	Unknown	13.1	2
CC-13A	09-14-89	Unknown	13.3	2
CC-13A	09-14-89	Unknown	13.6	9
CC-13A	09-14-89	Unknown	14.3	3
CC-13A	09-14-89	Unknown	16.1	2
CC-13A	09-14-89	Unknown	16.4	3
CC-16A	09-15-89	Unknown	10.7	100
CC-16A	09-15-89	Unknown	12.4	6
CC-16A	09-15-89	Unknown	13.1	8
CC-16A	09-15-89	Unknown	14.7	40
CC-16A	09-15-89	Unknown	36.3	7
CC-16A-R	09-15-89	Unknown	13.1	8
CC-16B	09-15-89	Unknown	12.2	20
CC-16B	09-15-89	Unknown	12.5	3
CC-17A	09-15-89	Unknown	15.0	2
CC-17A	09-15-89	Unknown	16.4	6
CC-18A	09-28-89	Unknown	7.0	10
CC-18B	09-28-89	Unknown	7.0	200
CC-18B	09-28-89	Unknown	11.2	20
CC-18B	09-28-89	Unknown	16.0	20
CC-22C	10-11-89	Unknown	0.9	4
CC-22C	10-11-89	Unknown	1.3	25
CC-22C	10-11-89	Unknown	2.0	3
CC-22C	10-11-89	Unknown	2.5	5
CC-22C	10-11-89	Unknown	2.6	4
CC-22C	10-11-89	Unknown	3.2	9
CC-23B	09-27-89	Unknown	2.2	30
CC-23B	09-27-89	Unknown	3.1	10
CC-23B	09-27-89	Unknown	3.7	4

Table 34. *Estimated concentrations of unknown compounds detected by library search for volatile organic compounds in ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland--Continued*

Sample no.	Sampling date	Unknown volatiles	Retention time (minutes)	Estimated concentration (µg/L)
CANAL CREEK AQUIFER				
CC-26A	09-21-89	Unknown	2.2	20
CC-26A	09-21-89	Unknown	2.5	4
CC-27A	09-18-89	Unknown	11.9	4
CC-27A	09-18-89	Unknown	12.2	20
CC-27A	09-18-89	Unknown	12.6	2
CC-27A	09-18-89	Unknown	13.0	2
CC-27A-R	09-18-89	Unknown	11.4	4
CC-27A-R	09-18-89	Unknown	11.6	4
CC-27A-R	09-18-89	Unknown	11.8	4
CC-27A-R	09-18-89	Unknown	12.2	10
CC-27A-R	09-18-89	Unknown	12.8	2
CC-27A-R	09-18-89	Unknown	13.1	2
CC-27A-R	09-18-89	Unknown	13.4	4
CC-27A-R	09-18-89	Unknown	14.1	2
CC-27A-R	09-18-89	Unknown	15.9	2
CC-27A-R	09-18-89	Unknown	16.4	2
CC-27B	09-18-89	Unknown	10.4	3
CC-27B	09-18-89	Unknown	12.2	30
CC-27B	09-18-89	Unknown	12.5	5
CC-27B	09-18-89	Unknown	13.1	10
CC-36B	10-11-89	Unknown	2.0	15
CC-36B	10-11-89	Unknown	2.4	2
CC-36B	10-11-89	Unknown	2.5	2
CC-36B	10-11-89	Unknown	2.6	4
CC-36C	10-11-89	Unknown	.4	3
CC-36C	10-11-89	Unknown	1.5	11
CC-36C	10-11-89	Unknown	2.0	11
CC-36C	10-11-89	Unknown	2.4	4
CC-102C	10-13-89	Unknown	2.0	15
CC-102C	10-13-89	Unknown	2.4	2
CC-104B	10-18-89	Unknown	1.4	12
CC-104B	10-18-89	Unknown	2.1	16
CC-104B	10-18-89	Unknown	2.3	2
CC-104B	10-18-89	Unknown	3.2	8
CC-104C	10-18-89	Unknown	1.3	6
CC-104C	10-18-89	Unknown	2.0	11
CC-104C	10-18-89	Unknown	3.2	10
CC-104C	10-18-89	Unknown	9.3	3
CANAL CREEK AQUIFER				
CC-107A	09-29-89	Unknown	11.2	2
CC-109A	09-28-89	Unknown	7.0	8
CC-117A	10-18-89	Unknown	2.1	30
CC-117A	10-18-89	Unknown	2.9	4
CC-117A	10-18-89	Unknown	6.5	9
CC-117A	10-18-89	Unknown	6.8	9
CC-117A	10-18-89	Unknown	7.4	7
CC-117A	10-18-89	Unknown	7.9	5
CC-117A	10-18-89	Unknown	10.3	6
CC-117A	10-18-89	Unknown	12.5	3
CC-117A	10-18-89	Unknown	16.1	6
CC-118A	09-28-89	Unknown	7.0	8
CC-118B	09-28-89	Unknown	7.0	50
CC-118B	09-28-89	Unknown	11.2	5
CC-120A	09-29-89	Unknown	11.2	20
CC-120A	09-29-89	Unknown	11.7	50
CC-120A	09-29-89	Unknown	16.0	500
CC-120A-R	09-29-89	Unknown	11.7	40
CC-120A-R	09-29-89	Unknown	12.6	50
CC-120A-R	09-29-89	Unknown	16.0	400
CC-120B	09-29-89	Unknown	11.8	30
CC-120B	09-29-89	Unknown	12.6	20
CC-120B	09-29-89	Unknown	16.0	300
CC-130A	09-14-89	Unknown	11.2	6
CC-130A	09-14-89	Unknown	11.4	3
CC-130A	09-14-89	Unknown	11.5	2
CC-130A	09-14-89	Unknown	12.1	30
CC-130A	09-14-89	Unknown	12.4	3
CC-130A	09-14-89	Unknown	12.7	3
CC-130A	09-14-89	Unknown	13.1	4
CC-130A	09-14-89	Unknown	13.2	2
CC-130A	09-14-89	Unknown	13.6	8
CC-130A	09-14-89	Unknown	15.0	2
CC-130A	09-14-89	Unknown	16.3	10
CC-136A	10-18-89	Unknown	2.0	8

Table 34. *Estimated concentrations of unknown compounds detected by library search for volatile organic compounds in ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland--Continued*

Sample no.	Sampling date	Unknown volatiles	Retention time (minutes)	Estimated concentration (μg/L)
CANAL CREEK AQUIFER				
CC-136B	10-18-89	Unknown	1.2	3
CC-136B	10-18-89	Unknown	1.3	3
CC-136B	10-18-89	Unknown	2.1	10
SURFICIAL AQUIFER				
CC-33A	10-11-89	Unknown	0.2	3
CC-33A	10-11-89	Unknown	.3	3
CC-33A	10-11-89	Unknown	2.0	6
CC-33A	10-11-89	Unknown	9.6	2
CC-33A	10-11-89	Unknown	16.3	5
CC-33A	10-11-89	Unknown	24.9	18
CC-33A	10-11-89	Unknown	27.4	4
CC-33B	10-11-89	Unknown	.2	3
CC-33B-R	10-11-89	Unknown	1.3	4
CC-33B-R	10-11-89	Unknown	1.9	4
CC-33B-R	10-11-89	Unknown	2.4	2
CC-114A	09-21-89	Unknown	10.7	5
CC-114A	09-21-89	Unknown	10.9	10
CC-114A	09-21-89	Unknown	11.1	3
CC-114A	09-21-89	Unknown	12.8	3

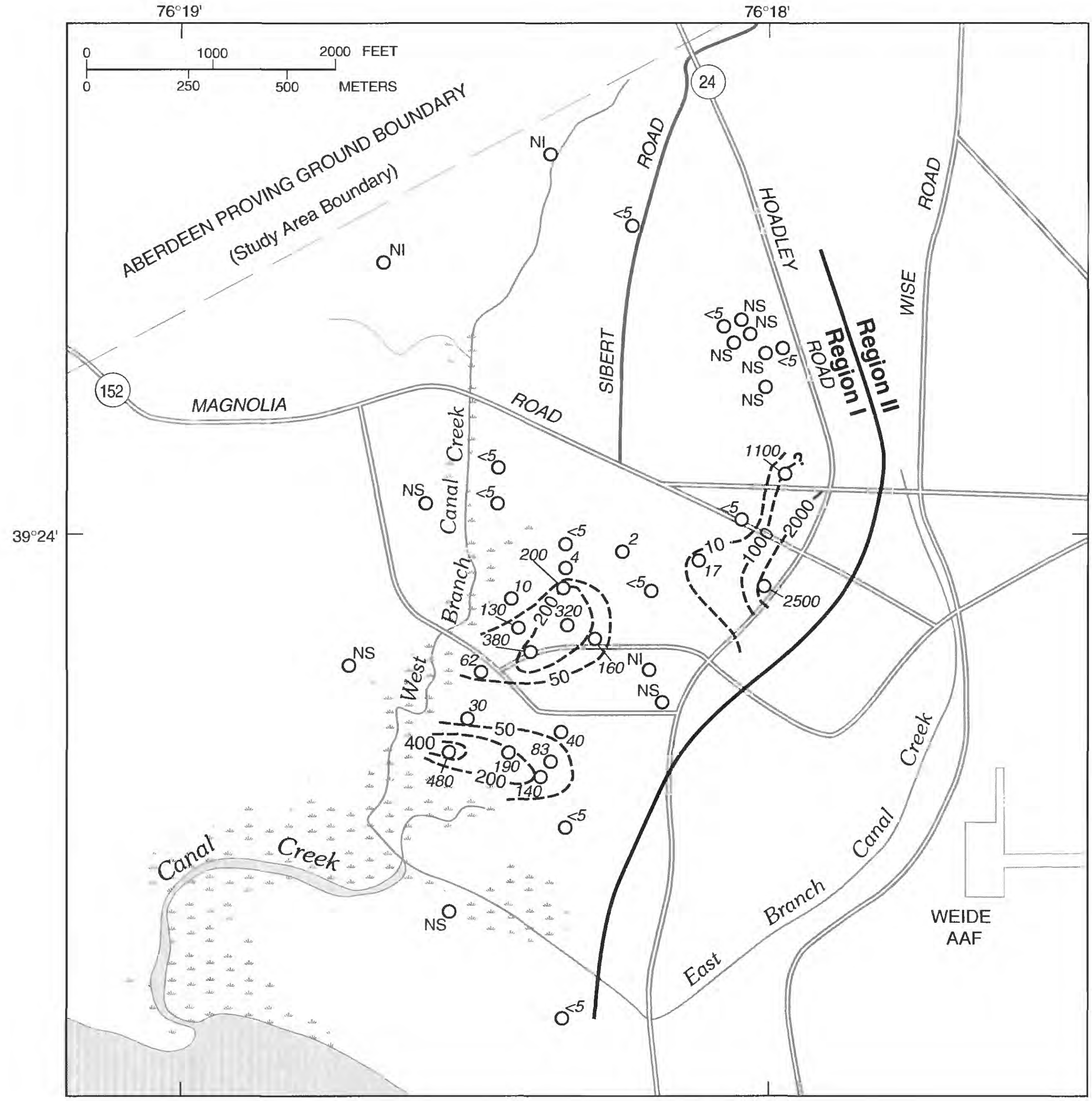


Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

?---20---	APPROXIMATE LINE OF EQUAL 1,1,2,2- TETRACHLOROETHANE CONCENTRATION - Interval in micrograms per liter, is variable. Queried where uncertain.
———	BOUNDARY BETWEEN REGION I AND II.
○ 18	WELL SITE - Number is average concentration of 1,1,2,2-tetrachloroethane, in micrograms per liter.
○ NS	WELL NOT SAMPLED.
○ NI	WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 50. Approximate distribution of 1,1,2,2-tetrachloroethane in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

?- - - 50 - - - APPROXIMATE LINE OF EQUAL CARBON TETRACHLORIDE CONCENTRATION - Interval in micrograms per liter, is variable. Queried where uncertain.

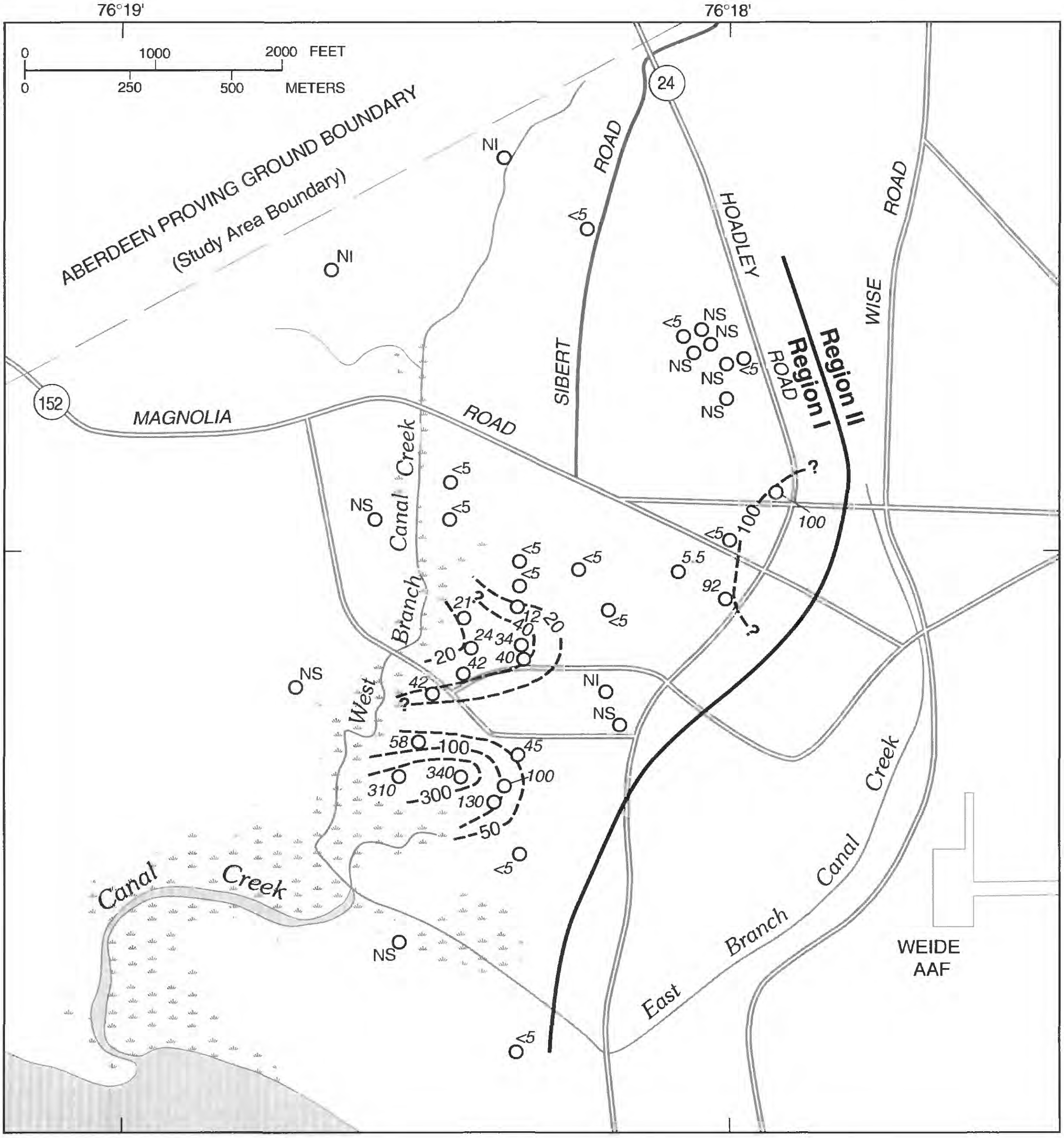
——— BOUNDARY BETWEEN REGION I AND II.

O 18 WELL SITE - Number is average concentration of carbon tetrachloride, in micrograms per liter.

O NS WELL NOT SAMPLED.

O NI WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 51. Approximate distribution of carbon tetrachloride in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

?---20--- APPROXIMATE LINE OF EQUAL CHLOROFORM CONCENTRATION - Interval in micrograms per liter, is variable. Queried where uncertain.

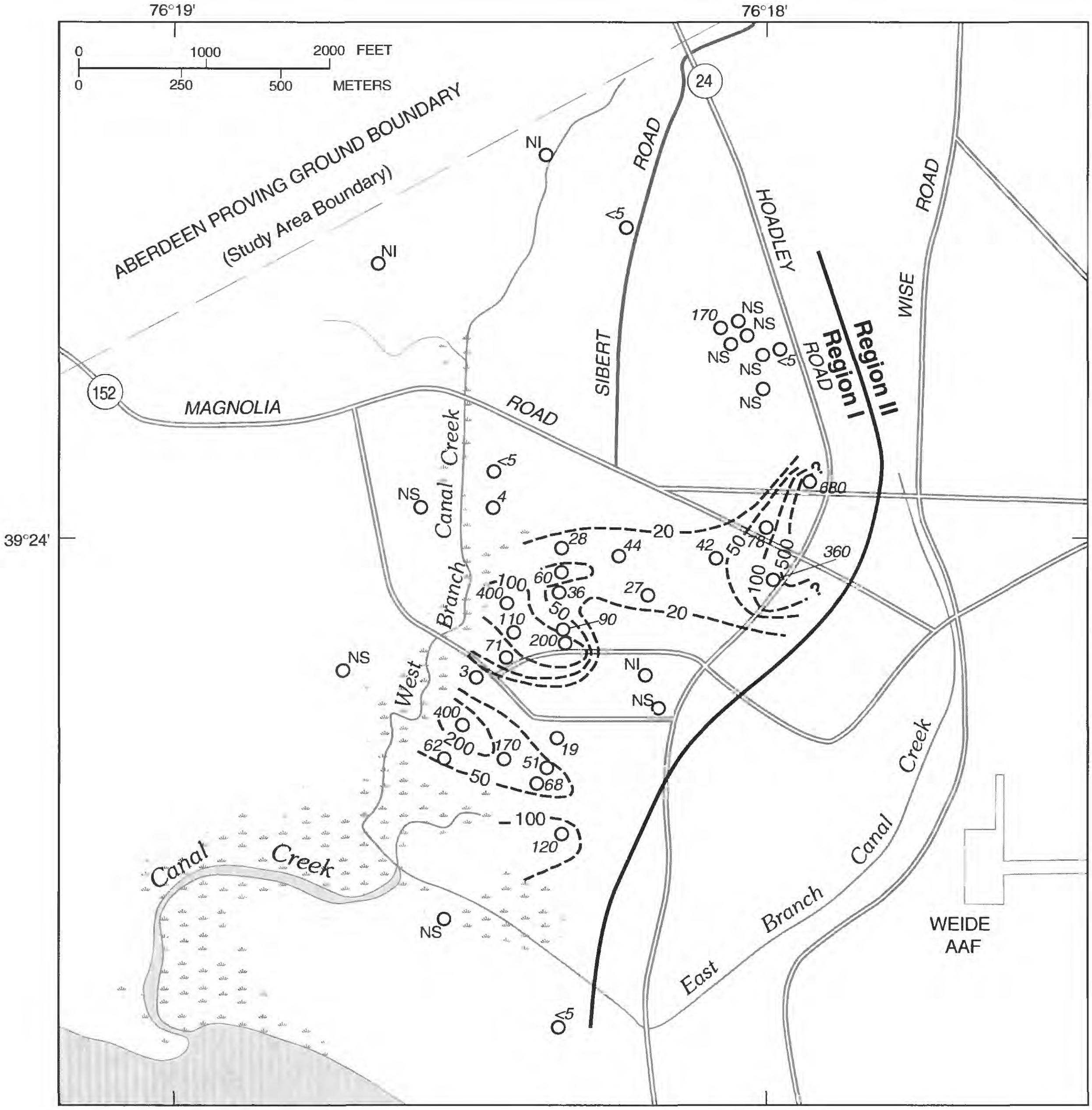
——— BOUNDARY BETWEEN REGION I AND II.

O 18 WELL SITE - Number is average concentration of chloroform, in micrograms per liter.

O NS WELL NOT SAMPLED.

O NI WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 52. Approximate distribution of chloroform in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

?---20--- APPROXIMATE LINE OF EQUAL TRICHLOROETHYLENE CONCENTRATION - Interval in micrograms per liter, is variable. Queried where uncertain.

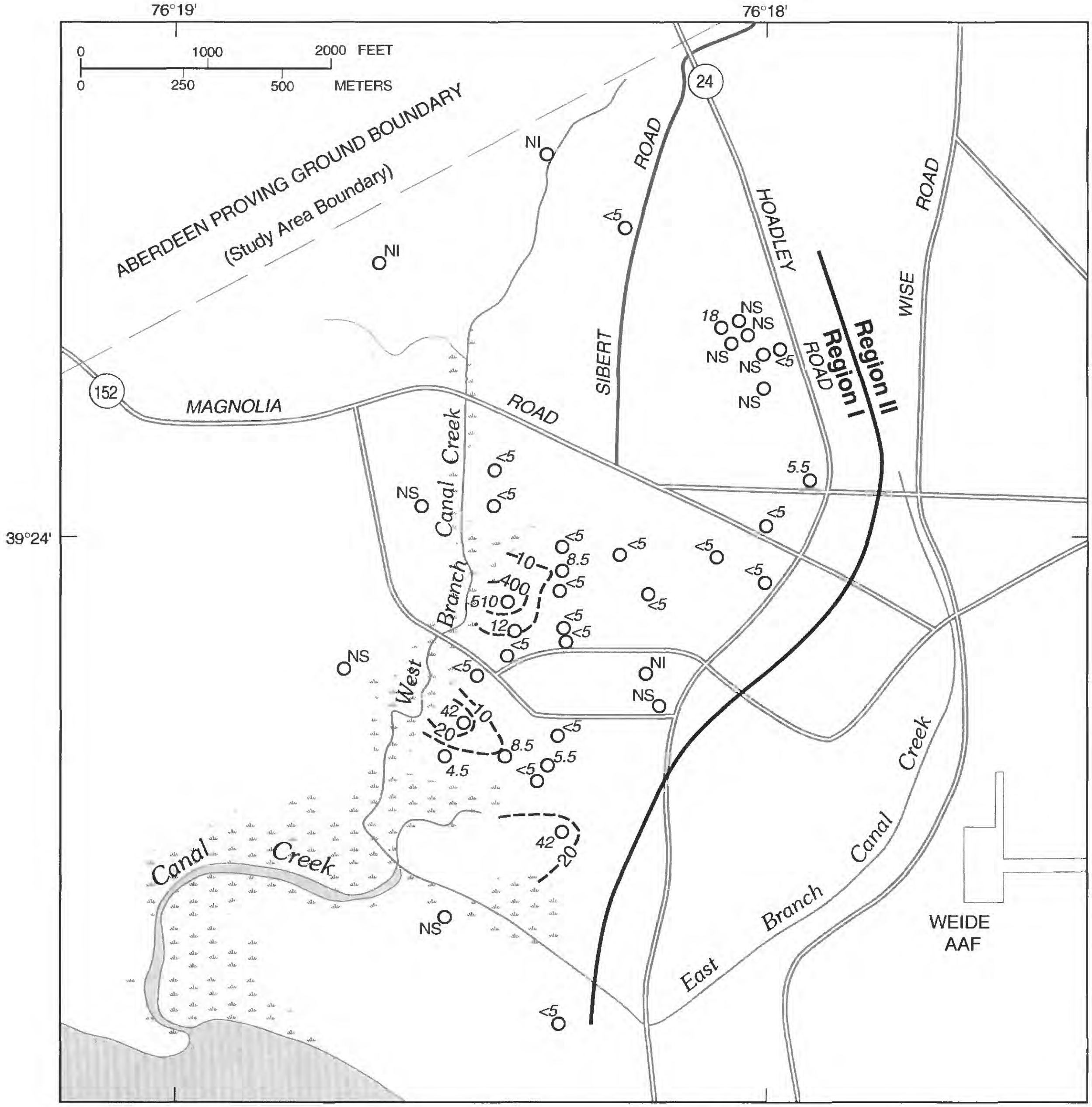
——— BOUNDARY BETWEEN REGION I AND II.

○18 WELL SITE - Number is average concentration of Trichloroethylene, in micrograms per liter.

○NS WELL NOT SAMPLED.

○NI WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 53. Approximate distribution of trichloroethylene in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

---10--- APPROXIMATE LINE OF EQUAL TRANS- 1,2-DICHLOROETHYLENE CONCENTRATION - Interval in micrograms per liter, is variable.

—— BOUNDARY BETWEEN REGION I AND II.

O 18 WELL SITE - Number is average concentration of Trans-1,2-dichloroethylene, in micrograms per liter.

O NS WELL NOT SAMPLED.

O NI WELL NOT SCREENED IN CANAL CREEK AQUIFER.

Figure 54. Approximate distribution of 1,2-*trans*-dichloroethylene in the Canal Creek aquifer in Region I, second sampling period (July-September 1988).

20 µg/L), whereas average 1,1,2,2-tetrachloroethane-concentrations in area IB were generally 100 to 300 µg/L.

The distribution of trichloroethylene in Region I is similar to the distribution of 1,1,2,2-tetrachloroethane (figs. 50 and 53). The trichloroethylene concentrations in Region I were highest at sites 120 and 108 in area IA, at site 16 near the pilot plant in area IC, and at site 27 in area ID (figs. 19 and 53). Both trichloroethylene and 1,1,2,2-tetrachloroethane also were detected in the Canal Creek aquifer in area IB, although trichloroethylene was present in lower concentrations than 1,1,2,2-tetrachloroethane was (figs. 19, 50, 53).

Although trichloroethylene and 1,1,2,2-tetrachloroethane were both widespread contaminants, trichloroethylene concentrations in the Canal Creek aquifer were generally lower than those for 1,1,2,2-tetrachloroethane throughout Region I (figs. 50 and 53). The sample from well 27A had the maximum concentrations of trichloroethylene (760 µg/L) and 1,1,2,2-tetrachloroethane (5,800 µg/L) observed in the Canal Creek aquifer during the second sampling period (table 24). Trichloroethylene and 1,1,2,2-tetrachloroethane were the major contaminants detected in ground water in area IE in the salvage yard (figs. 19, 50, and 53).

The areal extent of 1,2-*trans*-dichloroethylene in ground water in Region I (fig. 54) is less than the areal extent of the other major VOC's (figs. 50 to 53). Concentrations of 1,2-*trans*-dichloroethylene were highest in Region I at site 16, where the average concentration in the Canal Creek aquifer was around 510 µg/L during the second sampling period (figs. 19 and 54). Otherwise, 1,2-*trans*-dichloroethylene concentrations were generally less than 20 µg/L in Region I (fig. 54). Vinyl chloride was detected only at site 16 in Region I, and the vinyl chloride concentration in the sample from well 16A (210 µg/L) was the maximum concentration observed in the Canal Creek aquifer during the second sampling period (table 24).

Diagrams similar to Stiff diagrams were used to demonstrate the vertical variability in distributions of concentrations of the major VOC's along section B-B' in Region I (fig. 55). The diagrams on the sections show the concentrations, in micromoles per liter, of the chlorinated ethylenes on the right and the chlorinated ethanes on the left (figs. 55).

At most of the well sites along section B-B', concentrations of VOC's were higher in samples from the uppermost wells in the Canal Creek aquifer than in samples from wells screened deeper in the aquifer. This decrease in concentrations with depth in the aquifer is most clearly evident at sites 16, 118, and 120 (fig. 55). The shapes of the diagrams also show that more VOC's are present in the Canal Creek aquifer at sites 120 and 108 in area IA and at site 16 in area IC than are present at the other well sites along the section. Carbon tetrachloride and chloroform occurred in substantial concentrations in the Canal Creek aquifer only at sites 120 and 108 along section B-B' (fig. 55), and vinyl chloride and 1,2-dichloroethane occurred in substantial concentrations only at site 16.

Additional VOC's detected at a few sites in Region I include benzene, chlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and pentachloroethane. Maximum concentrations of the aromatic compounds were observed in samples from wells 16A, 21A, and 120A (tables 24 to 26). Samples from well 16A collected during the second sampling period had the maximum benzene concentration in the Canal Creek aquifer (140 µg/L) (table 24), and samples from wells 16A and 21A had the maximum concentrations of 1,2-dichlorobenzene during the third and fourth sampling periods, 28 µg/L and 43 µg/L, respectively (tables 25 and 26). Wells 16A and 21A are located in area IC near the pilot plant (fig. 19).

Samples from well 120A, located in contaminated area IA (fig. 19), had the maximum chlorobenzene concentration in the Canal Creek aquifer (100 µg/L) during the second sampling period (table 24) and the maximum concentrations of 1,4-dichlorobenzene during the third and fourth sampling periods (tables 25 and 26). Pentachloroethane was detected consistently only in samples collected from well 120A (tables 30 and 31).

In addition, the samples from wells 120A and 120B, located in area IA, had consistently high concentrations of volatile unknowns. Replicate samples from well 120A had total estimated concentrations of unknowns ranging from 490 to 1,000 µg/L during the third and fourth sampling periods (tables 33 and 34); samples from well 120B had total estimated concentrations of volatile unknowns ranging from 350 to 420 µg/L during three sampling periods (tables 32 to 34).

Region II

The areal distribution of the major VOC's in the Canal Creek aquifer are shown in figures 56 through 61 for Region II. Several wells in area IIA and one well in area IIC are screened in the surficial aquifer in Region II, and the major VOC's detected in samples from the surficial aquifer are given in table 27.

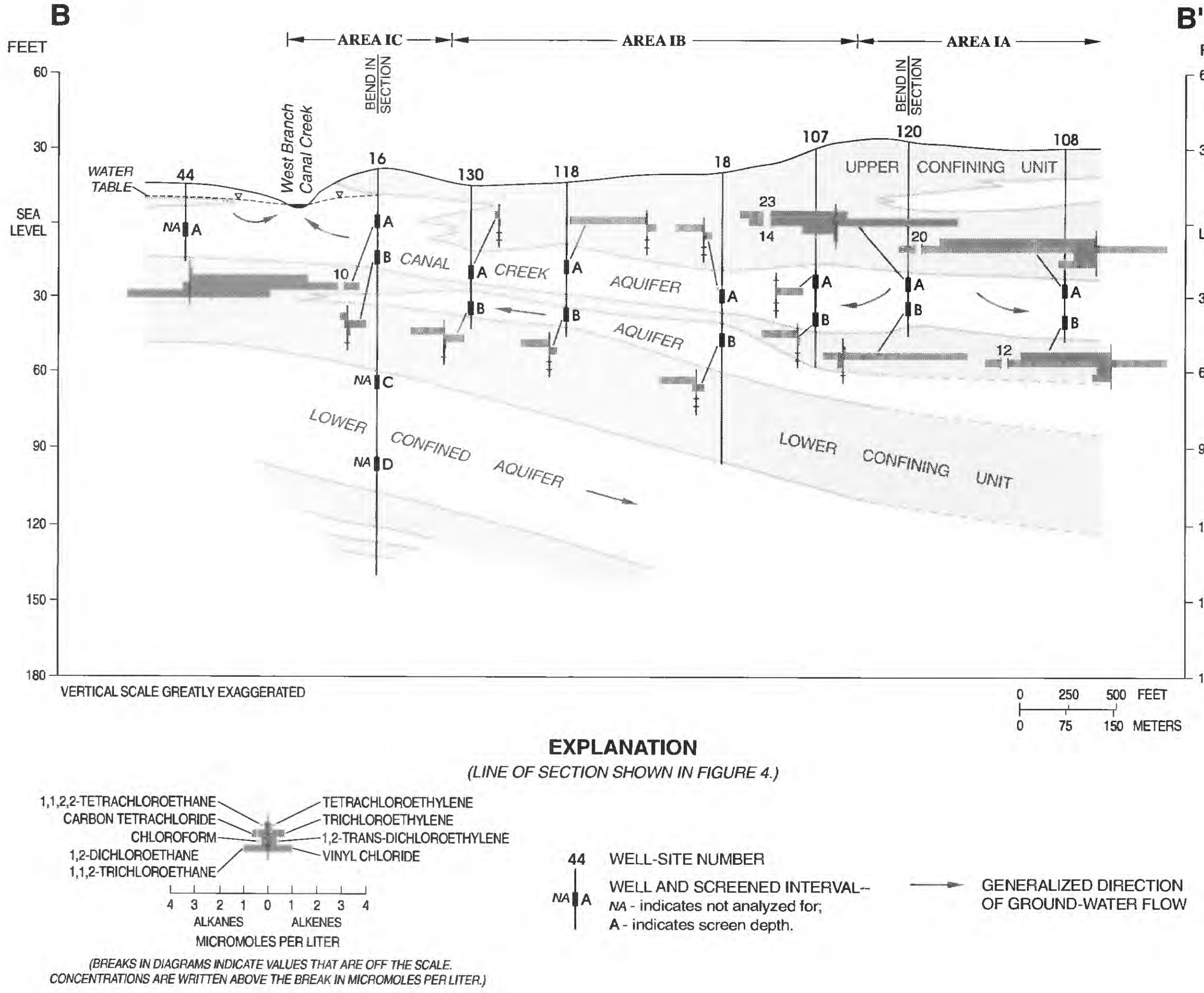
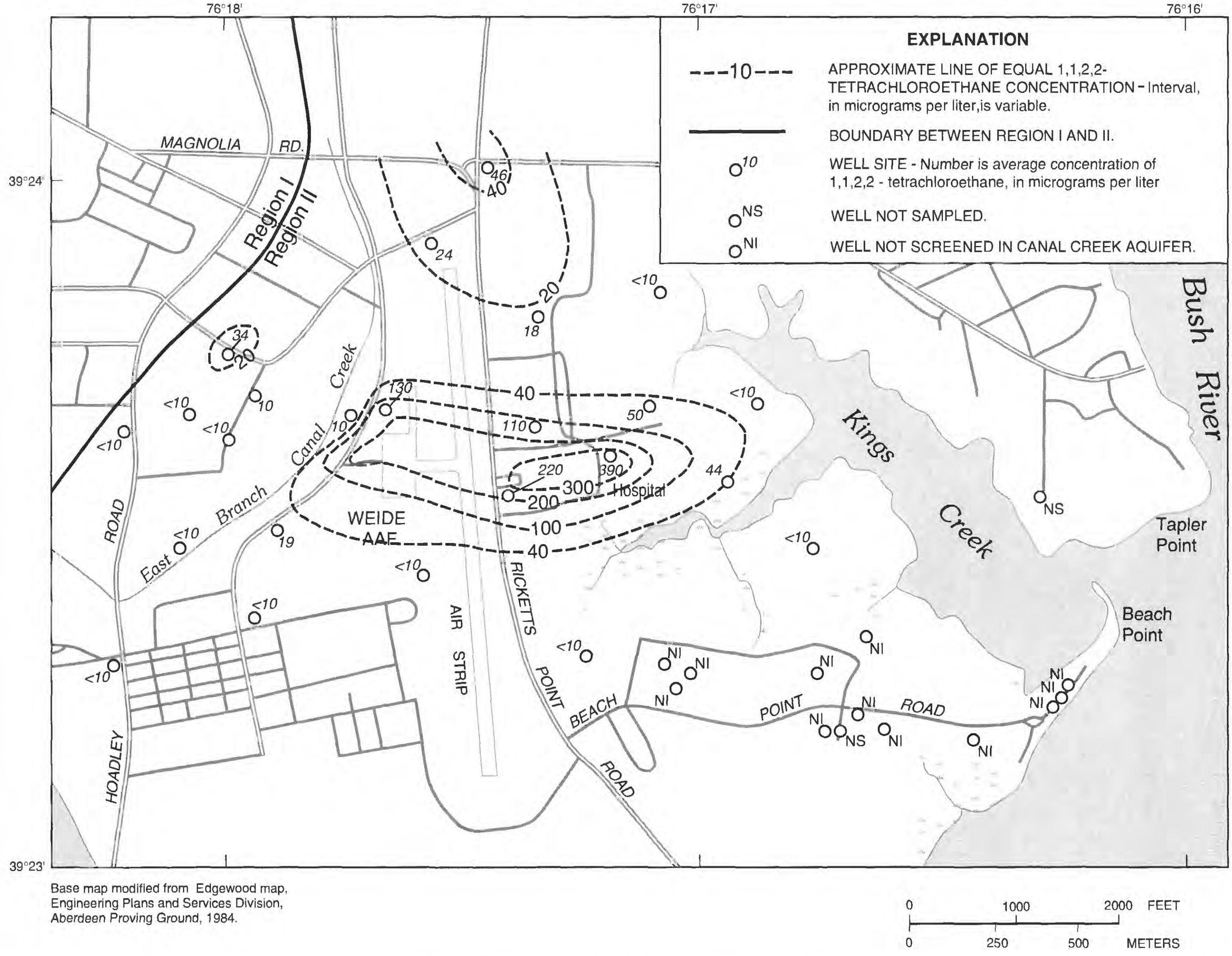


Figure 55. Distribution of selected volatile organic compounds in ground water along hydrogeologic section B-B', second sampling period (July-September 1988).

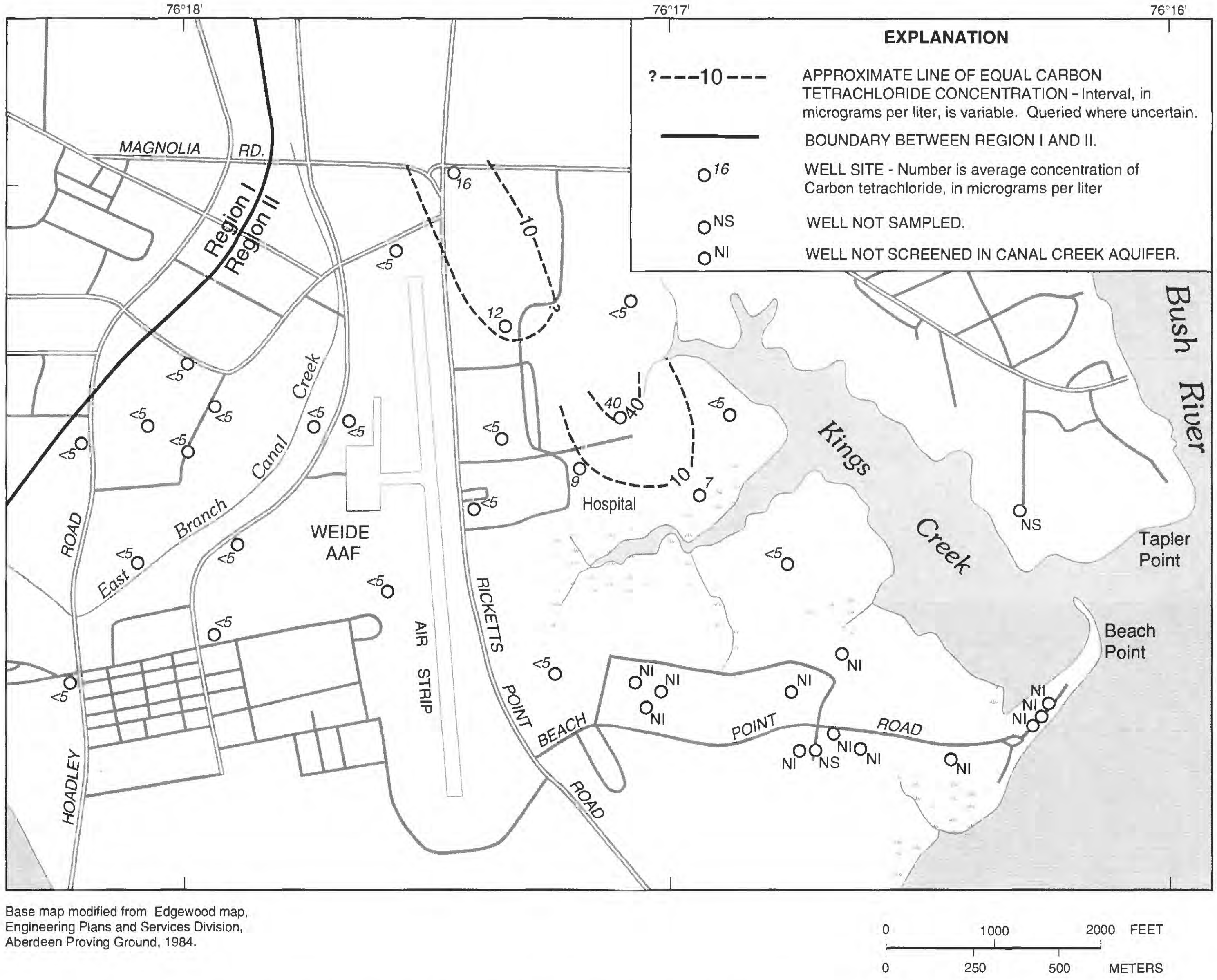
Widespread contamination by 1,1,2,2-tetrachloroethane and trichloroethylene, as was seen in Region I, was observed in the Canal Creek aquifer in Region II (figs. 56 and 59). In contrast to Region I, carbon tetrachloride and chloroform distributions in areas IIA and IIB were characterized by low concentrations (less than 50 µg/L) and by limited areal extent (figs. 57 and 58), whereas 1,2-*trans*-dichloroethylene and vinyl chloride were widespread contaminants (fig. 60 and 61).

In Region II, average concentrations of 1,1,2,2-tetrachloroethane in the Canal Creek aquifer were highest (about 400 µg/L) at site 8 near the downgradient edge of contaminated area IIB (figs. 19 and 56). The three chlorinated alkenes--trichloroethylene, 1,2-*trans*-dichloroethylene, and vinyl chloride --all had very similar areal distributions in the Canal Creek aquifer in Region II (figs. 59 to 61). Trichloroethylene and vinyl chloride concentrations were highest in the Canal Creek aquifer at sites 1 and 5 near the East Branch Canal Creek (figs. 19, 59, and 61). The 1,2-*trans*-dichloroethylene concentration was highest at site 1 (figs. 19 and 60), and the concentration of 1,100 µg/L in sample 1B was the maximum in the Canal Creek aquifer during the second sampling period (table 24). The distribution of 1,1,2,2-tetrachloroethane (fig. 56) and of the three chlorinated alkenes (figs. 59-61) differ in that 1,1,2,2-tetrachloroethane generally was not detected in the Canal Creek aquifer in the southern part of area IIA (sites 23, 22, 29, and 5 in fig. 19), whereas the chlorinated alkenes were contaminants in this area.



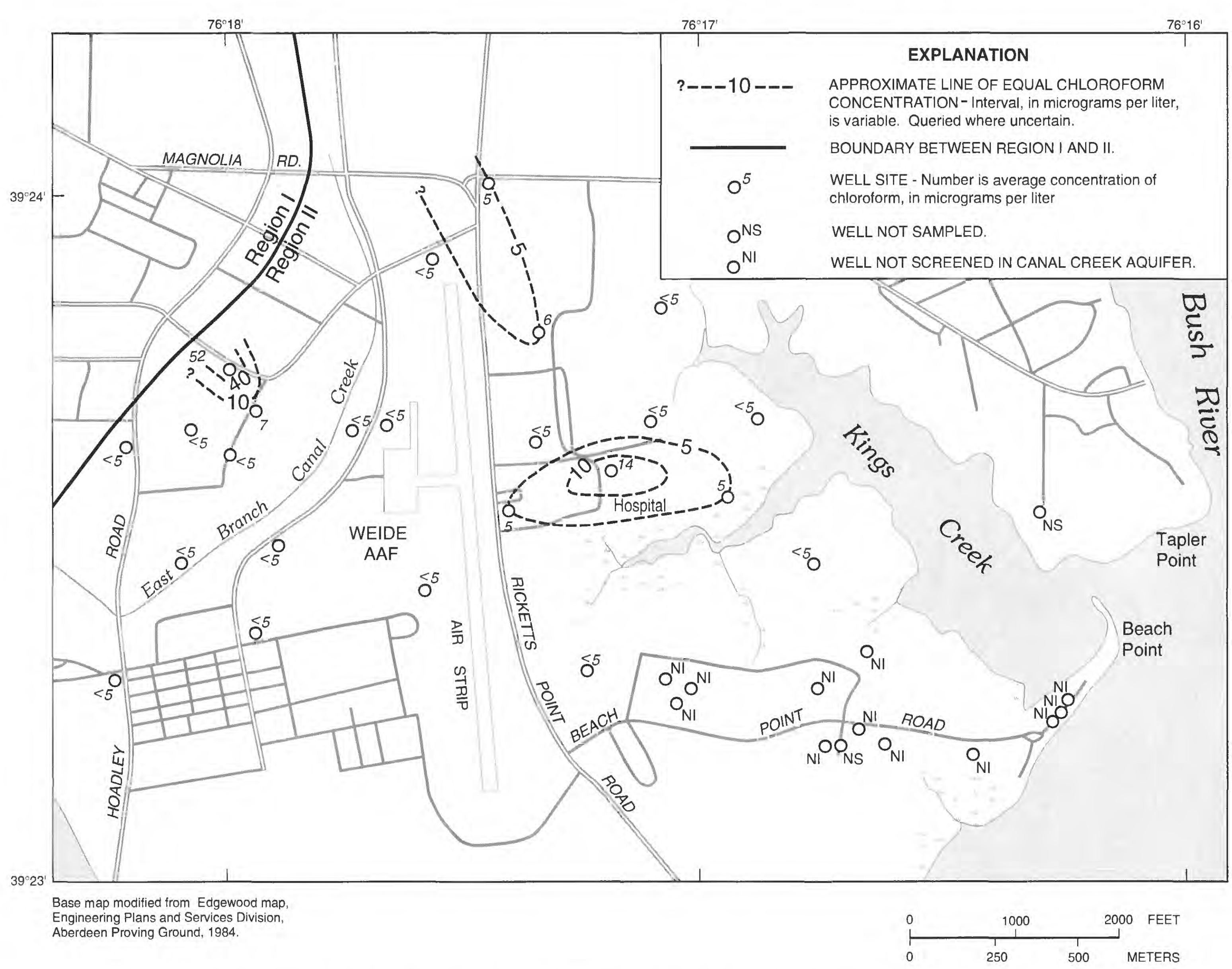
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 56. Approximate distribution of 1,1,2,2-tetrachloroethane in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



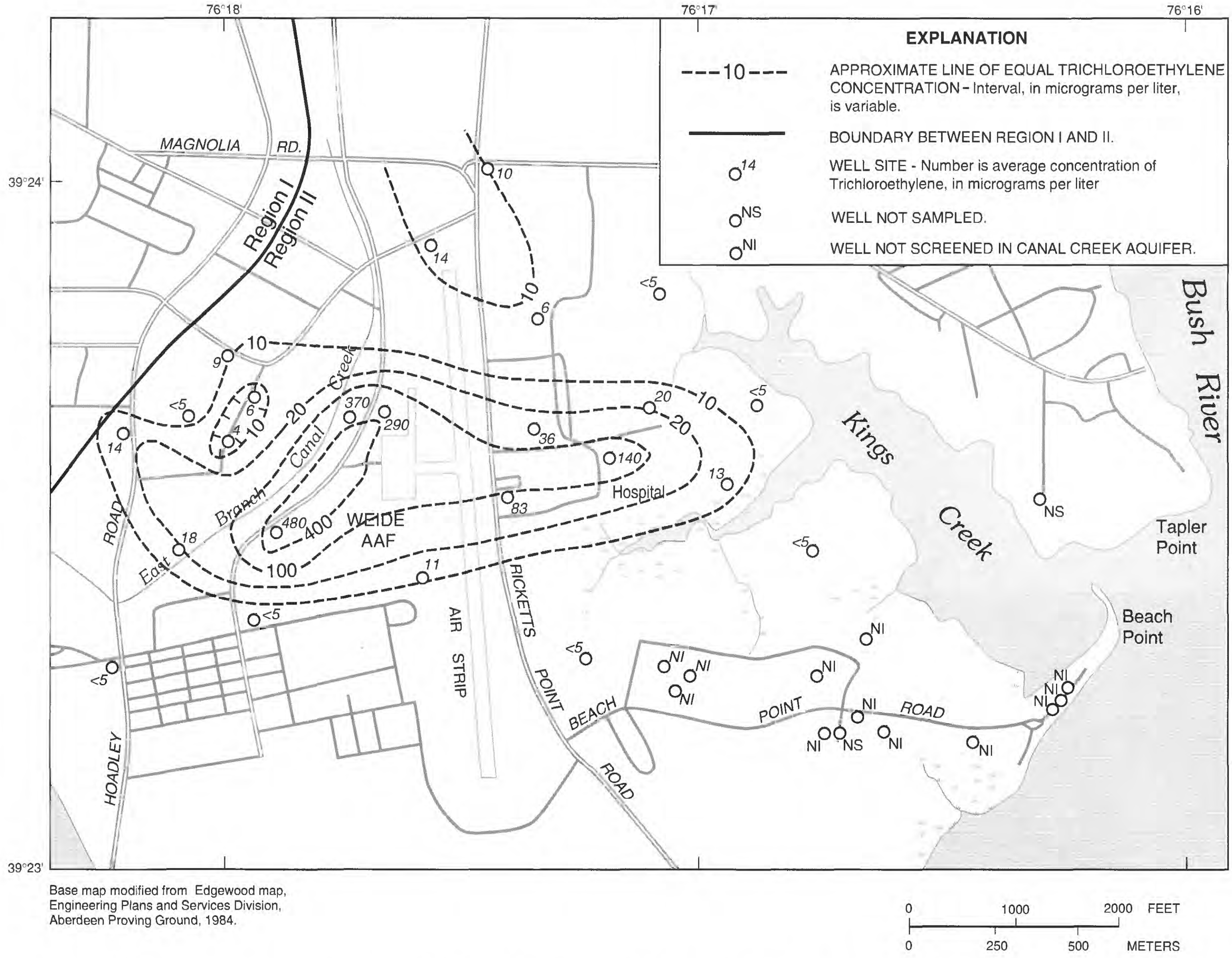
Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

Figure 57. Approximate distribution of carbon tetrachloride in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



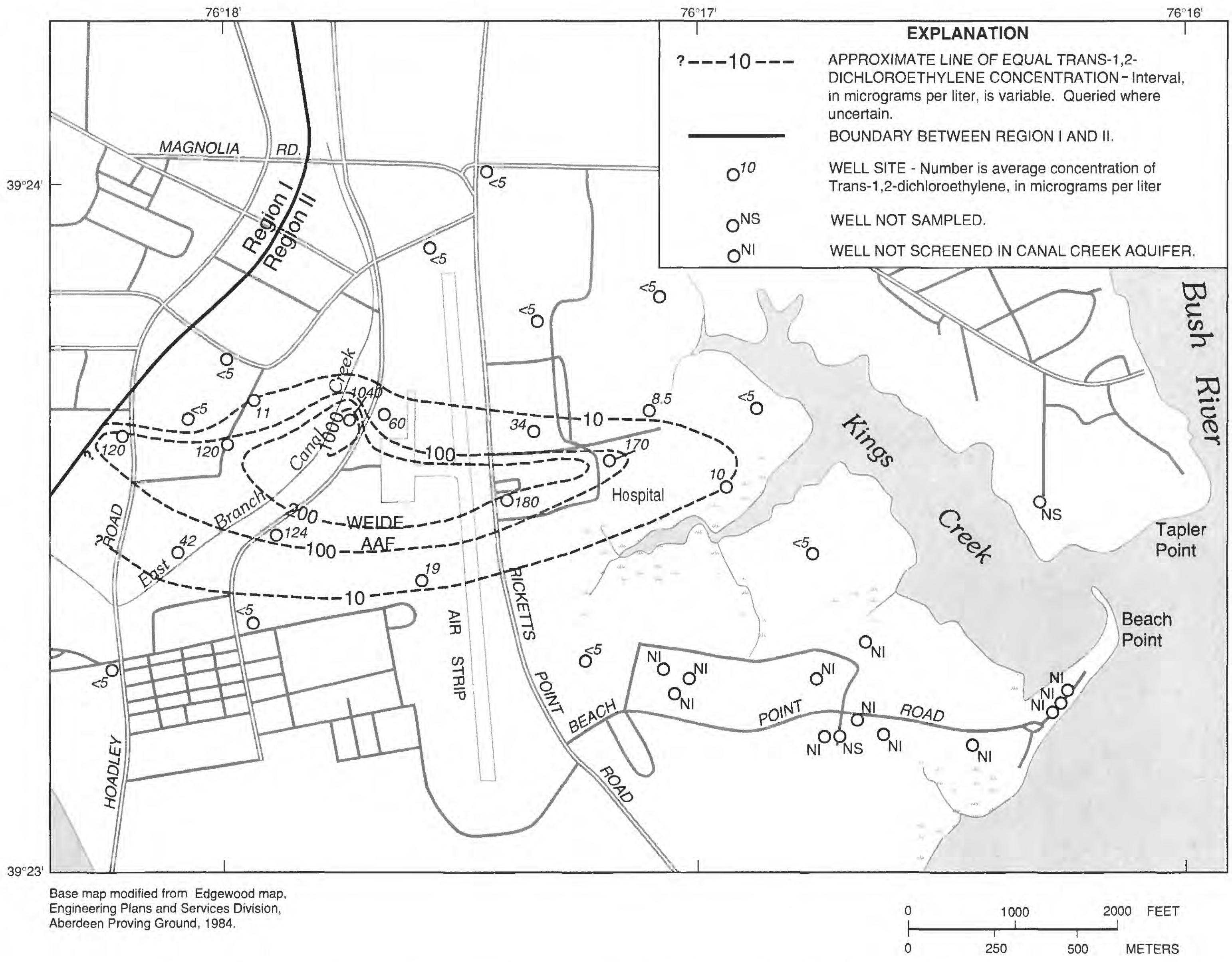
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 58. Approximate distribution of chloroform in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



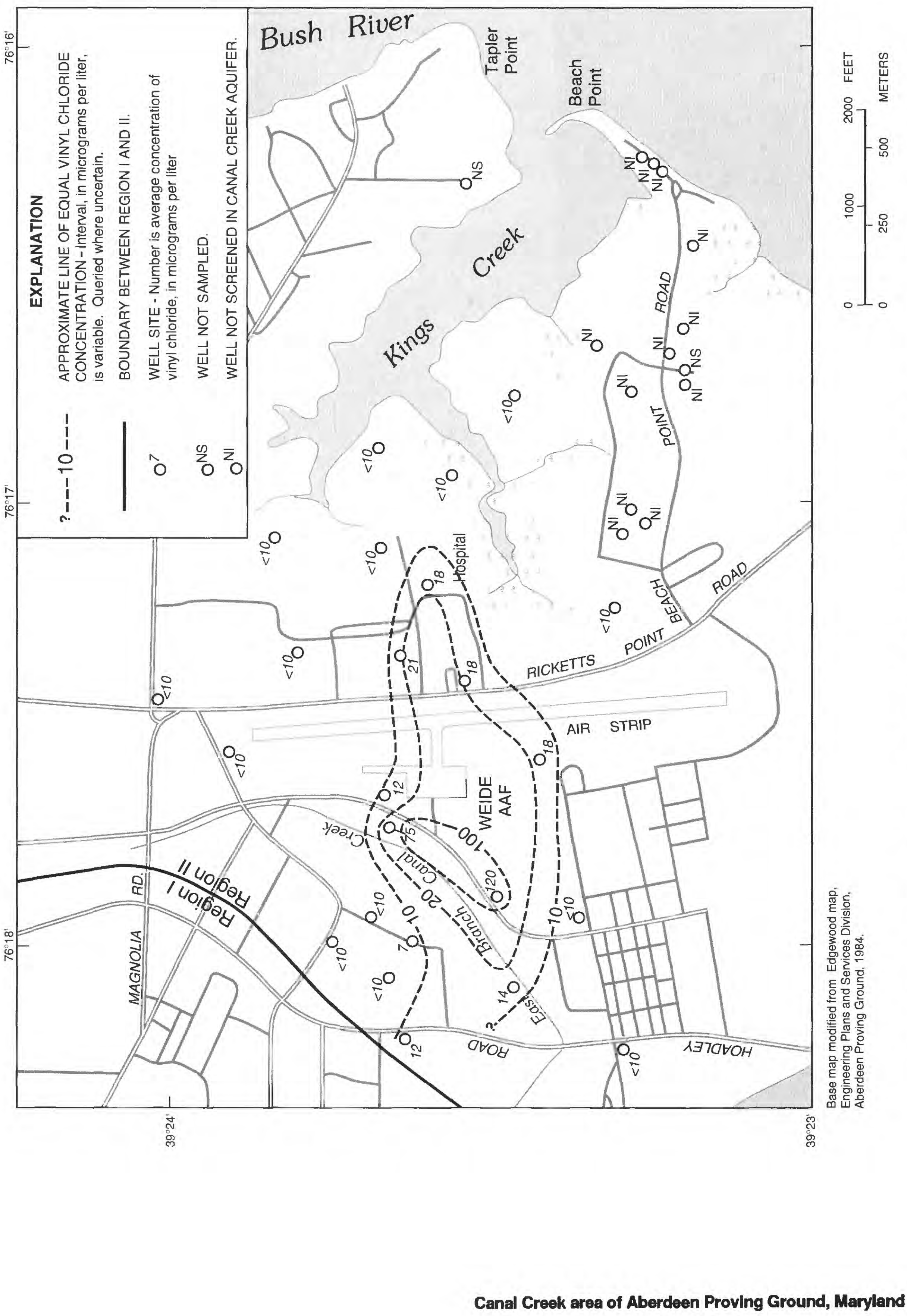
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 59. Approximate distribution of trichloroethylene in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 60. Approximate distribution of 1,2-*trans*-dichloroethylene in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 61. Approximate distribution of vinyl chloride in the Canal Creek aquifer in Region II, second sampling period (July-September 1988).

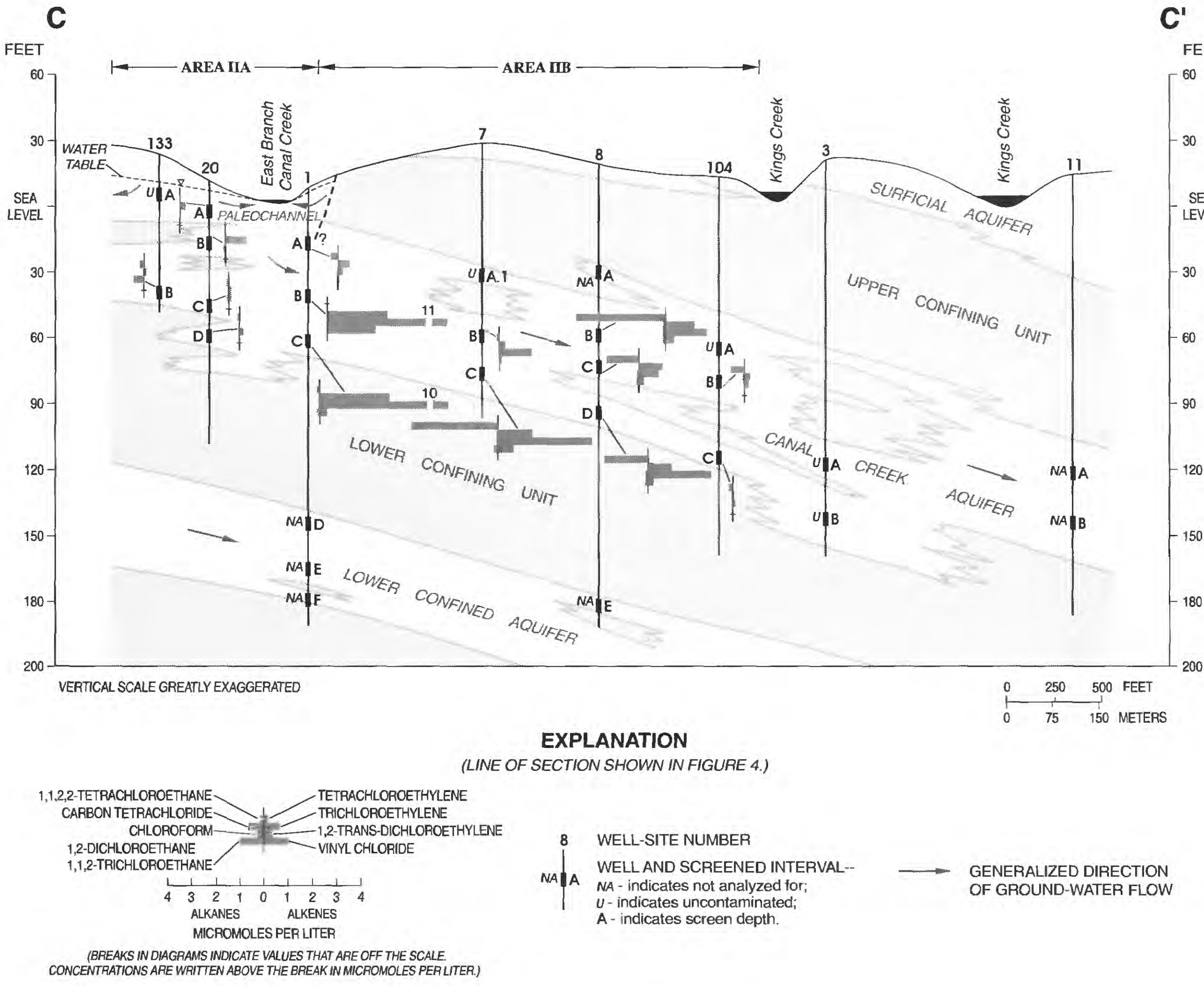


Figure 62. Distribution of selected volatile organic compounds in ground water along hydrogeologic section C-C', second sampling period (July-September 1988).

Contaminant concentrations and distributions were similar in Region II, area IIC, to those found in area IA (figs. 19 and 50 to 61). In both area IIC and area IA, 1,1,2,2-tetrachloroethane, carbon tetrachloride, and trichloroethylene were present in concentrations higher than those observed for the other VOC's; chloroform was present in relatively low concentrations; and, 1,2-*trans*-dichloroethylene and vinyl chloride were not detected.

The surficial aquifer in Region II, which is present mainly in the paleochannel in area IIA, contained the same VOC's that were detected in the Canal Creek aquifer in area IIA (table 27; fig. 62). At some sites, concentrations of the major VOC's were higher in the surficial aquifer than in the Canal Creek aquifer. Trichloroethylene concentrations were higher in samples from wells 20A and 20B, which are screened in the surficial aquifer (table 27), than the trichloroethylene concentrations in the Canal Creek aquifer at this site (fig. 62). At well site 1, concentrations of 1,1,2,2-tetrachloroethane were higher in the surficial aquifer (well 1A) than in the Canal Creek aquifer (table 27 and fig. 62). However, the concentrations of other VOC's at site 1, including trichloroethylene, 1,2-*trans*-dichloroethylene, and vinyl chloride, were higher in the Canal Creek aquifer than in the surficial aquifer (fig. 62).

Downgradient from site 1, where ground water flows in the deep confined part of the Canal Creek aquifer (fig. 62), samples from the uppermost wells in the aquifer at sites 7 and 104 were uncontaminated; samples from wells screened at lower depths at these sites did contain VOC's (fig. 62). Vertical variability in concentrations in Region II could be caused by changes in the ground-water-flow direction in the paleochannel area compared to the direction of flow in the deep confined system; local changes in ground-water-flow directions caused by the presence of lenses or thin layers of clay within the aquifers; changes in flow directions during pumping of water-supply wells in the past (fig. 21); and variations in distance from contaminant source areas.

Region III

The areas of contamination in the surficial aquifer in Region III are isolated hydrologically from the Canal Creek aquifer (figs. 17, 19, and 43). However, the types of major VOC's detected in the surficial aquifer in Region III are similar to those observed elsewhere in the surficial and Canal Creek aquifers (tables 24 and 27).

The highest concentrations of VOC's in the surficial aquifer were seen at Beach Point in Region IIID, especially in samples from well 33B (fig. 43; table 27). Maximum concentrations detected in ground water at Beach Point include 9,500 μg/L of 1,1,2,2-tetrachloroethane; 940 μg/L of trichloroethylene; 520 μg/L of 1,2-*trans*-dichloroethylene; and 200 μg/L of tetrachloroethylene (table 27).

Concentrations of VOC's were generally less than 50 μg/L in the surficial aquifer in areas IIIA, IIIB, and IIIC (table 27). Samples from well 9A in area IIIA had a maximum concentration of 19 μg/L of chlorobenzene during the second sampling period, which confirmed the chlorobenzene concentration of 14 μg/L observed during the first sampling period (Lorah and Vroblesky, 1989, p. 55). The maximum concentrations of VOC's measured in samples from the wells surrounding the toxics disposal pit in area IIIB (fig. 13 and 19) were 20 μg/L of 1,2-dichloroethane, 7.0 μg/L of 1,2-*trans*-dichloroethylene, and 8.2 μg/L of chloroform (table 27). In area IIIC, the maximum concentrations of VOC's were 47 μg/L of trichloroethylene in a sample from well 135A and 88 μg/L of carbon tetrachloride in a sample from well 10A.

Probable sources

Because organic solvents were the chemicals most commonly used and disposed of in the Canal Creek area throughout its history, the specific sources of the VOC's in the ground water are difficult to define. In many of the contaminated areas (fig. 19), several possible sources of VOC's were in close proximity: past manufacturing, filling, or research plants; various support facilities, such as machine shops and the airfield; waste-disposal areas; and leaky sewerlines and sewer discharge points (figs. 13 and 14). Most of the buildings were used for several different purposes throughout their history, and historical records of manufacturing and disposal practices are incomplete. Thus, the VOC's observed in the ground water in some areas could have originated from more than one source. In addition, defining sources of ground-water contamination is complicated because ground-water pumping during approximately 1950-68 caused past flow directions to differ from current flow directions (figs. 20 and 21).

In this section, the most probable primary sources of the major VOC's will be discussed for each contaminated area (fig. 19). Secondary sources from degradation reactions also could exist for some of the VOC's, including 1,2-*trans*-dichloroethylene, vinyl cloride, 1,1,2-trichloroethane, and 1,2-dichloroethane. These degradation products will be discussed mainly in the section on fate of the ground-water contaminants.

Region I

The location of maximum concentrations of VOC's and the overall distribution of the VOC's in Region I (figs. 50 to 54) indicate that major sources of contamination are located in area IA, area IC, and area ID. In area IA, the VOC's in the Canal Creek aquifer are probably related to activities in the filling plant in building 99 (fig. 13; table 1). The extremely high concentrations of VOC's measured in well 120A (figs. 50 to 54), which is adjacent to building 99, indicate that the well site is close to a source; no known activities upgradient from site 120 could account for the presence of these organic compounds. In addition, the long operational history (1918-81) and the large number of experimental operations that took place in building 99 (table 1) could account for the large variation in the types of VOC's, including unknowns, that were detected in the ground water at site 120.

Current ground-water-flow directions (fig. 20) indicate that the disposal pit south of site 120 (identification number 32 in fig. 13) could not be a source of the ground-water contaminants at site 120. However, when ground water was pumped from the water-supply wells in the past (figs. 21), the disposal pit could have been a source of ground-water contaminants to the south and east of site 120 in area IA. The disposal pit also could be a source of contaminants in area IB and IC under current ground-water-flow conditions (fig. 20). Little information is available on the types of materials that were buried in the pit, which was used from the early 1920's through the mid-1940's (table 1).

Although historical records for the building 99 filling plant do not specifically refer to the use of the VOC's that were detected in the ground water in area IA, VOC's were probably used as cleaning and degreasing agents for munitions metal parts, equipment, and storage containers and as decontaminating agents. DANC (an abbreviation for Decontaminating Agent, Non-Corrosive) was a commonly used decontaminating agent that contained 90 to 95 percent 1,1,2,2-tetrachloroethane by weight (Nemeth, 1989, p. 177). DANC was used to decontaminate mustard, lewisite, the nerve agent VX, and other agents that can be destroyed by chlorination. Because the ingredients for DANC were not mixed until ready for use, large amounts of 1,1,2,2-tetrachloroethane could have been stored in building 99 or in storage tanks that were located in a concrete pit next to the building (Nemeth, 1989, p. 901-902). Concentrations of 1,1,2,2-tetrachloroethane were greater than 1,000 µg/L in the ground water in area IA.

Some of the VOC's could also have been components of filling mixtures. For example, the CN mixture CNB contains 45 percent carbon tetrachloride and 45 percent benzene whereas the mixture CNS contains 38.5 percent chloroform (Nemeth, 1989, p. 43). Carbon tetrachloride, chloroform, and benzene were ground-water contaminants in area IA, and much of the munitions filling work in the Canal Creek area during the 1920's and 1930's involved smoke and CN munitions (Nemeth, 1989, p. 124). Aromatic compounds in the ground water also could be derived from petroleum products that are used in incendiary mixtures.

Leaks from storage tanks, sumps, and sewerlines are one method by which contaminants from building 99 could have been released to the environment. Building 99 was served only by a chemical wastewater and storm sewer that discharged to the East Branch Canal Creek southeast of the building until sometime during WW2, when it was connected to the sanitary sewer system. A covered concrete pit that contained storage tanks for chemicals used in the plant and seven sumps that were associated with the chemical sewer system are adjacent to or near building 99. At least two sumps are also inside the building (Nemeth, 1989, p. 901-902).

Activities that took place in the pilot plant in the building 87 complex (fig. 13; table 1) are most likely the major source of ground-water contamination in area IC (fig. 19). Although ground-water-flow directions indicate that contaminants from area IA move westward through area IC (fig. 20), the localized high concentrations of VOC's measured in the Canal Creek aquifer near the pilot plant (figs. 50 to 54) indicate an additional source in area IC. In fact, low and nondetectable concentrations of carbon tetrachloride and chloroform in area IB, which is directly downgradient from area IA (figs. 51 and 52), indicate that not all of the VOC's in area IC were derived from area IA. Some movement of contaminants from area 1A to IC could occur along ground-water flowlines to the south of area 1B (figs. 19 and 20), leaving little evidence of ground-water contamination in area IB. However, samples collected from well site 19, which is south of area IB (fig. 19), contained only low concentrations of chloroform and 1,1,2,2-tetrachloroethane (11 and 5.4 µg/L, respectively) (Lorah and Vroblesky, 1989, p. 54), an indication that ground-water flow from 1A to 1C along flowlines south of area IB is not a major contaminant migration route. Thus, the ground-water contaminants present in area IC are probably largely due to activities within area IC, such as the pilot plant in the building 87 complex.

The building 87 complex was used in 1942 to manufacture the clothing impregnite CC2 and from the mid-1940's until 1986 as a research and pilot manufacturing facility that mainly produced nerve agents (Nemeth, 1989, p. 902-907). In addition, munitions were filled with chemical agents in support of research and development work from the late 1940's until the plant closed in 1986. Sanitary and chemical sewer systems both served the building 87 complex. At least four sumps within the plant received chemical wastewater. The chemical wastewater was neutralized with caustic soda before it was discharged to the West Branch Canal Creek through the chemical sewerlines (fig. 14); however, the neutralization process did not treat chlorinated organic solvents. Between the late 1970's or early 1980's, the chemical sewer system was connected to the sanitary sewer system to eliminate wastewater discharge to Canal Creek. Some of the sewerline segments, such as the segment extending past well site 16 toward the creek (figs. 2 and 14), are known to have leaked and could have contributed to the ground-water contamination.

The solvent 1,1,2,2-tetrachloroethane was used to clean filters and other equipuiment during production of CC2 in the building 87 complex (Nemeth, 1989, p. 54). The amount of 1,1,2,2-tetrachloroethane used was approximately 9 to 10 percent of the quantity of CC2 manufactured. During 1942, approximately 1,677,130 lb of CC2 was manufactured in this plant (Nemeth, 1989, p. 53), which would have required the use of about 167,700 lb of 1,1,2,2-tetrachloroethane. All liquid wastes from CC2 production were discharged through the chemical sewerlines to the West Branch Canal Creek adjacent to the plant.

VOC's detected in ground water near the building 87 complex could have been used for various purposes during pilot-scale work with nerve agents and during munitions filling. Several references to uses of VOC's have been found in historical records. Carbon tetrachloride was used as a cooling medium during the production of the nerve agent GB during the mid-1950's (Nemeth, 1989, p. 107-108). Trichloroethylene was used at the plant in the 1950's for several purposes during production of methyldichlorophosphine (SW), an intermediate compound for manufacturing nerve agents (Nemeth, 1989, p. 111-115; Lorah and Vroblesky, 1989, p. 74). Trichloroethylene was circulated through the recycling columns to clean them, and the solvent was used as a simulant to test the final-purification distillation system. Because SW is highly reactive with water and water vapor, SW was drained into trichloroethylene when parts of the production system were drained for cleaning or repairing. The SW-trichloroethylene mixture was not reused. The method of disposal is unknown; however, operating procedures indicate that chemical spills would have been flushed into the sewer with large amounts of water. Because of safety considerations, the major components of the SW production plant were constructed outside and to the south of the main building in the 87 complex, which increased the possibility of release of contaminants to the soil.

Trichloroethylene also was used in the manufacturing process of an intermediate compound for the nerve agent VX during the late 1950's to early 1960's (Nemeth, 1989, p. 115-117). Condensers to recover butane, which was sometimes used as a carrier solvent during the manufacturing process, were made of coiled steel tubing placed inside 55-gal drums filled with dry ice and trichloroethylene. Benzene, which was detected in the Canal Creek aquifer at site 16 (table 24), was reportedly used in a scrubbing system for gases produced during manufacture of dimethylpolysulfide, abbreviated NM, which is a VX binary component (Nemeth, 1989, p. 119). NM was produced on the pilot scale in the building 87 plant from 1974-78.

VOC's known to be stored and disposed of at the building 87 pilot plant during the 1980's included 1,2-*trans*-dichloroethylene, trichloroethylene, 1,2-dichloroethane, trichloroethane, carbon tetrachloride, chloroform, chlorobenzene, benzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichloropropane (Office of the U.S. Attorney, Baltimore, Md., written commun., 1988, document 86-02534). All of these compounds were also detected in the ground water in the vicinity of the pilot plant.

Concentrations of 1,2-dichloroethane, which can be a degradation product from higher chlorinated alkanes, were commonly less than 10 μg/L in ground water from the Canal Creek area (Appendixes B2, B4, and B6); however, concentrations as high as 990 μg/L were measured in samples from well 16A next to the pilot plant during the first (Lorah and Vroblesky, 1989, p. 59) and second sampling periods (table 24). These high concentrations indicate that the 1,2-dichloroethane at site 16 was derived from a primary source and not from a secondary source such as degradation reactions.

Trans-1,2-dichloroethylene, another compound that could be derived from degradation reactions, was also detected in high concentrations only at site 16 in Region I (fig. 54). Because 1,2-*trans*-dichloroethylene is known to have been used, stored, and disposed of at the pilot plant, it is most likely that this compound is also derived from a primary source related to the pilot-plant operations and not from a secondary source of degradation reactions.

Activities in building 84, which is on the eastern side of the building 87 pilot plant (fig. 13), could have contributed to the VOC contaminantion in ground water in area IC. Building 84 was used for filling munitions with agents, which included phosgene, mustard, CNS, and CNB, and for degreasing bomb bodies during and after WW2. Building 84 was also used for cleaning and storing production equipment until the mid-1960's. Large amounts of chloroform, carbon tetrachloride, and benzene would have been handled during CNB and CNS filling; and equipment and munitions were probably degreased by use of a chlorinated solvent such as trichloroethylene (Nemeth, 1989, p. 896-897). At least during WW2, most or all of the wastewater from building 84 was discharged through a chemical sewer that led to the marsh north of the building (fig. 14). This sewer could also have been connected to the chemical sewer system for the building 87 pilot plant that discharged to the West Branch Canal Creek. Thus, activities in building 84 could have contributed to ground-water contamination in both areas IB and IC. The sewer discharge point, north of building 84 (figs. 13 and 14), is adjacent to well site 130 in area IB.

Trichloroethylene and 1,1,2,2-tetrachloroethane were the most widespread of the VOC's in ground water in area IB, and concentrations of these two compounds were relatively low compared to concentrations observed upgradient in area IA (figs. 50 and 53). The relatively low contaminant concentrations and the directions of ground-water flow (fig. 20) indicate that most, if not all, of the VOC contamination in area IB could be derived from migration of contaminants from area IA. However, the distribution of TOH in area IB shows that concentrations are slightly higher in the ground water at sites 18 and 118 than are concentrations observed upgradient at site 107 (figs. 19 and 41). Two possible contaminant sources within area IB near sites 18 and 118 are the munitions filling plant that operated in building 90 and the munitions filling plant and machine shop that operated in building 60 (fig. 13). Disposal pit #2 (identification number 32 in fig. 13), near well site 107, does not seem to be a significant source of contamination, based on available historical records and the distribution of VOC's in the ground water (figs. 19 and 41).

Building 90 was built during 1940-41 to be used as a munitions-filling plant for FS (a smoke mixture), CNB, and possibly CNS munitions (Nemeth, 1989, p. 889). The plant was then used for filling of WP munitions from 1944 until it was placed in standby condition after WW2. WP filling operations were activated again during the Korean and Vietnam wars, but the plant was used only intermittently after the Vietnam war for research and development work on WP munitions.

During WW2, large chemical storage tanks, containing FS, CNS, CNB, chloroform, carbon tetrachloride, benzene, and other chemicals used in the munitions-filling plant, were located in the west end of building 90. Because carbon tetrachloride, chloroform, and benzene were not observed in significant concentrations in ground water in area IB, the filling process for munitions with CNB and CNS and storage of these chemicals in building 90 does not seem to have been sources of ground-water contamination in area IB.

Building 60, constructed during 1941-42, was used as a mustard-filling plant until 1945 (Nemeth, 1989, p. 893-896). From 1945 until the mid-1960's, building 60 was used as a standby mustard-filling plant and for a variety of other purposes, including supply handling and storage, and equipment cleaning and storage. Building 60 was then used as a machine shop and fabrication facility from the mid-1960's until 1975.

Waste produced by building 90 and building 60 would have included organic solvents from decontamination, cleaning, and degreasing activities. Use of the decontaminant DANC could have been a source of the 1,1,2,2-tetrachloroethane in the Canal Creek aquifer in area IB (fig. 50). Waste from equipment cleaning, metal plating, and other machine shop activities in building 60 would also have included solvents. Trichloroethylene, which is found in relatively low concentrations in ground water in area IB (fig. 53), was the most commonly used chlorinated solvent for degreasing and other uses in machine shops since WW2 (Nemeth, 1989, p. 894).

The same sewer system served building 90 and building 60 (fig. 14). The chemical sewer discharged to a ditch about 500 ft west of building 60. Until about the 1970's, this chemical sewer received most or all of the chemical wastes from both buildings. A concrete neutralization sump containing limestone was added to the chemical sewer after WW2 to receive metal plating and acidic wastewater from building 60. The sump was adjacent to the north side of building 60 (Nemeth, 1989, p. 895). Contaminants could have leaked from the sewerlines and sump into the ground water in area IB; well sites 118 and 18 are near the chemical sewerlines (figs. 2 and 14).

Several major possible sources of contamination exist in area ID, including: the CN plant that operated in building 58; impregnite (CC2) manufacturing and clothing impregnating in building 103; the machine shops that operated in buildings 101, 88, and 103; mustard manufacturing and filling; and activities in the experimental plant area (fig. 13). Activities in the CN plant in building 58 are probably the major source of carbon tetrachloride and chloroform detected in the Canal Creek aquifer (figs. 51 and 52) and the surficial aquifer (table 27) in area ID.

More than 1.5 million pounds of CN was manufactured in building 58 during 1941-44, and much of the CN manufactured was used to make CNS and CNB (Nemeth, 1989, p. 43-45). Thus, several million pounds of chloroform, carbon tetrachloride, and benzene would have been handled at building 58 to make these CN mixtures. Carbon tetrachloride was received in tank cars and stored in tanks near building 58, whereas chloroform was received in steel drums, each of which held about 650 lb of chloroform. Drums and one-ton containers of raw materials were temporarily stored in open areas near building 58; and carbon tetrachloride and chloroform, which are dense solvents, could have easily infiltrated into the ground water from spills or leaky containers.

In addition, the acidic wastewaters from the plant dissolved the entire bottom of the concrete sewerline that extends southward from building 58 near well sites 114 and 26 (fig. 14). Significant quantities of the VOC's could have entered the ground water before the problem was discovered and the sewer was replaced. Solid waste and CN precipitate from leaking containers were likely buried in the marsh west of the plant (Nemeth, 1989, p. 45) and could account for the relatively high concentrations of carbon tetrachloride and chloroform observed in the Canal Creek aquifer at site 28 (figs. 51 and 52).

Impregnite manufacturing in building 103 was probably a large source of 1,1,2,2-tetrachloroethane in the ground water in area ID, because this solvent was used to clean filters. Small-scale experimental production of the impregnite CC2 took place in building 103 during 1933-39 and at least 22,000 lb of 1,1,2,2-tetrachloroethane was consumed (Nemeth, 1989, p. 52-53). The production of approximately 1,220,000 lb of CC2 during 1940-42 required the use of about 122,000 lb of 1,1,2,2-tetrachloroethane for filter maintenance. The solvent was most likely discharged as liquid waste to the sewer leading to the marsh along the West Branch Canal Creek (fig. 14).

Clothing-impregnating operations in building 103 used 1,1,2,2-tetrachloroethane to make impregnating solutions that also contained CC2 and chlorinated paraffin (Nemeth, 1989, p. 55-56). An experimental impregnating plant began operating during the early 1930's in building 103, and the first production-scale impregnating unit in the Edgewood area was installed in this building during 1934. During WW2, experimental studies of the impregnating process were again done in building 103. Waste from the clothing-impregnating operations were probably discharged through the sewer to the marsh by the West Branch Canal Creek (fig. 14). Spills in and around building 103 and leaky sewerlines could have released 1,1,2,2-tetrachloroethane to the ground water, where current ground-water-flow directions indicate that the dissolved solvent would have been transported to the west or northwest (fig. 20). The high concentration of 1,1,2,2-tetrachloroethane in ground water at site 27 (figs. 19 and 50) could indicate that solvent in undissolved form was buried or dumped in the marsh near this site.

The machine and maintenance shops that operated at various times in buildings 88, 101, and 103 (fig. 13) are probably the major source of trichloroethylene in area ID. Building 88 was constructed as a machine shop during 1922 and was active until the early or mid-1960's (Nemeth, 1989, p. 161). The building 101 complex was used for machine fabrication and maintenance facilities during and after WW2, and a nearby building was used for metal plating after WW2. Metal parts manufacturing for munitions was most active during WW2 in buildings 88, 101, and 103. Trichloroethylene was commonly used as a degreasing solvent.

Mustard manufacturing and filling, which took place during WW1 and WW2 in several buildings in the southern part of area ID (fig. 13), could have been a source of solvents used for cleaning equipment and decontamination. During WW2, chlorine absorbed in carbon tetrachloride and CC2 in 1,1,2,2-tetrachloroethane commonly were used for decontamination (Nemeth, 1989, p. 37). Ground water near and south of well site 25 would have been most affected by wastes related to mustard manufacturing and filling, and samples from this site had only low concentrations of 1,1,2,2-tetrachloroethane (fig. 50) and somewhat higher concentrations of trichloroethylene (fig. 53). The various activities that took place in the experimental-plants area (fig. 13) also could have contributed to the VOC contamination in area ID.

The former salvage yard (fig. 13) is the likely source of 1,1,2,2-tetrachloroethane and trichloroethylene in the Canal Creek aquifer in area IE (figs. 50 and 53). Solvent from containers are likely to have spilled or leaked during temporary storage and handling of chemicals during the time that the salvage yard operated. Some drums that contained unknown liquids were present in the salvage yard until site remediation began in 1990. A partly filled drum was found near well site 39, where ground-water samples had the highest concentrations of VOC's in the salvage yard (fig. 41). The label indicated that the drum originally contained trichloroethylene.

Region II

In Region II, the largest probable sources of VOC contamination were adjacent to the East Branch Canal Creek in area IIA and include the clothing-impregnating plant in building 73 and the first, second, and third filling units (fig. 13). The clothing-impregnating plant that operated in building 73 in 1942 is the most probable source of the 1,1,2,2-tetrachloroethane that has spread in a large east-trending plume in the Canal Creek aquifer in areas IIA and IIB (fig. 56). This clothing-impregnating plant used the organic-solvent impregnating process, except for 19 days when the plant used the water-suspension process (Nemeth, 1989, p. 58-60). In the organic-solvent process, approximately 85 percent of the impregnating solution consists of 1,1,2,2-tetrachloroethane. The plant operated for 278 days, 24 hours a day, using the solvent process to impregnate 3,874,918 lb of clothing. Approximately 1,024,000 lb of 1,1,2,2-tetrachloroethane was consumed during this period.

Large quantities of the 1,1,2,2-tetrachloroethane were released to the chemical wastewater and storm sewer because the solvent corroded the aluminum that was used to construct the mixing tanks and the solvent-recovery system. The sewer discharged to the East Branch Canal Creek near well site 1 (fig. 14). On one occasion, the failure of a mixing tank released 2,000 gal of impregnating solution to the sewer. The solvent-recovery rate for the plant was initially 79 percent, but the rate dropped to about 36 percent during the final months of operation. Much of the solvent lost from the recovery system was discharged with cooling water to the sewer. Nemeth (1989, p. 60) estimated that more than 100,000 gal of water containing 1,1,2,2-tetrachloroethane was discharged daily to the sewer during the last several months that the plant operated.

Much of the solvent probably was not dissolved in the water but was instead present as a separate dense liquid. Because the sewer-discharge point was where the upper confining unit is absent in the Pleistocene paleochannel (figs. 6 and 62), the dense solvent could have migrated through the surficial aquifer and directly into the Canal Creek aquifer. In addition, a dam that was present across the East Branch Canal Creek in 1942 (fig. 13) created a reservoir at the sewer-discharge point; the quiet water of the reservoir would have facilitated sinking of the dense, undissolved solvent through the streambed and would have reduced loss of the solvent to the atmosphere by volatilization.

The 1,1,2,2-tetrachloroethane detected in the Canal Creek aquifer in area IIB most likely was derived from the wastes discharged to the East Branch Canal Creek from the clothing-impregnating plant, whereas the 1,1,2,2-tetrachloroethane detected in the surficial and Canal Creek aquifers in area IIA probably originated from leaks along the sewerline and from spills or leaking storage containers in and around the plant (figs. 19 and 56). In area IIA, concentrations of 1,1,2,2-tetrachloroethane were commonly greater in the surficial aquifer than in the Canal Creek aquifer (table 27 and fig. 56). Tanks and 55-gal drums of 1,1,2,2-tetrachloroethane were delivered by rail to a concrete platform along the southwest side of the building (fig. 13). This platform was also used to store drums of the solvent. In addition, above-ground steel storage tanks for 1,1,2,2-tetrachloroethane were adjacent to the northwest side of the building, and a tank for recovered solvent was in a concrete pit adjacent to the west end of the building.

Trichloroethylene distribution in areas IIA and IIB (fig. 59) indicates that at least two sources of this solvent existed, resulting in high trichloroethylene concentrations in the ground water at site 1 in the northern part of the plume and at site 5 in the southern part of the plume. It could be significant that well sites 1 and 5 are both near past sewer-discharge points along the East Branch Canal Creek (fig. 14). When undissolved in water, trichloroethylene is a dense solvent like 1,1,2,2-tetrachloroethane that could sink through the streambed and marsh and into the surficial and Canal Creek aquifers.

The clothing-impregnating plant in building 73 could have been one source of trichloroethylene. Although the use of trichloroethylene in this plant has not been documented, the solvent may have been used for equipment cleaning and discharged through the sewer with the 1,1,2,2-tetrachloroethane. The sewer that discharged near well site 1 also received wastes during WW1 from the first and third filling plants and during WW2 from the third filling plant (which was then called building 501) and the chemical research laboratory in building 30 (fig. 13) (Nemeth, 1989, p. 790-792). The filling plants, which probably used trichloroethylene for cleaning and degreasing equipment and for cleaning munitions before filling, were most likely a larger source of waste than the research laboratory was.

Trichloroethylene was found in higher concentrations than 1,1,2,2-tetrachloroethane in the surficial and Canal Creek aquifers at well sites 20, 22, and 1, which are close to the possible sources in area IIA; this could indicate that trichloroethylene contamination was released after the clothing-impregnating plant released 1,1,2,2-tetrachloroethane in 1942. Building 501, or the third filling plant, was used for filling operations until the plant was demolished in the middle or late 1960's (table 1). Liquid wastes from building 501 were discharged through the sewer to the East Branch Canal Creek, and solid wastes could have been dumped in the adjacent marsh (Nemeth, 1989, p. 877). Although building 501 originally was used to fill munitions with various toxic agents, including mustard, the building was converted for use as a WP filling plant beginning in 1942 (Nemeth, 1989, p. 876). After the early 1950's, the work done in building 501 was primarily experimental.

The sewer that discharged near well site 5 (fig. 14) received waste during WW1 from the second filling unit and during WW2 from the smoke filling plant in the building 503 complex (fig. 13). The second filling unit, adjacent to building 503, was used briefly during WW1, was used intermittently after WW1, and was destroyed around the early 1930's (Nemeth, 1989, p. 840). Thus, the second filling unit probably was not a large source of wastewater discharge. The building 503 complex continues to be used for munitions filling and experimental work with smoke mixtures (table 1). Discharge of solvents to the sewer from the second filling unit and building 503 could be a source of the high trichloroethylene concentrations at site 5, but spills or leaks around the plant do not seem to have been a significant source of solvents. Elevated concentrations of some metals were observed in the Canal Creek aquifer at site 36, which is in the building 503 area; however, only low concentrations (less than 5 µg/L) of VOC's were measured in the surficial aquifer at site 36 (table 27), and VOC's were not detected in the Canal Creek aquifer at this site.

Relatively high concentrations of VOC's, including 1,2-*trans*-dichloroethylene and vinyl chloride (which are degradation products of trichloroethylene), were observed west of the building 503 area in the surficial and Canal Creek aquifers at site 23 (figs. 19, 59, 60, and 61). Two possible sources for the contamination at site 23 exist--the metal shops that operated north of site 23 and the sand pit adjacent to site 23 (fig. 13).

Although ground water in the Canal Creek aquifer does not flow from the former metal shops toward site 23 under present conditions (fig. 20), ground water could have flowed in this direction during the period of heavy pumping from during 1950-68. Simulations with the ground-water-flow model for the Canal Creek area that are based on pumping records from 1957 show that ground water could have flowed from the western edge of the metal shops southward to site 23 (fig. 21). The flow directions and location of the ground-water-flow divide shown in figure 21 are only approximated from 1 year of pumping records. The flow divide could actually have been further north than the position shown in figure 21, and ground water in the Canal Creek aquifer could have been pulled from the metal shops area south and southeast toward sites 23, 29, and 5.

After WW1, until the late 1930's or early 1940's, the sand pit (fig. 13), also referred to as "the building 103 dump" in historical records, was used as a dumping and burial site for miscellaneous waste that possibly included chemicals (Nemeth, 1989, p. 784). No information is available on the amount of chemical wastes placed in the dump; the pit could have been used mainly for unserviceable equipment and other waste. Recently, a storage tank became visible at the site because of erosion of soil cover. Samples from the tank contained bromobenzyl cyanide (a WW1 French riot control tear gas) and some degradation products of this compound.

The same VOC's were present in the Canal Creek aquifer in area IIC as in area IA (figs. 50 to 61). Because area IIA is near a ground-water-flow divide (figs. 19 and 20), ground water could flow to the southeast, especially from the eastern edge of the contaminant plume in area IA. In addition, southeastward movement of ground water in the Canal Creek aquifer from area IA was probably stronger during the period of heavy ground-water pumping than under current unstressed conditions (figs. 20 and 21). Thus, the VOC's in the Canal Creek area in area IIC could be derived from the munitions filling plant that operated in building 99 in area IA

Concentrations of VOC's are much lower in area IIC than in area IA. Possibly, a greater amount of contamination moved southwestward from area IA than southeastward toward area IIC, or the relatively low concentrations in area IIC could indicate that contaminant concentrations were diluted when they mixed with uncontaminated ground water as they moved from area IA into area IC. The distributions of carbon tetrachloride and chloroform in areas IIA and IIB (figs. 57 and 58) indicate that the contaminants from area IIC could have moved, at one time, far enough to the southeast to connect with the east-trending contaminant plume in area IIB. Radial flow inward toward the water-supply wells (fig. 21) that were pumped during about 1950-68 could have caused ground water in the Canal Creek aquifer to flow south from area IIC and east from area IIA, accounting for the observed distribution of VOC's (figs. 50 to 61).

No potential contaminant sources are known to be directly north of area IIC, but other possible contaminant sources within area IIC include the motor-pool garage and the runway (fig. 13). Past and present ground-water-flow directions (figs. 20 and 21) indicate that the garage and runway are not likely sources for the contamination observed in the ground water at site W6 in area IIC, but they could be sources for contamination observed at sites 124 and 6 (figs. 19 and 56-59).

Region III

In Region III, contamination was present only in the surficial aquifer, and the highest concentrations were observed in area IIID at Beach Point (fig. 43 and table 27). Clothing-impregnating operations at Beach Point were probably the major source of the VOC's in the surficial aquifer at Beach Point. A mobile impregnating plant operated at Beach Point during 1943 used the organic-solvent process and consumed approximately 100,000 lb of 1,1,2,2-tetrachloroethane (Nemeth, 1989, p. 731). Other solvents, including tetrachloroethylene, could have been tested in experimental studies of the impregnating process. Wastes were discharged to a small pit next to the mobile plant. The plant and waste-disposal pit were adjacent to well site 33, and samples from wells at this site contained the highest concentrations of VOC's, compared to concentrations measured in other wells at Beach Point (table 27).

After testing with the mobile units, a semipermanent impregnating facility that used the water suspension process was operated near the same location at Beach Point until at least 1947. Organic solvents could have been used by this plant for cleaning equipment.

Only one well is screened in the surficial aquifer in area IIIA (fig. 19), and samples from this well had low concentrations of chlorobenzene (less than 20 μg/L) (table 27). The building 330 laboratory complex (fig. 13), now designated building E3300 complex, is the most likely source. The original facilities in this complex were constructed in 1941 and 1942, and the complex has been used until the present (1992) for research and development work related to chemical warfare agents (Nemeth, 1989, p. 693-704). Chlorobenzene is a commonly used laboratory solvent. Two chemical wastewater and storm sewerlines that were used to discharge wastes to Kings Creek until about the early 1980's extended northward from the laboratory complex near well site 9.

Samples from two of the three shallow wells installed around the approximate location of the disposal pit in area IIIB (figs. 13 and 19) had low concentrations of several VOC's, including chloroform, 1,2-dichloroethane, and 1,2-*trans*-dichloroethylene (table 27). The approximate location of this pit is known only from an interview with a past employee in the area (Nemeth, 1989, p. 799). The pit was used from about 1943 until the late 1940's for disposal of toxic laboratory wastes, and the specific chemicals placed in the pit are unknown. Seepage of chemicals from this pit and spills from handling of chemicals at nearby laboratories could be sources of the VOC's in the surficial aquifer in area IIIB.

In area IIIC, two probable sources of ground-water contamination exist--the building 37xx complex near well site 10 and the pyrotechnic loading facility in building 3580 near well sites 12 and 135 (figs. 13 and 43). The building 37xx complex was constructed during 1942-43 as pilot plant facilities, but historical information on the type of work done in this pilot plant could not be found (Nemeth, 1989, p. 739). Wastewater from the complex was discharged through a chemical sewer that extends north past well site 10 to Kings Creek. Since the early 1960's, the complex has been used for testing of chemical agents and chemical-agent simulants, as well as for pyrotechnic smoke testing (Nemeth, 1989, p. 740).

Three underground storage tanks, two that hold 1,000 gal and one that holds 5,000 gal, were installed outside the building 37xx complex in the early 1960's to receive washdown and decontamination wastewater from the test chambers. Wastewater from these tanks was discharged through the chemical sewer to Kings Creek until about 1981 when the chemical sewer was connected to the sanitary sewer. A new 5,000-gal underground storage tank was installed in 1986. An integrity test of this new tank during early 1989 initially indicated leakage, but later testing did not show any leakage (Nemeth, 1989, p. 740). Leaking tanks or sewerlines could account for the relatively low concentrations of carbon tetrachloride and chloroform that were observed in the surficial aquifer at site 10 (table 27).

Near the pyrotechnic loading facility in building 3580, samples from the surficial aquifer at site 135 had relatively high concentrations of VOC's; the maximum concentration was 47 μg/L of trichloroethylene (table 27). Since 1952, building 3580 has been used as a research and development facility where pyrotechnic mixtures are prepared and loaded into munitions. Various VOC's commonly are used as solvents with the powdered pyrotechnic ingredients to make material handling easier and to clean equipment and tools (Nemeth, 1989, p. 715). From the mid-1960's until 1986, liquid chemicals used in the building were stored in 55-gal drums on a rack that was near site 135. Trichloroethylene is one chemical that is known to have been stored at the drum rack (Nemeth, 1989, p. 713).

Spills or leaks from the drums could have migrated directly into the shallow surficial aquifer. Drip pans were placed under the drum rack during the last year that it was used. Liquid chemicals are now stored in a small building immediately to the west of site 135; the building has concrete floors and interior berms to contain spills or leaks. Wastewater is generated at the facility by washing the work bays that are along the north and south sides of the building to remove dust derived from the pyrotechnic ingredients. Before 1986, the wastewater was allowed to flow to the ground outside the building, thus providing another possible means of contaminant release to the ground water.

Semivolatile Compounds

Distribution

A total of 70 semivolatile organic compounds, including base/neutral- and acid-extractable compounds, were analyzed quantitatively in selected ground-water samples collected during the second, third, and fourth sampling periods (tables 3 and 6). An additional 20 pesticides were included in the semivolatile analyses for the third and fourth sampling periods, but none of these pesticides were detectable in the ground-water samples (table 6). The semivolatile compounds detected by quantitative analysis and their concentrations are listed in tables 35 to 37 for the three sampling periods.

In addition, the results of organosulfur and explosives analyses for selected samples during the third sampling period are listed in tables 38 and 39. Many of these organosulfur and explosive compounds were also analyzed by the semivolatile method (USEPA Method 625), but the reported detection limits were generally higher (table 6) than those given by the organosulfur and explosives methods (tables 7 and 8). Estimated concentrations of semivolatile TIOC's and unknown compounds are listed in tables 40 through 45. Quality-control data for the semivolatile analyses include laboratory method blanks (tables 46 and 47) and trip and equipment blanks collected in the field (table 48). Four quality-control blanks were collected in the field for semivolatile analysis during the third and fourth sampling periods; no field blanks were collected during the second sampling period for semivolatile analysis. The quality-control blanks indicate that ground-water samples collected for semivolatile analysis generally were not contaminated by collection, handling, or shipping procedures (table 48).

Ground-water contamination by semivolatile compounds in the Canal Creek area was not as widespread as was the contamination by VOC's. Phthalate esters, including *bis*(2-ethylhexyl) phthalate, di-n-octyl phthalate, and butylbenzyl phthalate, were the most commonly detected semivolatile compounds in the ground-water samples from quantitative analysis (tables 35-37). In fact, phthalate esters were often the only semivolatile compounds detected in a sample (tables 35-37).

The phthalate esters are believed to be laboratory contaminants because (1) they were commonly detected in laboratory method blanks (tables 46 and 47), (2) they were the only semivolatile compounds detected in samples from background wells, such as wells 11B, 122A, 123A, 126A, and 136A, and from wells screened in the uncontaminated lower confined aquifer (tables 35 and 36), and (3) the presence of phthalate compounds was not confirmed by detections in samples from the same wells on more than one sampling period (tables 35-37). Phthalate esters are used extensively as plasticizers (Smith and others, 1988, p. 56-57) and could be present in laboratory equipment and containers.

The highest concentrations of semivolatile compounds that are not suspected laboratory contaminants were measured primarily in samples from four wells screened in the Canal Creek aquifer in Region I: wells 16A, 25A, 112A, and 120A (fig. 19). The semivolatile compounds quantitated in these ground-water samples were chloroaromatic and nitroaromatic compounds, including 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, and nitrobenzene (tables 35-37). Either or both of the dichlorobenzene compounds were observed in samples from wells 16A, 113A, and 120A; concentrations ranged from 2 to 29 μg/L. Repeated detections in samples from the three sampling periods confirmed the presence of the dichlorobenzene compounds at wells 16A and 120A. VOC analyses during the third and fourth sampling periods also showed dichlorobenzene compounds in samples collected from wells 16A, 113A, and 120A (Appendixes B4 and B6). Dichlorobenzene concentrations were generally higher in the samples collected for volatile analysis (tables 25 and 26) than in those collected for semivolatile analysis (tables 35 to 37) because the compounds could be partially lost through volatilization from the semivolatile samples. The samples for semivolatile analysis were not collected without headspace, whereas the samples for VOC analysis were.

Two trichlorobenzene compounds, 1,2,3-trichlorobenzene and 1,2,4-trichlorobenzene, were observed in samples from well 120A in area IA (fig. 19) during the three sampling periods (tables 35 to 37). Repeated detections in replicate samples and during three different sampling periods confirmed the presence of trichlorobenzene compounds in samples from 120A. Concentrations of 1,2,3-trichlorobenzene ranged from 14 to 18 μg/L during the three sampling periods, and concentrations of 1,2,4-trichlorobenzene ranged from 4.8 to 25 μg/L. The maximum 1,2,4-trichlorobenzene concentration of 25 μg/L exceeds the proposed MCL of 9 μg/L for this compound; 1,2,4-trichlorobenzene is the only semivolatile compound that was detected in the ground-water samples for which a Federal drinking-water regulation is in effect or has been proposed.

Nitrobenzene was observed in samples from wells 112A and 120A during three sampling periods (tables 35-37). Nitrobenzene concentrations that were reported by quantitative semivolatile analyses ranged from 37 to 100 μg/L in samples from well 112A and from 40 to 280 μg/L in samples from well 120A. Nitrobenzene concentrations reported by explosives analyses for the same wells (table 39) were higher than those reported by quantitative semivolatile analysis (tables 35-37). The nitrobenzene concentrations determined by explosives analyses were 140 and 370 μg/L for samples from wells 112A and 120A, respectively (table 39).

Table 35. *Semivolatile organic compounds quantitated in ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; method blank indicates the corresponding laboratory method blank analysis, listed in table 46; dashes indicate that data are not available; J, estimated concentration, peak present but concentration is below reported detection limit; µg/L, micrograms per liter]

Sample no.	Method blank	Sampling date	Semivolatile compound	Concentration (µg/L)
			CANAL CREEK AQUIFER	
CC-1B	MB-11	08-18-88	*bis*(2-Ethylhexyl) phthalate	6.0J
CC-1C	MB-11	08-18-88	*bis*(2-Ethylhexyl) phthalate	10
CC-W6	MB-1	07-13-88	*bis*(2-Ethylhexyl) phthalate	7.0J
CC-W6	MB-1	07-13-88	Di-n-octyl phthalate	4.0J
CC-7A.1	MB-10	08-15-88	*bis*(2-Ethylhexyl) phthalate	14
CC-7A	MB-10	08-15-88	*bis*(2-Ethylhexyl) phthalate	18
CC-8B	MB-10	08-11-88	*bis*(2-Ethylhexyl) phthalate	6.0J
CC-13A	MB-3	07-20-88	*bis*(2-Ethylhexyl) phthalate	3.0J
CC-16A	MB-5	07-25-88	1,4-Dichlorobenzene	2.0J
CC-16A	MB-5	07-25-88	1,2-Dichlorobenzene	29
CC-16A	MB-5	07-25-88	*bis*(2-Ethylhexyl) phthalate	23
CC-17A	MB-5	07-25-88	*bis*(2-Ethylhexyl) phthalate	24
CC-18A	MB-2	07-18-88	*bis*(2-Ethylhexyl) phthalate	22
CC-18A-R	MB-2	07-18-88	*bis*(2-Ethylhexyl) phthalate	7.0J
CC-25A	MB-7	08-01-88	Di-n-butyl phthalate	2.0J
CC-25A	MB-7	08-01-88	*bis*(2-Ethylhexyl) phthalate	4.0J
CC-26A	MB-6	07-27-88	*bis*(2-Ethylhexyl) phthalate	5.0J
CC-28A	MB-7	07-28-88	*bis*(2-Ethylhexyl) phthalate	4.0J
CC-28A-R	MB-7	07-28-88	None detected	--
CC-39A	MB-13	09-08-88	*bis*(2-Ethylhexyl) phthalate	1,000
CC-39A	MB-13	09-08-88	Di-n-octyl phthalate	73
CC-101B	MB-11	08-17-88	*bis*(2-Ethylhexyl) phthalate	4.0J
CC-102B	MB-11	08-16-88	*bis*(2-Ethylhexyl) phthalate	12
CC-104A	MB-10	08-12-88	*bis*(2-Ethylhexyl) phthalate	3.0J
CC-104B	MB-10	08-12-88	*bis*(2-Ethylhexyl) phthalate	2.0J
CC-104C	MB-10	08-12-88	Di-n-octyl phthalate	3.0J
CC-108B	MB-10	07-15-88	Di-n-octyl phthalate	5.0J
CC-110A	MB-3	07-21-88	Phenol	7.0J
CC-110A	MB-3	07-21-88	4-Methylphenol	2.0J
CC-110A	MB-3	07-21-88	*bis*(2-Ethylhexyl) phthalate	30
CC-112A	MB-5	07-26-88	Nitrobenzene	79
CC-112A	MB-5	07-26-88	*bis*(2-Ethylhexyl) phthalate	12
CC-113A	MB-7	07-28-88	1,4-Dichlorobenzene	2.0J
CC-113A	MB-7	07-28-88	*bis*(2-Ethylhexyl) phthalate	3.0J
CC-114B	MB-2	07-27-88	*bis*(2-Ethylhexyl) phthalate	5.0J
CC-120A	MB-1	07-12-88	*bis*(2-Chloroethyl) ether	2.0J
CC-120A	MB-1	07-12-88	1,4-Dichlorobenzene	9.0J
CC-120A	MB-1	07-12-88	1,2-Dichlorobenzene	5.0J
CC-120A	MB-1	07-12-88	Nitrobenzene	40
CC-120A	MB-1	07-12-88	1,2,4-Trichlorobenzene	7.0J
CC-120A	MB-1	07-12-88	*bis*(2-Ethylhexyl) phthalate	5.0J
CC-120B	MB-1	07-12-88	Di-n-octyl phthalate	3.0J
CC-122A	MB-4	08-03-88	*bis*(2-Ethylhexyl) phthalate	13
CC-123A	MB-1	07-14-88	*bis*(2-Ethylhexyl) phthalate	3.0J
CC-123A	MB-1	07-14-88	Di-n-octyl phthalate	3.0J
CC-124B	MB-1	07-13-88	Di-n-octyl phthalate	2.0J
CC-130B	MB-2	07-21-88	*bis*(2-Ethylhexyl) phthalate	19
			SURFICIAL AQUIFER	
CC-33B	MB-12	09-07-88	*bis*(2-Ethylhexyl) phthalate	72
CC-126A	MB-8	08-04-88	*bis*(2-Ethylhexyl) phthalate	46
CC-128A	MB-8	08-04-88	*bis*(2-Ethylhexyl) phthalate	32
CC-129A	MB-8	08-04-88	*bis*(2-Ethylhexyl) phthalate	3.0J
			LOWER CONFINED AQUIFER	
CC-6C	MB-1	07-11-88	*bis*(2-Ethylhexyl) phthalate	3.0J
CC-6C	MB-1	07-11-88	Di-n-octyl phthalate	4.0J
CC-140A	MB-4	08-03-88	*bis*(2-Ethylhexyl) phthalate	6.0J

Table 36. *Semivolatile organic compounds quantitated in ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; "(N)" indicates that sample was analyzed by the U.S. Geological Survey National Water Quality Laboratory; dashes indicate data not available; µg/L, micrograms per liter]

Sample no.	Sampling date	Laboratory no.	Semivolatile compound	Concentration (µg/L)
			CANAL CREEK AQUIFER	
CC-8B(N)	05-25-89	--	*bis*(2-Ethylhexyl) phthalate	6.0
CC-11B(N)	05-31-89	--	*bis*(2-Ethylhexyl) phthalate	17
CC-13A	05-04-89	SAK008	Butylbenzyl phthalate	10
CC-23B	05-15-89	SAM004	Butylbenzyl phthalate	20
CC-25A	05-17-89	SAM008	1,4-Oxathiane	16
CC-27A	05-01-89	SAK005	Butylbenzyl phthalate	100
CC-112A	05-15-89	SAM002	Nitrobenzene	100
CC-112A-R	05-15-89	SAM003	Nitrobenzene	100
CC-120A	05-15-89	SAM006	Nitrobenzene	200
CC-120A	05-15-89	SAM006	1,4-Dichlorobenzene	25
CC-120A	05-15-89	SAM006	1,2,3-Trichlorobenzene	18
CC-120A	05-15-89	SAM006	1,2,4-Trichlorobenzene	4.8
CC-120A-R	05-15-89	SAM005	Nitrobenzene	100
CC-120A-R	05-15-89	SAM005	1,2,3-Trichlorobenzene	14
CC-120A-R	05-15-89	SAM005	1,4-Dichlorobenzene	20
CC-120A-R(N)	05-15-89	--	Nitrobenzene	280
CC-120A-R(N)	05-15-89	--	1,2,4-Trichlorobenzene	25
CC-120A-R(N)	05-15-89	--	*bis*(2-Chloroethyl)ether	8.0
CC-120A-R(N)	05-15-89	--	*bis*(2-Chloroisopropyl)ether	5.0
CC-136A(N)	05-26-89	--	*bis*(2-Ethylhexyl) phthalate	8.0
			SURFICIAL AQUIFER	
CC-12A.1	04-25-89	SAI004	Butylbenzyl phthalate	40
CC-20A(N)	05-18-89	--	*bis*(2-Ethylhexyl) phthalate	6.0
CC-127A	04-25-89	SAI005	Butylbenzyl phthalate	30
CC-129A	04-25-89	SAI001	Butylbenzyl phthalate	10
CC-135A	04-25-89	SAI003	Butylbenzyl phthalate	20
			LOWER CONFINED AQUIFER	
CC-1D(N)	06-01-89	--	*bis*(2-Ethylhexyl) phthalate	13
CC-1E(N)	06-06-89	--	*bis*(2-Ethylhexyl) phthalate	20

Cyclotrimethylenetrinitramine, which is also called cyclonite or RDX, was the only other explosives compound detected (table 39). A low RDX concentration of 0.5 µg/L was measured in the samples from wells 112A and 120A (table 39). RDX is a cyclic nitrogen compound with the chemical formula $C_3H_6N_6O_6$ (Windholz and others, 1983, p. 392-393). Another cyclic nitrogen compound, 4-chloroaniline, was quantitated in one sample from well 16A that was collected during the fourth sampling period (table 37).

The results of the organosulfur analyses showed the presence of dithiane (8.3 µg/L) and 1,4-oxathiane (24 µg/L) in well 25A (table 38), which is screened in the Canal Creek aquifer in area ID (fig. 19). The measurement of 16 µg/L of 1,4-oxathiane in the quantitative semivolatile analysis of sample 25A during the third sampling period (table 36) confirmed the presence of this compound in ground water from well 25A; and, dithiane was tentatively identified by library search in the sample from well 25A during the second sampling period (table 40). Molecular sulfur, which could be associated with the organosulfur compounds, was tentatively identified by library search in samples from well 25A during the second and third sampling periods (tables 40 and 41). Low concentrations of dithiane (3.0 to 3.2 µg/L) were also measured by organosulfur analysis of replicate samples from well 33B (table 38), which is screened in the surficial aquifer in area IIID (fig. 19).

Table 37. *Semivolatile organic compounds quantitated in ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; µg/L, micrograms per liter]

Sample number	Sampling date	Laboratory number	Semivolatile compound	Concentration (µg/L)
		CANAL CREEK AQUIFER		
CC-16A	09-15-89	SAW001	1,2-Dichlorobenzene	14
CC-16A	09-15-89	SAW001	4-Chloroaniline	78
CC-112A	09-18-89	SAW002	Nitrobenzene	37
CC-120A	09-29-89	SBA001	Nitrobenzene	200
CC-120A	09-29-89	SBA001	1,4-Dichlorobenzene	20
CC-120A	09-29-89	SBA001	1,2,3-Trichlorobenzene	16
CC-120A	09-29-89	SBA001	1,2,4-Trichlorobenzene	6.9
CC-120A-R	09-29-89	SBA002	Nitrobenzene	120
CC-120A-R	09-29-89	SBA002	1,4-Dichlorobenzene	18
CC-120A-R	09-29-89	SBA002	1,2,3-Trichlorobenzene	17
CC-120A-R	09-29-89	SBA002	1,2,4-Trichlorobenzene	5.5
CC-120A-R	09-29-89	SBA002	*bis*(2-Chloroethyl)ether	16

Table 38. *Semivolatile organic compounds quantitated by organosulfur analysis (gas chromatography) for ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; µg/L, micrograms per liter]

Sample number	Sampling date	Laboratory number	Organosulfur compound	Concentration (µg/L)
		CANAL CREEK AQUIFER		
CC-25A	05-17-89	OAF004	Dithiane	8.3
CC-25A	05-17-89	OAF004	1,4-Oxathiane	24
		SURFICIAL AQUIFER		
CC-33B	04-26-89	OAB010	Dithiane	3.0
CC-33B-R	04-26-89	OAB006	Dithiane	3.2

Table 39. *Semivolatile organic compounds quantitated by explosives analysis (high pressure liquid chromatography) for ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

[Alternative compound name(s) inside brackets; µg/L, micrograms per liter]

Sample number	Sampling date	Explosive compound	Concentration (µg/L)
CC-112A	05-15-89	Nitrobenzene	140
CC-112A	05-15-89	Cyclotrimethylene- trinitramine [cyclonite/RDX]	.5
CC-120A	05-15-89	Nitrobenzene	370
CC-120A	05-15-89	Cyclotrimethylene trinitramine [cyclonite/RDX]	.5

Many of the semivolatile compounds that were tentatively identified by library search (tables 40-42) were laboratory contaminants or were quantified previously by the VOC analyses (Appendixes B2, B4, and B6). Laboratory contaminants that appeared in method blanks, especially during analysis of samples collected during the second sampling period (table 46), include the dioctyl ester of hexanedioic acid, butyrolactone, toluene, and 3-methyloctane. Hexanoic acid and octane are two compounds that were detected in ground-water samples that could be related to these laboratory contaminants (tables 40 and 46). Compounds such as 1,1,2,2-tetrachloroethane, tetrachloroethylene, and chlorobenzene were detected by library search for semivolatile compounds (tables 40-42) but were also quantitatively measured by VOC analyses (Appendixes B2, B4, and B6). Pentachloroethane, a chlorinated alkane with the chemical formula C_2HCl_5, was detected in samples from well 120A by library searches for both VOC's (tables 30 and 31) and semivolatile organic compounds (table 41).

Table 40. *Estimated concentrations of tentatively identified organic compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[Method blank indicates the corresponding laboratory method blank analysis,listed in table 46; TIOC's, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample no.	Method blank	Sampling date	Semivolatile TIOC's	Estimated concentration (µg/L)
			CANAL CREEK AQUIFER	
CC-1B	MB-11	08-18-88	Dithiane	3
CC-1C	MB-11	08-18-88	Dithiane	2
CC-W6	MB-1	07-13-88	1-Methyl-2-pyrrolidinone	6
CC-W6	MB-1	07-13-88	2-Ethyl-hexanoic acid	9
CC-W6	MB-1	07-13-88	Dioctyl ester hexanedioic acid	59
CC-7A	MB-10	08-15-88	1-Methyl-2-propyl cyclohexane	10
CC-7A	MB-10	08-15-88	2-Ethyl-hexanoic acid	17
CC-7A	MB-10	08-15-88	2-Chlorophosphate ethanol	27
CC-7B	MB-10	08-15-88	Tetrachloroethylene	2
CC-7B	MB-10	08-15-88	Chlorobenzene	3
CC-7B	MB-10	08-15-88	1,1,2,2-Tetrachloroethane	21
CC-7B	MB-10	08-15-88	1-Methyl-2-propyl cyclohexane	11
CC-8B	MB-10	08-11-88	1,1,2,2-Tetrachloroethane	3
CC-8B	MB-10	08-11-88	1-Methyl-2-propyl cyclohexane	6
CC-13A	MB-3	07-20-88	2-Methyl-1-penten-3-ol	3
CC-16A	MB-5	07-25-88	1,2,3,4-Tetrahydro-5-methyl naphthalene	4
CC-16A	MB-5	07-25-88	Dichlorobenzene isomer	7
CC-16A	MB-5	07-25-88	1,1'-Oxybis benzene	4
CC-16A	MB-5	07-25-88	Trichlorobenzenamine isomer	7
CC-16A	MB-5	07-25-88	Dimethyl naphthalene isomer	4
CC-16A	MB-5	07-25-88	Dimethyl naphthalene isomer	3
CC-16A	MB-5	07-25-88	Dimethyl naphthalene isomer	2
CC-16A	MB-5	07-25-88	Dimethyl naphthalene isomer	2
CC-16A	MB-5	07-25-88	2-Methyl 1-penten-3-ol	3
CC-17A	MB-5	07-25-88	Dioctyl ester hexanedioic acid	140
CC-18A	MB-2	07-18-88	Ethyl urea	4
CC-20D	MB-12	08-19-88	2-Propyl-1,3-dioxolane	8
CC-20D	MB-12	08-19-88	Butyrolactone	30
CC-20D	MB-12	08-19-88	1-Methyl-2-pyrrolidinone	3
CC-20D	MB-12	08-19-88	2-Ethyl-hexanoic acid	3
CC-20D	MB-12	08-19-88	2-Ethyl-4-methyl-1,3,-dioxolane	2
CC-25A	MB-7	08-01-88	Octane	5
CC-25A	MB-7	08-01-88	3-Methyl octane	8
CC-25A	MB-7	08-01-88	Dithiane	6
CC-25A	MB-7	08-01-88	2,2-Dimethyl-1-(2-hydroxy-1-methyl ethyl)propyl ester 2-methyl-propanoic acid	3
CC-25A	MB-7	08-01-88	3-Hydroxy-2,4,4-trimethyl pentyl ester 2-methyl-propanoic acid	2
CC-25A	MB-7	08-01-88	Molecular sulfur	4
CC-28A	MB-7	07-28-88	4,5-Dimethyl nonane	4
CC-28A	MB-7	07-28-88	3-Methyl octane	8
CC-104B	MB-10	08-12-88	1-Methyl-2-propyl cyclohexane	9
CC-110A	MB-3	07-21-88	2-Methyl 2-hexanol	4
CC-110A	MB-3	07-21-88	1-Methyl 2-pyrrolidinone	4
CC-110A	MB-3	07-21-88	Hexadecane	2
CC-110A	MB-3	07-21-88	Heptadecane	6
CC-110A	MB-3	07-21-88	2,6,10,14-Tetramethyl pentadecane	5
CC-110A	MB-3	07-21-88	Docosane	5
CC-110A	MB-3	07-21-88	2-(2H-Benzotriazol-2-yl)-4-methyl-phenol	4
CC-110A	MB-3	07-21-88	Dioctyl ester hexanedioic acid	13
CC-113A	MB-7	07-26-88	3-Methyl octane	6
CC-114B	MB-2	07-27-88	Fluoro-substituted 1,1-biphenyl	9

Table 40. *Estimated concentrations of tentatively identified organic compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland--Continued*

Sample no.	Method blank	Sampling date	Semivolatile TIOC's	Estimated concentration (μg/L)
			CANAL CREEK AQUIFER--Continued	
CC-120A	MB-1	07-12-88	1,2-Dibromoethene	3
CC-120A	MB-1	07-12-88	Toluene	4
CC-120A	MB-1	07-12-88	1,2-Dibromoethene	7
CC-120A	MB-1	07-12-88	Tetrachloroethylene	9
CC-120A	MB-1	07-12-88	Chlorobenzene	17
CC-120A	MB-1	07-12-88	1,1,2,2-Tetrachloroethane	4
CC-120A	MB-1	07-12-88	Tribromoethene	220
CC-120A	MB-1	07-12-88	C13 benzene isomer	2
CC-120A	MB-1	07-12-88	Docosane	8
CC-120B	MB-1	07-12-88	Tribromoethene	81
CC-120B	MB-1	07-12-88	2-Ethyl hexanoic acid	3
CC-124B	MB-1	07-13-88	Toluene	7
			SURFICIAL AQUIFER	
CC-33B	MB-12	09-07-88	Butyrolactone	71
CC-33B	MB-12	09-07-88	1-Methyl 2-pyrrolidinone	6
CC-33B	MB-12	09-07-88	2-Ethyl-hexanoic acid	6
CC-33B	MB-12	09-07-88	Ethynyl-cyclobutane	3
CC-33B	MB-12	09-07-88	Methyl ester diethyl-borinic acid	5
CC-33B	MB-12	09-07-88	Dioctyl ester hexanedioic acid	450

Additional semivolatile TIOC's detected include the organosulfur compounds dithiane and sulfur (which were previously discussed), hexachloroethane, 1,2-dibromoethene, tribromoethene, naphthalene compounds, and various compounds related to petroleum fuels such as hexadecane, heptadecane, and pentadecane. These semivolatile TIOC's commonly occurred in only one or two ground-water samples and in low concentrations (less than 10 μg/L).

Hexachloroethane, an alkane with six chlorine atoms, was tentatively identified in one sample from well 120A at a low estimated concentration of 2 μg/L (table 41). Hexachloroethane was also quantitatively determined in all semivolatile samples, but concentrations were less than the reported detection limits of 5.1 or 10 μg/L (table 6).

Tribromoethene was detected at the relatively high estimated concentrations of 220 and 81 μg/L in samples from wells 120A and 120B, respectively, during the second sampling period (table 40). Although tribromoethene was tentatively identified only in samples collected during the second sampling period, 1,2-dibromoethene was tentatively identified in samples from well 120A during the second and third sampling periods (tables 40 and 41). Estimated concentrations of 1,2-dibromoethene ranged from 3 to 10 μg/L.

Naphthalene compounds, which are polycyclic aromatic hydrocarbons or PAH's, were tentatively identified in the sample collected from well 16A during the second sampling period; estimated concentrations of the naphthalene compounds ranged

Table 41. *Estimated concentrations of tentatively identified organic compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; "(N)" indicates sample was analyzed by U.S. Geological Survey National Water Quality Laboratory; dashes indicate data not available; TIOC'S, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample no.	Sampling date	Laboratory number	Semivolatile TIOC's	Estimated concentration (µg/L)
		CANAL CREEK AQUIFER		
CC-13A	05-04-89	SAK008	1,1,2,2-Tetrachloroethane	100
CC-16B	05-03-89	SAK001	1,1,2,2-Tetrachloroethane	30
CC-25A	05-17-89	SAM008	Sulfur	1
CC-25A	05-17-89	SAM008	1,1,2,2-Tetrachloroethane	3
CC-26A	04-27-89	SAJ002	1,1,2,2-Tetrachloroethane	20
CC-27A	05-01-89	SAK005	1,1,2,2-Tetrachloroethane	800
CC-28A	04-28-89	SAJ005	1,1,2,2-Tetrachloroethane	20
CC-30A	05-03-89	SAK002	1,1,2,2-Tetrachloroethane	100
CC-107A	05-09-89	SAL003	1,1,2,2-Tetrachloroethane	7
CC-108A	05-09-89	SAL002	1,1,2,2-Tetrachloroethane	60
CC-111A	05-01-89	SAK003	1,1,2,2-Tetrachloroethane	90
CC-111B	05-03-89	SAK007	1,1,2,2-Tetrachloroethane	100
CC-112A	05-15-89	SAM002	1,1,2,2-Tetrachloroethane	5
CC-112A-R	05-15-89	SAM003	1,1,2,2-Tetrachloroethane	5
CC-120A	05-15-89	SAM006	1,1,2,2-Tetrachloroethane	400
CC-120A	05-15-89	SAM006	Pentachloroethane	8
CC-120A-R	05-15-89	SAM005	1,1,2,2-Tetrachloroethane	400
CC-120A-R	05-15-89	SAM005	Pentachloroethane	4
CC-120A(N)	05-15-89	--	Hexachloroethane	2
CC-120A(N)	05-15-89	--	1,2-Dibromoethene	10
CC-120A(N)	05-15-89	--	Dibromochloroethene	100
CC-120A(N)	05-15-89	--	Napthalene	3
		SURFICIAL AQUIFER		
CC-33B	04-26-89	SAJ004	2-Ethylhexanoic acid	8
CC-33B	04-26-89	SAJ004	1,1,2,2-Tetrachloroethane	600
CC-33B-R	04-26-89	SAJ001	2-Ethylhexanoic acid	4
CC-33B-R	04-26-89	SAJ001	1,1,2,2-Tetrachloroethane	800

from 2 to 4 µg/L (table 40). Hydrocarbons that are related to petroleum fuels, including hexadecane, heptadecane, pentadecane, and docosane, were tentatively identified in one sample from well 110A in estimated concentrations that ranged from 2 to 6 µg/L (table 40).

Semivolatile unknowns were reported in samples from the Canal Creek and surficial aquifers (tables 43-45) and in laboratory and field quality-control blanks (tables 46-48). Although the estimated concentrations of individual unknown compounds were usually 10 µg/L or less, the total concentration of semivolatile unknowns detected in a sample was as high as 300 µg/L. The maximum total concentration of semivolatile unknowns was measured in the sample from either well 16A or 120A during each sampling period (tables 43-45). In the laboratory method blanks, the total concentrations of semivolatile unknowns ranged from 1 to 270 µg/L, and the median was 10 µg/L in the 14 method blanks in which unknowns were detected (tables 46 and 47). Thus, the unknown compounds are at least partly the result of laboratory contamination.

Probable sources

Semivolatile compounds that probably are not related to laboratory contamination were detected primarily in the Canal Creek aquifer in samples from well 120A in area IA, from wells 16A, 112A, and 110A in area IC, and from well 25A in area ID. The samples from these wells also contained VOC's, and both types of contaminants were probably derived from the same sources.

Table 42. *Estimated concentrations of tentatively identified organic compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in sample number indicates a replicate sample; dashes indicate data not available; TIOC's, tentatively identified organic compounds; µg/L, micrograms per liter]

Sample number	Sampling date	Laboratory number	Semivolatile TIOC's	Estimated concentration (µg/L)
		CANAL CREEK AQUIFER		
CC-W6	10-10-89	SBB002	1,1,2,2-Tetrachloroethane	6
CC-108A	10-10-89	SBB001	1,1,2,2-Tetrachloroethane	700
CC-118A	09-28-89	SAZ---	1,1,2,2-Tetrachloroethane	200
CC-120A	09-29-89	SBA001	1,1,2,2-Tetrachloroethane	300
CC-120A-R	09-29-89	SBA001	1,1,2,2-Tetrachloroethane	90
CC-120B	09-29-89	SBA004	1,1,2,2-Tetrachloroethane	10

Activities in the incendiary and experimental filling plant that operated in building 99 (fig. 13) are the most likely source of the semivolatile contaminants detected in the Canal Creek aquifer in area IA. The chlorinated aromatics, including 1,2-dichlorobenzene, 1,4-dichlorobenzene, and 1,2,4-trichlorobenzene, are commonly used as solvents, heat-transfer fluids, or intermediates in chemical manufacturing processes (Smith and others, 1988, p. 55). Nitrobenzene, which is used as a solvent in explosives production (Smith and others, 1988, p. 52), was probably used in incendiary and smoke mixtures that were handled in the filling plant. The presence of cyclonite, or RDX, in samples from well 120A (table 39) also indicates that activities in building 99 were a primary source of the ground-water contamination in this area. Experimental work with explosive pellets was reported to have taken place in building 99 after WW2 (Nemeth, 1989, p. F-16), and no other sources of explosives are known to be near well site 120A.

Hexachloroethane, which was tentatively identified in one sample from well 120A (table 41), is most likely derived from the use of HC smoke mixtures. Pentachloroethane, which was reported as both a volatile and a semivolatile TIOC in samples from well 120A, could be a microbial degradation product of hexachloroethane (Vogel and others, 1987; Bouwer and Wright, 1988).

In area IC, former activities in the pilot plant in the building 87 complex are the probable source of semivolatile contaminants detected in samples from well 16A, and possibly from well 112A. Although the pilot plant was used originally for impregnite manufacturing, the complex was used from the mid-1940's until 1986 as a research and pilot manufacturing plant for chemical agents, especially nerve agents. Nitrobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and aniline are among the wide range of chemicals that were reportedly used, stored, and disposed of at the pilot plant in the early 1980's (Office of the U.S. Attorney, Baltimore, Maryland, written commun., 1988, document 86-02534).

The aniline compound 4-chloroaniline that was detected in a sample from well 16A could have been formed by the reaction of aniline with chlorine in the wastewater or ground water. The nitrobenzenes and chlorobenzenes could have been used as solvents, as intermediates in chemical manufacturing, or as heat-transfer fluids in degassing columns. Dowtherm, which was another name for 1,2-dichlorobenzene (Montgomery and Welkom, 1990, p. 199), was reportedly used in degassing columns during manufacturing of the nerve agent GB (Nemeth, 1989, p. 107). The naphthalene compounds that were tentatively identified in samples from well 16A (table 40) most likely were derived from petroleum fuels that were used in the plant for various purposes, such as carrier solvents in manufacturing processes (Nemeth, 1989, p. 115).

Many of the semivolatile contaminants detected in the ground water at site 120 were also detected at site 112, including nitrobenzene and RDX. The ground water at both sites also contained many of the same volatile aromatic compounds. The presence of the explosive-related compounds in the ground water at site 112 indicates that this site, in addition to site 120, was affected by incendiary materials. Building 701, near site 112 (fig. 13), was used during 1943-44 for production-scale filling of munitions with various incendiary materials that would have included petroleum and explosive compounds (table 1). The sewerline that received wastes from building 701 during this time discharged to the marsh near site 112 (fig. 14).

Dithiane, 1,4-oxathiane, and molecular sulfur were the major semivolatile contaminants detected in samples from well 25A in area ID. Mustard manufacturing and filling that took place near well 25A (figs. 2 and 13) is the most likely source of these sulfur compounds. Various sulfur compounds, including colloidal or crystalline sulfur and dithiane (which is also referred to as "1,4-dithiane"), were

Table 43. *Estimated concentrations of unknown compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[Method blank number indicates the corresponding laboratory method blank analysis, listed in table 46; µg/L, micrograms per liter]

Well number	Method blank	Sampling date	Unknown semivolatiles	Retention time (minutes)	Estimated concentration (µg/L)
			CANAL CREEK AQUIFER		
CC-1B	MB-11	08-18-88	Unknown	5.53	2
CC-1B	MB-11	08-18-88	Unknown	5.73	2
CC-1B	MB-11	08-18-88	Unknown	6.32	1
CC-1B	MB-11	08-18-88	Unknown	9.95	67
CC-1B	MB-11	08-18-88	Unknown	24.2	2
CC-1B	MB-11	08-18-88	Unknown	24.8	2
CC-1C	MB-11	08-18-88	Unknown	5.56	1
CC-1C	MB-11	08-18-88	Unknown	8.47	1
CC-1C	MB-11	08-18-88	Unknown	13.2	2
CC-1C	MB-11	08-18-88	Unknown alkane	14.9	2
CC-1C	MB-11	08-18-88	Unknown	24.2	6
CC-1C	MB-11	08-18-88	Unknown	28.5	5
CC-1C	MB-11	08-18-88	Unknown	29.2	47
CC-1C	MB-11	08-18-88	Unknown	33.6	6
CC-7A	MB-10	08-15-88	Unknown	5.50	3
CC-7A	MB-10	08-15-88	Unknown	6.28	2
CC-7A	MB-10	08-15-88	Unknown	6.55	2
CC-7A	MB-10	08-15-88	Unknown	7.62	5
CC-7A	MB-10	08-15-88	Unknown	7.91	2
CC-7A	MB-10	08-15-88	Unknown	8.11	2
CC-7A	MB-10	08-15-88	Unknown	8.50	16
CC-7A	MB-10	08-15-88	Unknown	8.55	4
CC-7A	MB-10	08-15-88	Unknown	8.77	3
CC-7A	MB-10	08-15-88	Unknown	8.02	2
CC-7A	MB-10	08-15-88	Unknown	9.04	2
CC-7A	MB-10	08-15-88	Unknown	9.89	3
CC-7A	MB-10	08-15-88	Unknown	11.3	12
CC-7A	MB-10	08-15-88	Unknown	28.4	3
CC-7A	MB-10	08-15-88	Unknown	29.1	12
CC-7A	MB-10	08-15-88	Unknown	31.8	14
CC-7B	MB-10	08-15-88	Unknown	5.53	2
CC-7B	MB-10	08-15-88	Unknown	5.60	3
CC-7B	MB-10	08-15-88	Unknown	6.59	6
CC-7B	MB-10	08-15-88	Unknown	7.60	5
CC-7B	MB-10	08-15-88	Unknown	7.74	2
CC-7B	MB-10	08-15-88	Unknown	7.99	2
CC-7B	MB-10	08-15-88	Unknown	8.19	2
CC-7B	MB-10	08-15-88	Unknown	8.48	2
CC-7B	MB-10	08-15-88	Unknown	8.57	18
CC-7B	MB-10	08-15-88	Unknown	8.63	5
CC-7B	MB-10	08-15-88	Unknown	8.84	4
CC-7B	MB-10	08-15-88	Unknown	8.91	3
CC-7B	MB-10	08-15-88	Unknown	9.11	2
CC-7B	MB-10	08-15-88	Unknown	9.99	7
CC-7B	MB-10	08-15-88	Unknown	29.2	25
CC-8B	MB-10	08-11-88	Unknown	7.65	3
CC-8B	MB-10	08-11-88	Unknown	8.52	9
CC-8B	MB-10	08-11-88	Unknown	8.57	2
CC-8B	MB-10	08-11-88	Unknown	8.78	2
CC-8B	MB-10	08-11-88	Unknown	8.85	1
CC-13A	MB-3	07-20-88	Unknown	5.96	4

Table 43. *Estimated concentrations of unknown compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland--Continued*

Well number	Method blank	Sampling date	Unknown semivolatiles	Retention time (minutes)	Estimated concentration (µg/L)
			CANAL CREEK AQUIFER--Continued		
CC-16A	MB-5	07-25-88	Unknown	6.17	13
CC-16A	MB-5	07-25-88	Unknown	7.04	77
CC-16A	MB-5	07-25-88	Unknown	7.57	80
CC-16A	MB-5	07-25-88	Unknown	7.62	23
CC-16A	MB-5	07-25-88	Unknown	9.39	14
CC-16A	MB-5	07-25-88	Unknown	9.51	8
CC-16A	MB-5	07-25-88	Unknown	11.3	80
CC-16A	MB-5	07-25-88	Unknown	17.7	2
CC-16A	MB-5	07-25-88	Unknown	20.4	6
CC-20D	MB-12	08-19-88	Unknown	4.61	10
CC-20D	MB-12	08-19-88	Unknown	6.40	10
CC-20D	MB-12	08-19-88	Unknown	6.52	21
CC-20D	MB-12	08-19-88	Unknown	8.16	1
CC-20D	MB-12	08-19-88	Unknown	8.65	2
CC-20D	MB-12	08-19-88	Unknown	14.0	1
CC-28A	MB-7	07-28-88	Unknown	7.04	25
CC-39A	MB-13	09-08-88	Unknown	4.61	9
CC-39A	MB-13	09-08-88	Unknown	6.32	41
CC-39A	MB-13	09-08-88	Unknown	6.38	15
CC-39A	MB-13	09-08-88	Unknown	6.50	22
CC-101B	MB-11	08-17-88	Unknown	5.60	6
CC-101B	MB-11	08-17-88	Unknown	5.80	1
CC-101B	MB-11	08-17-88	Unknown	6.40	4
CC-101B	MB-11	08-17-88	Unknown	7.04	1
CC-101B	MB-11	08-17-88	Unknown	8.61	2
CC-101B	MB-11	08-17-88	Unknown	8.66	3
CC-101B	MB-11	08-17-88	Unknown	28.4	2
CC-101B	MB-11	08-17-88	Unknown	33.5	6
CC-102C	MB-11	08-16-88	Unknown	8.62	2
CC-102C	MB-11	08-16-88	Unknown	10.0	15
CC-104B	MB-10	08-12-88	Unknown	5.25	1
CC-104B	MB-10	08-12-88	Unknown	5.53	3
CC-104B	MB-10	08-12-88	Unknown	6.32	3
CC-104B	MB-10	08-12-88	Unknown	6.59	1
CC-104B	MB-10	08-12-88	Unknown	7.65	5
CC-104B	MB-10	08-12-88	Unknown	7.94	1
CC-104B	MB-10	08-12-88	Unknown	8.03	1
CC-104B	MB-10	08-12-88	Unknown	8.14	2
CC-104B	MB-10	08-12-88	Unknown	8.53	14
CC-104B	MB-10	08-12-88	Unknown	8.58	4
CC-104B	MB-10	08-12-88	Unknown	8.80	3
CC-104B	MB-10	08-12-88	Unknown	8.85	2
CC-104B	MB-10	08-12-88	Unknown	9.06	2
CC-113A	MB-7	07-28-88	Unknown	7.07	7
CC-113A	MB-7	07-28-88	Unknown	23.4	3
CC-113A	MB-7	07-28-88	Unknown	26.4	5
CC-110A	MB-3	07-21-88	Unknown	10.6	6
CC-110A	MB-3	07-21-88	Unknown alkane	21.8	4
CC-114B	MB-2	07-27-88	Unknown	21.6	2
CC-114B	MB-2	07-27-88	Unknown	32.1	41

Table 43. *Estimated concentrations of unknown compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland--Continued*

Well number	Method blank	Sampling date	Unknown semivolatiles	Retention time (minutes)	Estimated concentration (μg/L)
			CANAL CREEK AQUIFEr--Continued		
CC-120A	MB-1	07-12-88	Unknown	7.12	5
CC-120A	MB-1	07-12-88	Unknown	7.13	65
CC-120A	MB-1	07-12-88	Unknown	7.66	7
CC-120A	MB-1	07-12-88	Unknown	8.25	3
CC-120A	MB-1	07-12-88	Unknown	10.6	4
CC-120A	MB-1	07-12-88	Unknown	26.6	6
CC-120A	MB-1	07-12-88	Unknown	28.8	4
CC-120A	MB-1	07-12-88	Unknown alkane	29.0	3
CC-120A	MB-1	07-12-88	Unknown alkane	31.0	3
CC-120A	MB-1	07-12-88	Unknown alkane	32.9	13
CC-120A	MB-1	07-12-88	Unknown phthalate	34.1	12
CC-120B	MB-1	07-12-88	Unknown phthalate	30.5	3
			SURFICIAL AQUIFER		
CC-12A.1	MB-9	08-09-88	Unknown	7.04	12
CC-33B	MB-12	09-07-88	Unknown	4.61	8
CC-33B	MB-12	09-07-88	Unknown	5.63	10
CC-33B	MB-12	09-07-88	Unknown	5.69	2
CC-33B	MB-12	09-07-88	Unknown	5.77	3
CC-33B	MB-12	09-07-88	Unknown	6.42	39
CC-33B	MB-12	09-07-88	Unknown	6.50	12
CC-33B	MB-12	09-07-88	Unknown	7.64	9
CC-33B	MB-12	09-07-88	Unknown	13.4	6

reported to be present in the mustard (Nemeth, 1989, p. 30-31). Dithiane and 1,4-oxathiane can also be produced during chemical decontamination or burning of mustard (Nemeth, 1989, p. 185-186; Vroblesky and others, 1989, p. 100). Mustard manufacturing during WW1 and WW2 produced large quantities of wastes, and most wastes were discharged through the sewers to the marsh south and east of the plant (fig. 13). Mustard-contaminated soil was found near the mustard plant during and after WW2 (Nemeth, 1989, p. 38). In addition, a disposal pit (identification number 29 on fig. 13) south of well site 25 (fig. 2) was used to dispose of "wild runs" and other mustard manufacturing wastes, including reactor cleanout and decontamination wastes, during about 1937-41 (Nemeth, 1989, p. 810).

Probable Fate and Movement of Major Ground-Water Contaminants

The geochemical, microbial, and transport processes that affect the probable fate and movement of the major ground-water contaminants in the Canal Creek area are discussed in this section. The VOC's, especially the chlorinated alkanes and alkenes, were the most prevalent ground-water contaminants that were measured in relatively high concentrations (table 24), and these major contaminants are discussed in the greatest detail. Some processes that could have affected the distribution and movement of the trace metals that were present in elevated concentrations were discussed previously in the section on probable sources of the minor inorganic constituents and are not discussed here.

General Processes

General processes that affect the fate and movement of VOC's in ground water include dissolution of immiscible phases, advection and dispersion, volatilization, sorption, and abiotic and biotic degradation reactions. Advection and dispersion are the principal physical transport processes for dissolved constituents. Advective transport refers to the movement of solutes as a result of the bulk motion

Table 44. *Estimated concentrations of unknown compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the third sampling period (April-May 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in the sample number indicates a replicate sample; µg/L, micrograms per liter]

Sample no.	Sampling date	Unknown semivolatiles	Retention time (minutes)	Estimated concentration (µg/L)
	CANAL CREEK AQUIFER			
CC-13A	05-04-89	Unknown	57.1	1
CC-13A	05-04-89	Unknown	57.2	1
CC-16A	05-03-89	Unknown	54.6	10
CC-16A	05-03-89	Unknown	57.0	3
CC-16A	05-03-89	Unknown	57.1	1
CC-16A	05-03-89	Unknown	57.2	1
CC-16A	05-03-89	Unknown	59.5	2
CC-16A	05-03-89	Unknown	66.0	10
CC-16A	05-03-89	Unknown	68.2	6
CC-16B	05-03-89	Unknown	57.1	1
CC-16B	05-03-89	Unknown	57.2	2
CC-16B	05-03-89	Unknown	61.7	1
CC-16B	05-03-89	Unknown	66.0	5
CC-16B	05-03-89	Unknown	68.2	3
CC-23B	05-15-89	Unknown	57.1	2
CC-23B	05-15-89	Unknown	57.2	3
CC-23B	05-15-89	Unknown	61.7	1
CC-25A	05-17-89	Unknown	57.1	1
CC-25A	05-17-89	Unknown	57.2	1
CC-26A	04-27-89	Unknown	57.3	1
CC-27A	05-01-89	Unknown	53.6	5
CC-27A	05-01-89	Unknown	57.1	3
CC-27A	05-01-89	Unknown	57.2	4
CC-27A	05-01-89	Unknown	61.1	5
CC-28A	04-28-89	Unknown	57.3	1
CC-28A	04-28-89	Unknown	61.7	1
CC-28A	04-28-89	Unknown	63.9	2
CC-28A	04-28-89	Unknown	64.8	10
CC-30A	05-03-89	Unknown	57.2	1
CC-30A	05-03-89	Unknown	57.2	1
CC-107A	05-09-89	Unknown	61.7	1
CC-107A	05-09-89	Unknown	66.0	5
CC-107A	05-09-89	Unknown	68.1	3
CC-108A	05-09-89	Unknown	61.7	1
CC-111A	05-01-89	Unknown	57.2	3
CC-111A	05-01-89	Unknown	61.7	4
CC-111A	05-01-89	Unknown	63.9	3
	CANAL CREEK AQUIFER			
CC-111B	05-03-89	Unknown	57.1	1
CC-111B	05-03-89	Unknown	57.2	1
CC-111B	05-03-89	Unknown	59.2	1
CC-111B	05-03-89	Unknown	61.7	1
CC-111B	05-03-89	Unknown	66.0	4
CC-112A	05-15-89	Unknown	57.1	1
CC-112A	05-15-89	Unknown	57.2	2
CC-112A	05-15-89	Unknown	61.7	2
CC-112A-R	05-15-89	Unknown	57.1	1
CC-112A-R	05-15-89	Unknown	57.2	1
CC-112A-R	05-15-89	Unknown	61.7	1
CC-120A	05-15-89	Unknown	53.6	100
CC-120A	05-15-89	Unknown	54.2	4
CC-120A	05-15-89	Unknown	56.5	50
CC-120A	05-15-89	Unknown	61.7	1
CC-120A-R	05-15-89	Unknown	53.6	90
CC-120A-R	05-15-89	Unknown	54.2	3
CC-120A-R	05-15-89	Unknown	56.5	40
CC-120A-R	05-15-89	Unknown	61.7	1
	SURFICIAL AQUIFER			
CC-12A1	04-25-89	Unknown	57.1	1
CC-12A1	04-25-89	Unknown	57.3	1
CC-33B	04-26-89	Unknown	54.2	4
CC-33B	04-26-89	Unknown	61.7	4
CC-33B	04-26-89	Unknown	63.9	8
CC-33B-R	04-26-89	Unknown	61.7	2
CC-33B-R	04-26-89	Unknown	63.9	3
CC-127A	04-25-89	Unknown	57.3	1
CC-128A	04-25-89	Unknown	57.1	1
CC-128A	04-25-89	Unknown	57.3	1
CC-129A	04-25-89	Unknown	57.3	1
CC-129A	04-25-89	Unknown	63.9	6
CC-135A	04-25-89	Unknown	57.1	1
CC-135A	04-25-89	Unknown	57.3	1

Table 45. *Estimated concentrations of unknown compounds detected by library search for semivolatile organic compounds for ground-water samples collected during the fourth sampling period (September-October 1989), Aberdeen Proving Ground, Maryland*

["-R" suffix in the sample number indicates a replicate sample; µg/L, micrograms per liter]

Sample no.	Sampling date	Unknown semivolatiles	Retention time (minutes)	Estimated concentration (µg/L)
		Canal Creek aquifer		
CC-W6	10-10-89	Unknown	54.1	2
CC-W6	10-10-89	Unknown	54.4	3
CC-W6	10-10-89	Unknown	55.9	3
CC-16A	09-15-89	Unknown	55.3	40
CC-16A	09-15-89	Unknown	55.9	10
CC-16A	09-15-89	Unknown	57.1	10
CC-16A	09-15-89	Unknown	57.3	20
CC-16A	09-15-89	Unknown	57.7	10
CC-16A	09-15-89	Unknown	57.9	9
CC-16A	09-15-89	Unknown	58.0	8
CC-16A	09-15-89	Unknown	58.1	4
CC-16A	09-15-89	Unknown	58.5	2
CC-16A	09-15-89	Unknown	58.7	4
CC-16A	09-15-89	Unknown	59.0	6
CC-16A	09-15-89	Unknown	59.1	10
CC-16A	09-15-89	Unknown	59.3	3
CC-16A	09-15-89	Unknown	59.4	10
CC-108A	10-10-89	Unknown	54.6	30
CC-111A	09-15-89	Unknown	59.1	30
CC-112A	09-18-89	Unknown	57.2	2
CC-112A	09-18-89	Unknown	59.1	20
CC-118A	09-28-89	Unknown	57.2	2
CC-118A	09-28-89	Unknown	57.3	3
CC-120A	09-29-89	Unknown	55.1	8
CC-120A-R	09-29-89	Unknown	55.1	7
CC-120B	09-29-89	Unknown	54.2	4
CC-120B	09-29-89	Unknown	55.1	5
CC-120B	09-29-89	Unknown	56.0	3
CC-134A	09-12-89	Unknown	52.8	30
CC-134A	09-12-89	Unknown	52.9	10
		Surficial aquifer		
CC-23A	09-27-89	Unknown	57.2	2
CC-23A	09-27-89	Unknown	57.3	4

of the ground water. Dispersion, which causes a contaminant to occupy a larger volume of the aquifer than would be expected from advection, is attributed to molecular diffusion and to velocity variations within the porous medium. If volatilization, sorption, or degradation reactions occur, the rate of movement of dissolved contaminants will be retarded compared to the advective flow rate. These general processes are summarized in detail in the literature (Smith and others, 1988; Lorah and Vroblesky, 1989, p. 78-89; Ram and others, 1990; Montgomery and Welkom, 1990); a brief review of these processes is given here.

Table 46. *Semivolatile organic compounds detected in laboratory method blanks during the analysis of ground-water samples collected during the second sampling period (July-September 1988), Aberdeen Proving Ground, Maryland*

[Analysis type: S, semivolatile compounds by gas chromatography/mass spectrometry; SL, library search for semivolatile organic compounds: library search compounds are tentatively identified organic compounds, and their concentrations are estimated; (10.6), retention time in minutes; dashes indicate that data are not available; µg/L, micrograms per liter]

Sample no.	Analysis date	Analysis type	Semivolatile compound	Concentration (µg/L)
MB-1	8-23-88	S	Di-n-octyl phthalate	5.0
MB-1	8-23-88	SL	Toluene	5
MB-1	8-23-88	SL	1,2-Benzenedicarboxylic acid, diisononyl ester	8
MB-1	8-23-88	SL	Unknown phthalate (32.8)	11
MB-1	8-23-88	SL	Unknown phthalate (34.1)	11
MB-2	9-01-88	--	None detected	--
MB-3	9-01-88	SL	Unknown (5.94)	5
MB-4	9-02-88	S	*bis*(2-Ethylhexyl) phthalate	37
MB-4	9-02-88	S	Di-n-octyl phthalate	4.0
MB-5	9-02-88	SL	Hexanedioic acid, dioctyl ester	28
MB-6	9-02-88	--	None detected	--
MB-7	9-02-88	SL	Octane, 3-methyl	7
MB-8	9-03-88	--	None detected	--
MB-9	9-03-88	SL	Unknown (7.04)	12
MB-10	10-22-88	SL	Unknown (6.67)	2
MB-10	10-22-88	SL	Unknown (8.58)	3
MB-10	10-22-88	SL	Unknown (8.62)	1
MB-10	10-22-88	SL	Unknown (9.32)	2
MB-11	10-22-88	SL	Unknown (5.71)	1
MB-12	11-30-88	S	*bis*(2-Ethylhexyl) phthalate	36
MB-12	11-30-88	SL	Unknown (4.61)	7
MB-12	11-30-88	SL	Unknown (6.28)	12
MB-12	11-30-88	SL	Unknown (6.48)	8
MB-12	11-30-88	SL	Hexanedioic acid, dioctyl ester	370
MB-13	11-30-88	SL	Butyrolactone	20
MB-13	11-30-88	SL	Unknown (6.48)	13
MB-13	11-30-88	SL	Unknown (10.6)	10
MB-13	11-30-88	SL	Unknown (25.4)	250

Table 47. *Semivolatile organic compounds detected in laboratory method blanks during the analysis of ground-water samples collected during the third (April-May 1989) and fourth (September-October 1989) sampling periods, Aberdeen Proving Ground, Maryland*

[**Analysis type**: S, semivolatile compounds by gas chromatography/mass spectrometry; SL, library search for semivolatile organic compounds; library search compounds are tentatively identified organic compounds, and their concentrations are estimated; (57.1), retention time in minutes; µg/L, micrograms per liter]

Analysis type	Sample no.	Semivolatile compound	Concentration (µg/L)
April-May 1989			
S	SA1002	Butylbenzyl phthalate	20
SL	SA1002	Unknown (57.1)	1
SL	SAK004	Unknown (57.1)	1
SL	SAK004	Unknown (57.2)	1
SL	SAK004	Unknown (59.2)	1
SL	SAM007	Unknown (57.1)	1
SL	SAM007	Unknown (57.2)	1
September-October 1989			
S	SAT003	Butylbenzyl phthalate	14
SL	SAT003	Unknown (52.8)	1
SL	SAT003	Unknown (52.9)	6
SL	SAT003	Unknown (57.4)	4
SL	SAT003	Unknown (57.8)	6
SL	SAT003	Unknown (58.4)	30
SL	SAT003	Unknown (58.5)	3
SL	SAT003	Unknown (58.8)	3
SL	SAT003	Unknown (59.0)	3
SL	SAT003	Unknown (59.1)	30
SL	SAT003	Unknown (59.2)	100
SL	SAT003	Unknown (59.3)	3
SL	SAT003	Unknown (59.3)	8
SL	SAT003	Unknown (60.2)	2
SL	SAT003	Unknown (60.3)	2
SL	SAT003	Unknown (61.3)	2
SL	SAW006	Unknown (58.4)	2
SL	SAW006	Unknown (61.0)	3
SL	SBA005	Unknown (54.2)	30
SL	SBA005	Unknown (55.7)	60
SL	SBA005	Unknown (59.2)	40
SL	SBB003	Unknown (58.5)	4
SL	SBB003	Unknown (59.1)	6
SL	SBB003	Unknown (59.2)	20
SL	SBB003	Unknown (62.4)	20

Most of the chlorinated alkenes and alkanes and chloroaromatic and nitroaromatic compounds have a density greater than that of water in their free product form and are classified as DNAPL's, or dense non-aqueous-phase liquids. Benzene is the only VOC present in substantial concentrations in ground water of the Canal Creek area that has a lower density than water. DNAPL's would have been included in the wastes released in the Canal Creek area by discharge to sewers, disposal in marsh areas, spills or leaks, and use of decontaminants such as DANC.

Table 48. *Semivolatile-organic-chemical data for quality-control blanks collected in the field during the third (April-May 1989) and fourth (September-October 1989) sampling periods, Aberdeen Proving Ground, Maryland*

[In the sample number, "-F" indicates an equipment blank and the number preceded by "CC-"indicates the well site at which the sample was collected; analysis type, SL, is library search for semivolatile compounds; library search compounds are tentatively identified organic compounds, and their concentrations are estimated; dashes indicate data not available; (54.2), retention time in minutes; μg/L, micrograms per liter]

Sample no.	Sampling date	Semi-volatile compound	Analysis type	Concentration (μg/L)
CC-17C-F	06-02-89	None detected	SL	--
CC-33B-F	04-26-89	None detected	SL	--
CC-120A-F	05-15-89	None detected	SL	--
CC-120A-F	09-29-89	Dimethyl disulfide	SL	2
CC-120A-F	09-29-89	Unknown (54.2)	SL	5
CC-120A-F	09-29-89	Unknown (55.7)	SL	8

DNAPL's released at or near the surface will migrate vertically downward through the unsaturated zone to the capillary fringe or to a low-permeability layer (Schwille, 1988). Downward movement could then cease if the amount of DNAPL is small. If the volume of solvent is large, however, adequate pressure head could develop to allow the free product to penetrate the water-bearing zone or the low-permeability layer (Schwille, 1988). Alternatively, the DNAPL could flow horizontally until a discontinuity in the low-permeability layer is intercepted, and the solvent could then migrate downward. Once the DNAPL has penetrated an aquifer, the solvent tends to accumulate at the base of the aquifer where a relatively impermeable layer exists (Gillham and Rao, 1990, p. 146). Lateral spreading of the DNAPL at the base of the aquifer is controlled by the topography of the underlying low-permeability layer rather than by the hydraulic gradient in the ground water (Gillham and Rao, 1990, p. 146).

During vertical migration and lateral spreading in the aquifer, some of the solvent remains trapped as droplets in pore spaces, as films on grain surfaces, or as disseminated irregularly shaped bodies. As ground water flows past this residual immobile DNAPL or over pools of liquid at the base of the aquifer, some of the DNAPL will dissolve in the water. Thus, although the DNAPL itself will generally remain near the spill, the VOC's that are in aqueous solution could migrate great distances in the direction of ground-water flow. Residual DNAPL in the unsaturated zone and aquifer can be a long-term source of dissolved contaminants (Lorah and Vroblesky, 1989, p. 80).

Mobility of the VOC's dissolved in the ground water is controlled mainly by their solubility and tendency to sorb to sediments. Most of the VOC's present in the Canal Creek area are considered to be moderately to highly mobile because they have relatively high solubilities and relatively low organic carbon sediment-water partition coefficients, or K_{oc} values (Roy and Griffin, 1985; Lorah and Vroblesky, 1989, p. 81). The solubilities of the VOC's present in the Canal Creek area, including carbon tetrachloride, chloroform, 1,1,2,2-tetrachloroethane, trichloroethylene, 1,2-*trans*-dichloroethylene, and vinyl chloride, generally range from 600 to 8,000 mg/L at 20 to 25 °C (Lorah and Vroblesky, 1989, p. 79).

Organic compounds whose K_{oc} values exceed 500 are classified as having a low mobility because they have a strong tendency to sorb onto solid-phase organic matter in sediments (Roy and Griffin, 1985, p. 245). Most of the VOC's present in the Canal Creek area have K_{oc} values below 500. In addition, sorption to solid-phase organic matter in contaminated aquifers of the Canal Creek area is not likely to be significant because the aquifer sediments have a very low organic carbon content (less than 0.01 percent) (Lorah and Vorblesky, 1989, p. 82-84). However, some sorption could be occurring on mineral surfaces (Roy and Griffin, 1985, p. 245), especially on clay minerals, and in marsh areas where the organic carbon content of sediments could be high. Sorption is usually a reversible process; thus, the contaminants would not be permanently removed from transport in the aquifer.

VOC's also have a tendency to partition from the aqueous to the vapor phase and diffuse across an air-water interface. However, volatilization can be a significant removal mechanism for the VOC's only in the unsaturated zone or at the water table, where the ground water is in contact with an air phase. The relative volatility of the individual VOC's can be determined from their Henry's Law constant, which is defined as vapor pressure divided by the solubility. As Henry's Law constant increases, the tendency for a compound to volatilize increases.

Degradation reactions can result in complete, irreversible removal of VOC's. Degradation reactions that can occur in ground water can be divided

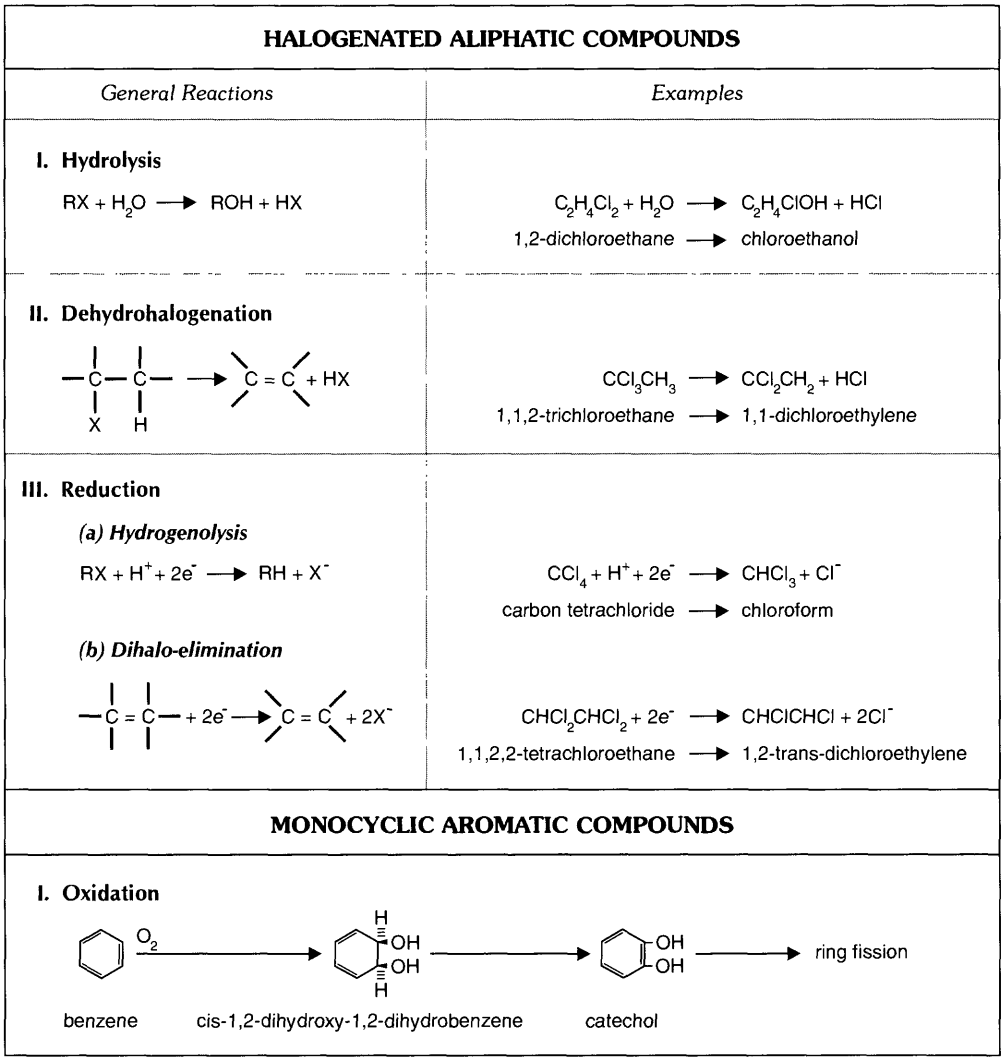


Figure 63. Types of degradation reactions possibly affecting the organic constituents in ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland.

into two types of reactions that are generally abiotic--hydrolysis and dehydrohalogenation--and two types of reactions that are usually mediated by microorganisms--oxidation and reduction (fig. 63) (Vogel and others, 1987; Lorah and Vroblesky, p. 83-89). Abiotic hydrolysis and dehydrohalogenation reactions are generally believed to occur at slower rates in water than microbially mediated oxidation-reduction reactions (Vogel and others, 1987, p. 722; Pfaender, 1990, p. 210). However, most of the data available on degradation rates and mechanisms have been generated through laboratory studies under controlled conditions, and the extent to which these data can be extrapolated to a natural environment is not clear.

Chlorinated alkanes and alkenes have a higher oxidation state than the nonhalogenated monoaromatic compounds. Thus, the clorinated aliphatics are more susceptible to reduction than to oxidation, whereas the monoaromatics are more susceptible to oxidation than to reduction. Degradation of benzene, which is the most frequently detected aromatic contaminant in ground water of the Canal Creek area (table 24), has been shown to occur by microbial oxidation reactions under aerobic conditions (Barker and others, 1987) and under anaerobic conditions (Lovely and others, 1989; Cozzarelli and others, 1990).

Chlorinated alkanes and alkenes were first discovered to be biologically transformed under anaerobic conditions by hydrogenolysis or dihaloelimination reactions (fig. 63) (Alvarez-Cohen and McCarty, 1991, p. 1381). Hydrogenolysis, also called reductive dehalogenation, entails the sequential replacement of chlorine atoms by hydrogen atoms to produce degradation products that are more reduced than the parent compound. Dihaloelimination involves the loss of two chlorine atoms simultaneously from adjacent carbons on a polyhalogenated alkane, forming an alkene. Reductive dehalogenation is the most commonly reported anaerobic biodegradation process for the chlorinated aliphatic compounds (Pfaender, 1990, p. 216-219); however, the relative importance of reductive dehalogenation reactions as opposed to dihaloelimination reactions can be difficult to define because of complex mixtures of parent and intermediate compounds (Lesage and others, 1990, p. 564; Pfaender, 1990, p. 218).

Although several studies in the early 1980's indicated that chlorinated aliphatic compounds could not be biodegraded under aerobic conditions, recent studies have shown that several types of aerobic microorganisms have enzymatic systems capable of oxidizing chlorinated aliphatics through cometabolism (Alvarez-Cohen and McCarty, 1991; Pfaender, 1990, p. 212-216). Laboratory and field studies, however, have shown that the appropriate microbial communities need to be stimulated by injections of the primary growth substrate before the chlorinated aliphatic compound is substantially degraded (Pfaender, 1990, p. 216-220). Primary growth substrates for aerobic microorganisms that can cometabolize trichloroethylene include methane, toluene and other aromatic hydrocarbons, propane, and ammonia (Alvarez-Cohen, 1990, p. 1381). Aerobic oxidation can result in complete mineralization of the chlorinated aliphatic compounds to carbon dioxide.

Fate and Movement in Ground Water of the Canal Creek Area

The probable fate and movement of the major ground water contaminants is described for each of the three regions in the Canal Creek area (fig. 19). Because the hydrogeologic framework and geochemistry differ in each region, the transformation processes affecting the contaminants can differ in each region. General ground-water-flow velocities and directions are discussed in this section to describe the movement of the contaminants, but more detailed information on ground-water flow is given in a later section on the ground-water-flow model.

Ground water in Region I

In Region I, the movement of DNAPL contaminants is most evident in area IA (fig. 19). The upper confining unit in area IA has a thickness of about 40 ft, which is greater than in other areas of Region I. The VOC's must have been in their undissolved, dense form to have migrated through about 40 ft of silty clay. In addition, the highly localized distribution of high dissolved concentrations of the VOC's in this area (figs. 50-53) indicates that the DNAPL's did not migrate far laterally once they reached the Canal Creek aquifer.

Thus, DNAPL's are probably present in the Canal Creek aquifer in area IA and probably provide a continuous source for high dissolved concentrations of VOC's in this area. Advective ground-water-flow velocities are relatively high in Region I (about 100 ft/yr), and the contaminants could have been released to the environment in area IA as early as 1918. Yet, concentrations of the VOC's are relatively low or below detection limits in area IB, which is immediately downgradient from area IA under present unstressed ground-water-flow conditions (figs. 19 and 20). Dispersion and dilution as the contaminated ground water moves toward area IB and mixes with relatively uncontaminated ground water could account for the decreased dissolved concentrations in area IB. Another possible reason for the low dissolved contaminant concentrations in area IB compared to area IA is that changes in ground-water-flow directions in the past could have slowed the migration of dissolved contaminants from area IA to area IB. Ground-water-flow directions in areas IA and IB could have been the reverse of current flow directions during pumping of the old water-supply wells around 1950-68 and also during use of the phossy water disposal ponds (fig. 13).

Residual DNAPL's are also likely to be present in the Canal Creek aquifer and surficial sediments in other areas of Region I. Except for the pilot plant in the building 87 complex, which operated until recently (fig. 13), chemical manufacturing and waste disposal primarily took place during WW1 and WW2; thus, many of the primary contaminant sources have not been active for several decades.

Continued dissolution of residual DNAPL's is the most likely process to account for the persistence of relatively high concentrations of VOC's in the shallow flow system of Region I where ground-water-flow velocities are relatively high. In addition, leaky containers could still provide an active source of ground-water contamination at the sites closest to the marshy landfill areas along the West Branch Canal Creek (fig. 14).

Transformation processes that could affect the fate of VOC's in the Canal Creek aquifer in Region I include volatilization and biodegradation. Volatilization could be significant only immediately adjacent to the West Branch Canal Creek where the upper confining unit is absent (fig. 6). Biodegradation does not seem to be a significant process for the chlorinated VOC's in Region I. Relatively rapid recharge rates and ground-water-flow velocities in this shallow flow system maintain oxic conditions in the Canal Creek aquifer at most sites in Region I (fig. 25), and other studies have shown that the chlorinated VOC's are not easily biodegraded under these conditions (Vogel and others, 1987; Pfaender, 1990). Benzene is the only major VOC in the ground water that is easily biodegraded under aerobic conditions.

A few of the VOC's present in the Canal Creek aquifer in Region I could be intermediate products from anaerobic biodegradation reactions. Anaerobic biodegradation by reductive dehalogenation could be occurring at the few sites where dissolved-oxygen concentrations are below 0.5 mg/L in Region I (fig. 25) or in microzones of reducing conditions within the generally oxygenated aquifer. The possible anaerobic degradation products that were identified at a few sites include 1,2-*trans*-dichloroethylene, 1,1,2-trichloroethane, and 1,2-dichloroethane. Although chloroform can be produced by biodegradation of carbon tetrachloride, the possible importance of this reaction cannot be determined because chloroform has many possible primary sources in Region I from its use in the filling and manufacturing plants, especially the CN plant in building 58 (fig. 13).

Reductive dehalogenation of trichloroethylene can produce 1,2-*trans*-dichloroethylene as an intermediate product, and reductive dehalogenation of 1,1,2,2-tetrachloroethane can produce 1,1,2-trichloroethane and 1,2-dichloroethane sequentially. Although trichloroethylene and 1,1,2,2-tetrachloroethane are widely distributed in the Canal Creek aquifer in Region I (figs. 50 and 53), the three possible degradation products were found in low concentrations and were not widely distributed; therefore, anaerobic degradation is probably not a major process in Region I. Concentrations of 1,2-*trans*-dichloroethylene were generally less than 40 μg/L in the Canal Creek aquifer in Region I (fig. 54), and concentrations of 1,1,2-trichloroethane and 1,2-dichloroethane were generally less than 10 μg/L (Appendixes B2, B4, and B6). High concentrations of 1,2-*trans*-dichloroethylene (about 500 μg/L) and 1,2-dichloroethane were measured in ground water near the building 87 pilot plant (figs. 13 and 54), but the concentrations probably resulted from direct disposal of these compounds, which are known to have been used in the plant, rather than from biodegradation.

Ground water in Region II

In Region II, movement of DNAPL's, advective flow and dispersion, and anaerobic biodegradation are probably the major processes affecting the movement and fate of VOC's in the ground water. Volatilization could also occur from a limited area of the surficial aquifer in Region II in the paleochannel area.

Sinking of DNAPL contaminants largely controlled the initial movement of the VOC's in the paleochannel area where the upper confining unit is absent. Raw solvent discharged from the clothing-impregnating plant (building 73, fig. 13) in 1944 and from other plants in the area through the sewer system to the East Branch Canal Creek (fig. 14) could easily migrate downward through the creek bed and surficial aquifer into the Canal Creek aquifer (fig. 62). Further downward migration of the DNAPL contaminants seems to have been impeded by the thick confining unit beneath the Canal Creek aquifer, and contamination is not present in the lower confined aquifer (fig. 62). DNAPL contaminants could also have migrated into the Canal Creek aquifer from solvent spills around the manufacturing and filling plants that operated near the East Branch Canal Creek (fig. 13) and from leaky sewer lines (fig. 14). Residual DNAPL's in the surficial and Canal Creek aquifers could still provide a source of dissolved VOC's in the ground water.

Dissolved VOC's have since migrated into the regional flow system of the confined Canal Creek aquifer in area IIB (fig. 62), spreading eastward and southward from the primary sources near the East Branch Canal Creek by advective flow and dispersion. Pumping of the water-supply wells during 1950-68 would have increased ground-water-flow velocities and probably increased rates of contaminant movement eastward from area IIA into IIB (figs. 19 and 21). After pumping stopped, ground-water transport of contaminants in the current southward flow direction (fig. 20) caused the plume to widen. Dispersion, which occurs as a result of mixing of contaminated water with uncontaminated water, also has caused the plume to widen more than might be expected as a result of advection alone. Dispersion effects would have been greater in Region II than Region I because of the repeated changes in ground-water-flow directions in 1950-68 caused by pumping of different water-supply wells at various times and because of the change in flow directions when pumping finally stopped.

Microbial degradation seems to be a more significant process in Region II than in Region I. The degradation products 1,2-*trans*-dichloroethylene and vinyl chloride are widespread in Region II (figs. 60 and 61) and were observed in higher concentrations than in Region I (fig. 54). No primary sources of 1,2-*trans*-dichloroethylene and vinyl chloride are known to exist in Region II. Instead, the areal distributions of 1,2-*trans*-dichloroethylene and vinyl chloride in the Canal Creek aquifer in Region II are very similar to the distribution of trichloroethylene (figs. 59 to 61), indicating that they are derived from anaerobic reductive dehalogenation of trichloroethylene. In Region II, the Canal Creek aquifer is confined, except in the paleochannel area. Compared to the shallow flow system of the Canal Creek aquifer in Region I, ground water follows longer flowpaths in the regional flow system of the Canal Creek aquifer in Region II, and recharge rates are lower. Thus, oxygen is consumed by biogeochemical reactions in Region II at a faster rate than it can be replenished by recharge water, and the anoxic conditions that are necessary for reductive dehalogenation reactions have developed at most sites in Region II (fig. 25).

Dissolved oxygen is consumed quickly, even in the paleochannel area where the Canal Creek aquifer is connected hydraulically to the surficial aquifer; the rapid consumption indicates that microbial degradation of organic compounds is a significant and active process. Water from wells 20A and 20B in the surficial aquifer of the paleochannel (fig. 62) had high dissolved-oxygen concentrations of approximately 4 mg/L during the second sampling period (Appendix B1), whereas water from the wells screened in the Canal Creek aquifer at the same site had an average dissolved-oxygen concentration of 0.15 mg/L (fig. 25). Data from site 1 in the paleochannel area also provides evidence of intense consumption of dissolved oxygen. Even the surficial aquifer samples from well 1A (fig. 62), screened at a depth of 22 to 27 ft, consistently had dissolved-oxygen concentrations that were less than 0.10 mg/L during all four sampling periods.

The degradation products 1,2-*trans*-dichloroethylene and vinyl chloride were not present in the surficial aquifer at site 20, where oxygen is present, but low concentrations of these degradation products were seen in the Canal Creek aquifer at this site (fig. 62). At site 1, where anoxic conditions exist in the surficial and Canal Creek aquifers, high concentrations of the degradation products occur (fig. 62). In fact, concentrations of trichloroethylene and its anaerobic degradation products generally were higher in the Canal Creek aquifer at site 1 than at other sites in Region II (figs. 59 to 61). Because well site 1 is adjacent to a sewer-discharge point (fig. 14) that is the suspected source area for the trichloroethylene, the amount of DNAPL residue in the aquifer is probably high at this site, providing a continuous source of high concentrations of trichloroethylene for degradation reactions in this area. The rate of reductive dehalogenation decreases as the degree of halogenation of the organic compound decreases (Pfaender, 1990, p. 219). Thus, the less halogenated intermediate compounds 1,2-*trans*-dichloroethylene and vinyl chloride tend to accumulate during reductive dehalogenation of trichloroethylene.

High dissolved-methane concentrations (Appendixes B2, B4, and B6) also are associated with the degradation products, indicating that trichloroethylene in the Canal Creek aquifer is preferentially degraded under strongly reducing methanogenic conditions. Several field and laboratory studies have indicated that reductive dehalogenation of chlorinated aliphatic compounds can occur under methanogenic conditions (Bouwer and McCarty, 1983; Bouwer and Wright, 1988; Pfaender, 1990, p. 216-219). Analytical results from samples collected along section C-C' (fig. 62) during three sampling periods showed that methane concentrations were highest in the Canal Creek aquifer at well sites 1, 7, and 8, where concentrations of the degradation products also were high (fig. 62). Methane concentrations in the Canal Creek aquifer ranged from 960 to 6,200 μg/L at these three sites (Appendixes B2, B4, and B6). In contrast, the maximum methane concentration was 170 μg/L in the Canal Creek aquifer at site 20, where only low concentrations of trichloroethylene and its degradation products were present (fig. 62). At site 11, where the Canal Creek aquifer is uncontaminated (fig. 17 and 62), methane concentrations ranged from 15 to 100 μg/L. Thus, low concentrations of methane are produced by natural decomposition reactions in the deep, confined Canal Creek aquifer, but the high concentrations observed within the contaminant plume are associated with degradation of the anthropogenic organic contaminants.

Other studies have shown that reductive dehalogenation of trichloroethylene leads to the formation of one or more of the three dichloroethylene isomers: 1,2-*trans*-dichloroethylene, 1,2-*cis*-dichloroethylene, and 1,1-dichloroethylene (Vogel and others, 1987; Pfaender, 1990, p. 217). The dichloroethylene compounds are then degraded to vinyl chloride by the same process of reductive dehalogenation (Pfaender, 1990). As discussed previously, 1,2-*cis*-dichloroethylene was a component of the concentrations reported as 1,2-*trans*-dichloroethylene for ground water in the Canal Creek area (table 28). However, production of the 1,1-dichloroethylene isomer does not seem to be significant because its concentrations were less than 10 µg/L in all samples collected from the Canal Creek aquifer (table 24).

Dihalo-elimination reactions could also produce the metabolites 1,2-*trans*-dichloroethylene and vinyl chloride from parent compounds of 1,1,2,2-tetrachloroethane and 1,1,2-trichloroethane, respectively (Lorah and Vroblesky, 1989, p. 88). Dihalo-elimination reactions could account for a part of 1,2-*trans*-dichloroethylene and vinyl chloride concentrations in Region II, but reductive dehalogenation of trichloroethylene is probably the most significant biodegradation reaction producing these compounds. The distributions of these two degradation products (figs. 60 and 61) correspond more closely to the distribution of trichloroethylene (fig. 59) than that of 1,1,2,2-tetrachloroethane (fig. 56) or 1,1,2-trichloroethane. The distribution of 1,1,2-trichloroethane is the most limited in areal extent, and concentrations are low. During the second sampling period, the highest concentration of 1,1,2-trichloroethane measured in the Canal Creek aquifer in Region II was 12 µg/L (Appendix B2).

The low concentrations of 1,1,2-trichloroethane and 1,2-dichloroethane that were measured in Region II probably result from reductive dehalogenation of 1,1,2,2-tetrachloroethane. The low concentrations of these possible degradation products of 1,1,2,2-tetrachloroethane indicate that either 1,1,2,2-tetrachloroethane is not easily degraded at this site or the daughter products themselves degrade rapidly and do not accumulate. This second possibility is not likely because the rate of reductive dehalogenation reactions is believed to decrease as the degree of halogenation of the organic compound decreases (Pfaender, 1990, p. 216). Another possibility is that other mechanisms, such as dihalo-elimination, are degrading the 1,1,2,2-tetrachloroethane and that not all of the degradation products have been identified.

Although not all of the possible biodegradation processes can be identified from the data collected during this study, reductive dehalogenation of trichloroethylene seems to be the dominant process in Region II. Dihalo-elimination reactions and reductive dehalogenation of 1,1,2,2-tetrachloroethane seem to be less important. Whatever transformation proceses are affecting the VOC's, it is evident that the processes occur relatively slowly because of the persistence of VOC's in the ground water from at least WW2 until the present. Tritium concentrations in the Canal Creek aquifer were very low or below the detection limit at sites 7, 8, and 104 (Appendix B3) along section C-C' (fig. 62), indicating that the ground water in Region IIB consists mainly of pre-1953 water (Robertson and Cherry, 1989). Thus, contaminants have been present in the Canal Creek aquifer in this area for at least four decades.

Ground water in Region III

The movement and fate of the VOC's in the surficial aquifer in Region III (fig. 19, table 27) is difficult to assess adequately with the available data because of the isolated flow systems of the surficial aquifer in Region III and the small number of wells. The contaminants in this region are moving in a shallow ground-water-flow system with short flowpaths and would discharge to the local surface-water bodies. Volatilization could be a significant removal process for the VOC's in this shallow flow system.

In the surficial aquifer at Beach Point (fig. 19), the sinking of DNAPL's and biodegradation reactions have affected the distribution and types of contaminants. The highest concentrations of VOC's were observed in the deepest well installed on Beach Point (well 33B; table 27), indicating that DNAPL's sank downward about 70 ft to the base of the aquifer (table 2).

Although samples from the shallowest well at site 33 commonly had dissolved-oxygen concentrations greater than 1.0 mg/L, dissolved-oxygen concentrations in samples from the deeper wells in the surficial aquifer at this site were low (less than 0.6 mg/L) or undetectable (less than 0.1 mg/L) (Appendix B1-B5). The low dissolved-oxygen concentrations and the presence of degradation products in samples from well 33B (table 27) indicates that anaerobic biodegradation is occurring in deeper parts of the surficial aquifer at Beach Point. Primary wastes disposed of at Beach Point included 1,1,2,2-tetrachloroethane, tetrachloroethylene, and trichloroethylene. The remaining major organic contaminants that were present in samples from well 33B, 1,2-*trans*-dichloroethylene and 1,1,2-trichloroethane (table 27), can be produced by reductive dehalogenation of these primary wastes.

SURFACE-WATER CONTAMINATION

Surface-water samples were collected in September 1988 and June 1989 from the West and East Branches of Canal Creek, Kings Creek, and the Bush River near Beach Point (fig. 15). The concentrations of inorganic constituents and of VOC's that were quantitatively determined in surface-water samples during these two sampling periods are listed at the end of the report in Appendixes C1 through C4. Other surface-water chemical data are presented throughout this section. Many of the organic compounds for which analyses were done (tables 5 and 6) were not detected in any of the samples and are not discussed here.

No enforceable Federal standards have been established for contaminant levels in surface water; however, the U.S. Environmental Protection Agency (1986) has compiled criteria for acute and chronic toxicity to aquatic life that reflect the Agency's recommendations for acceptable concentrations of various inorganic and organic constituents in surface water. In the discussion that follows, the concentrations of inorganic and organic constituents measured in surface-water samples collected in the Canal Creek area are compared to the toxicity criteria that have been established for freshwater aquatic life.

A total of 10 inorganic constituents were detected in concentrations that exceed the acute or chronic toxicity criteria for freshwater species (table 49). Phthalate esters, which are common laboratory contaminants, were the only organic compounds detected in the surface-water samples that exceed the toxicity criteria (table 49). Some VOC's were detected in the surface water, especially in samples collected from the West and East Branches of Canal Creek, but the concentrations did not exceed the toxicity criteria for freshwater aquatic life (U.S. Environmental Protection Agency, 1986). The toxicity criteria for VOC's established for freshwater aquatic life are higher than the standards established for concentrations of VOC's in drinking water (table 24); the toxicity criteria for the VOC's are commonly in the order of milligrams per liter, rather than micrograms per liter.

Inorganic Constituents

Distribution

Concentrations of inorganic constituents in the surface-water samples in the Canal Creek area varied considerably. For each sampling period, concentrations differed among the surface-water bodies, among sampling locations along the same water body, and between unfiltered and filtered samples (fig. 15; Appendixes C1 and C3). In addition, the surface-water chemistry observed for the two sampling periods differed significantly. The variation in inorganic chemistry can be largely attributed to the tidal nature of the creeks and estuaries and to varying amounts of ground-water input at the different sampling locations.

The boxplots in figures 64 and 65 illustrate the differences observed in the surface-water chemistry between the two sampling periods. The boxplots were constructed by use of data from unfiltered samples (excluding less-than values) that were collected at the same sampling sites during both periods. The ranges of chloride and sodium concentrations were much greater in September 1988 than in June 1989 (fig. 64); a similar pattern was found for sulfate and magnesium. Calcium is the only major ion whose concentration did not differ more in September 1988 than in June 1989 (fig. 64). Median concentrations of several trace metals, including lead and zinc (fig. 65), were higher for June 1989 than for September 1988.

Concentrations of the major ions calcium (fig. 66), sodium, magnesium, chloride, and sulfate were either the same or slightly higher in unfiltered samples than in filtered samples collected at the same sites. Higher concentrations of trace metals were generally measured in unfiltered samples than in filtered samples (fig. 67). For example, the median iron concentration in unfiltered samples from September 1988 was about 1,500 μg/L, whereas the median iron concentration in filtered samples collected at the same sites and on the same date was only about 100 μg/L (fig. 67). A similar pattern of concentrations was observed for lead and zinc, although median concentrations cannot be clearly identified in some cases because of a small number of detectable concentrations (fig. 67).

The higher concentrations of trace metals in unfiltered samples compared to those in filtered samples indicate that the trace metals are associated with large colloids, sediment particles, or organic particulates that are present in the water column. Suspended matter is known to act as an efficient scavenger of metals (de Groot and others, 1976, p. 132; Elder, 1988, p.8). For the September 1988 data, the median concentration of total solids in unfiltered samples was significantly higher than the median concentration of dissolved solids that was measured in filtered samples collected at the same sites (fig. 66). The median total-solids concentration was about 2,000 mg/L, whereas the median

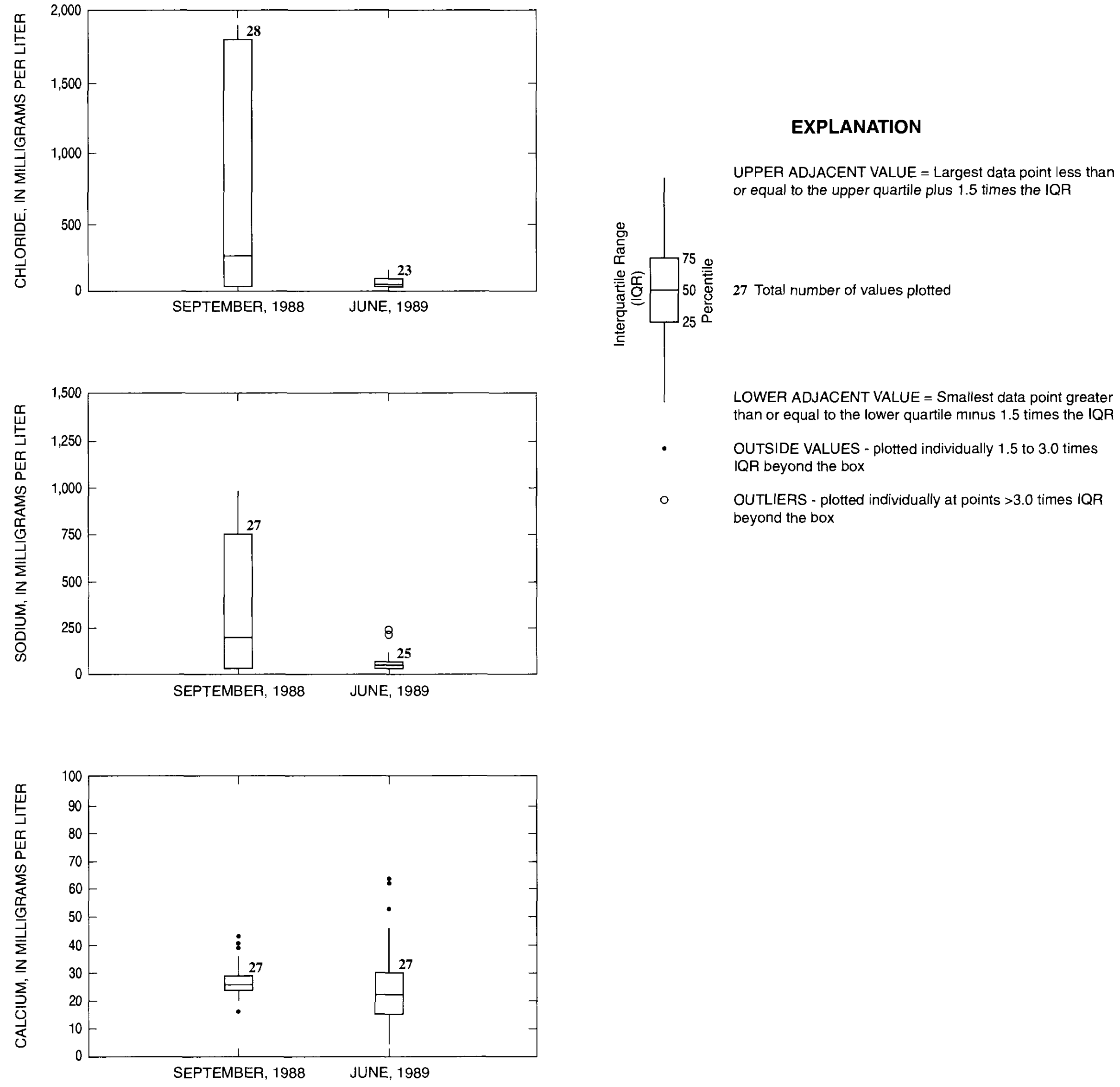


Figure 64. Concentrations of selected major ions in unfiltered surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland, in September 1988 and June 1989.

dissolved-solids concentration was about 1,200 mg/L (fig. 66). This difference in total- and dissolved-solids concentrations indicates that significant concentrations of suspended particles (median of about 800 mg/L) were present in the water column at most sites.

The concentrations in surface-water samples were compared to the water-quality criteria for freshwater species rather than to those for saltwater species (table 49). The relatively low dissolved-solids concentrations and salinities measured in surface water in the Canal Creek area (Appendixes C1 and C3) indicate that the water is either fresh or slightly brackish. Freshwater is defined as having a dissolved-solids concentrations less than about 1,000 mg/L; brackish water has dissolved-solids concentrations from about 1,000 to 20,000 mg/L (Drever, 1988, p. 13). The maximum dissolved-

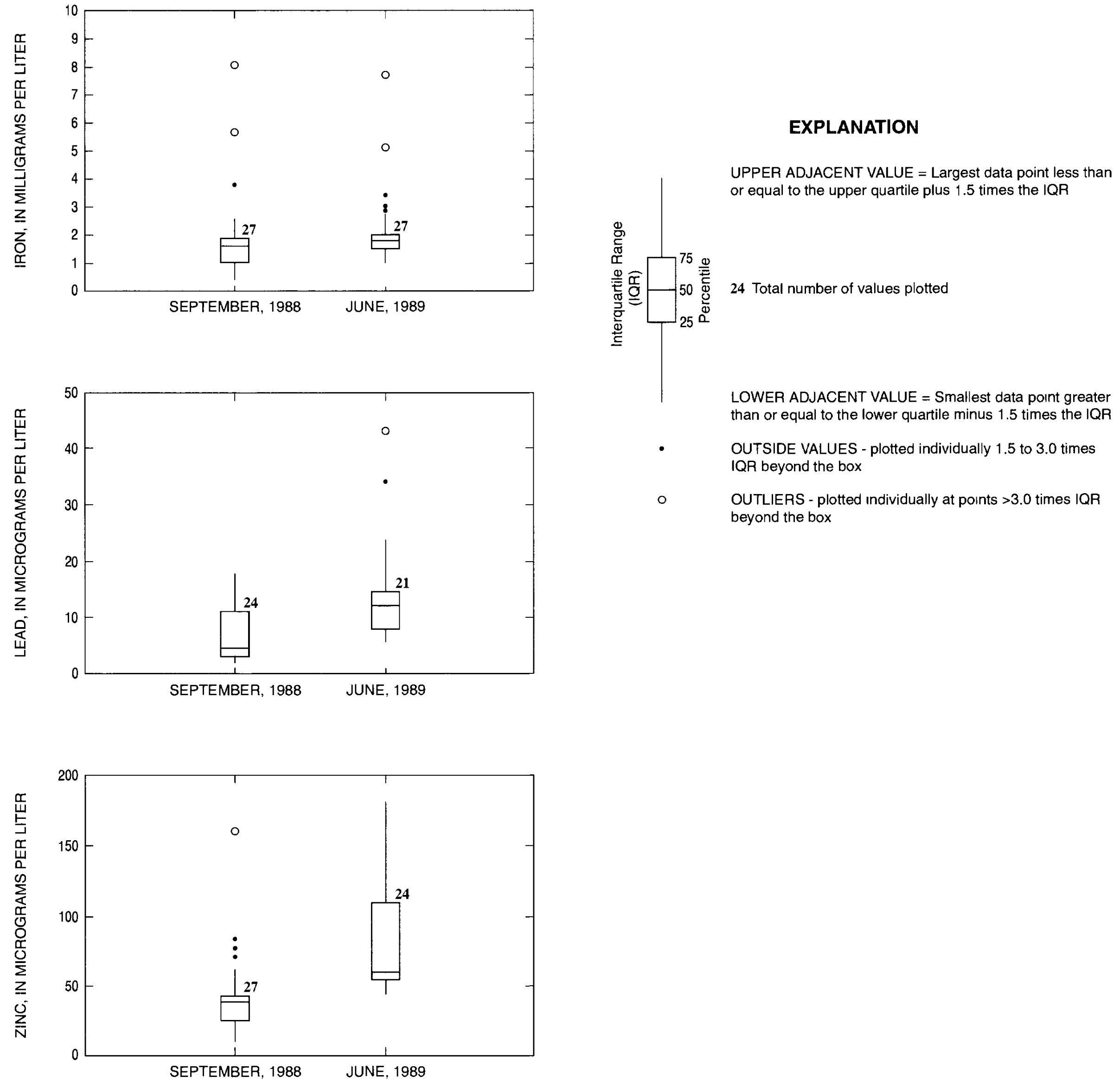


Figure 65. Concentrations of selected minor constituents in unfiltered surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland, in September 1988 and June 1989.

solids concentration measured during the two sampling periods was 3,430 mg/L, and concentrations were less than 1,000 mg/L at many sites, especially in June 1989 (Appendixes C1 and C3). For many constituents, the water-quality criteria are lower for freshwater species than for saltwater species (U.S. Environmental Protection Agency, 1986); thus, constituent concentrations in surface-water samples exceeded more freshwater criteria than the saltwater criteria.

A total of 10 inorganic constituents were detected in concentrations that exceed the acute or chronic toxicity criteria for freshwater species: beryllium, cadmium, copper, cyanide, iron, lead, mercury, silver, thallium, and zinc (table 49). The toxicity criteria were considered to be exceeded at a site if concentrations were above the criteria in any one of the unfiltered or filtered replicates collected at a site. Among the determinations for the

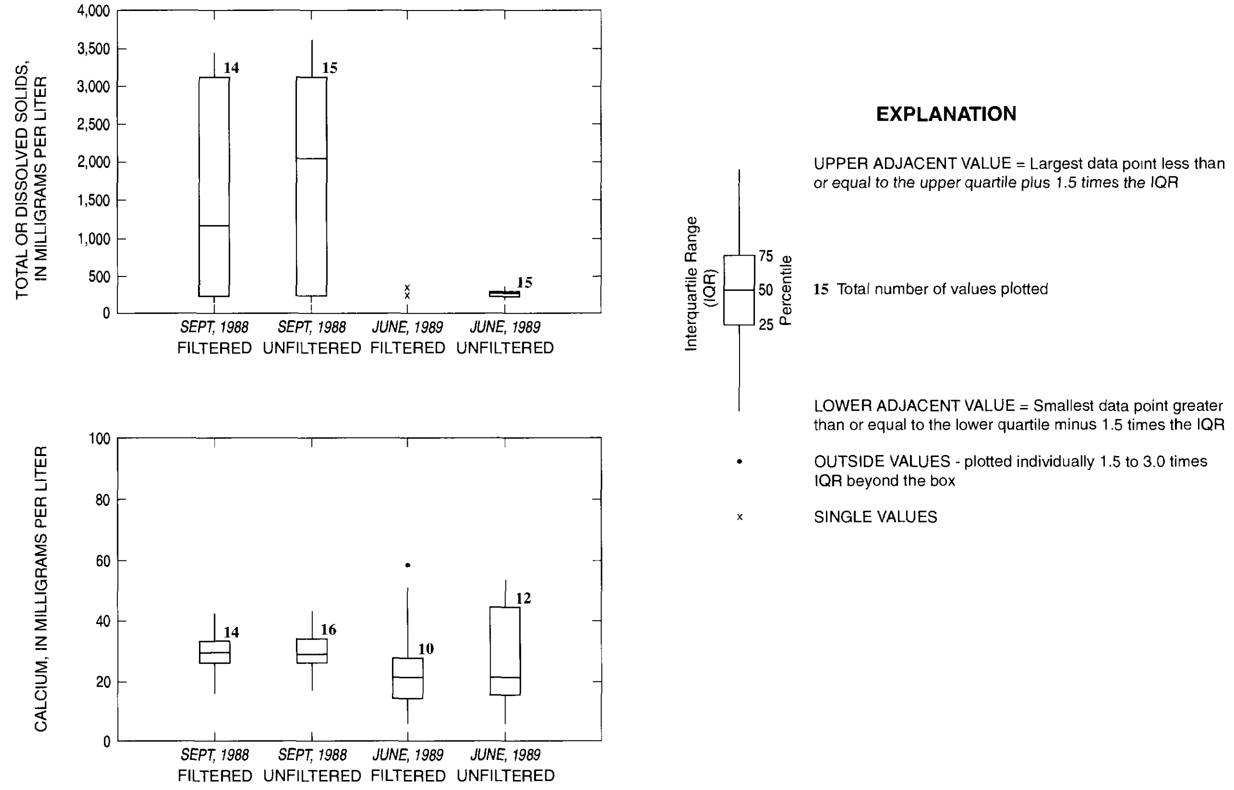


Figure 66. Concentrations of selected major ions in unfiltered and filtered surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland.

inorganic constituents, cyanide seemed to have the greatest error between replicate samples. At four of the five sites where the toxicity criterion was exceeded (table 49), cyanide concentrations were below the detection limit in replicate samples (Appendix C1).

Most of the samples that had concentrations exceeding the toxicity criteria for the inorganic constituents were collected at sites in Kings Creek and the Bush River that surround Beach Point (sites 2 to 9 in fig. 15) and at other sites in Kings Creek (sites 10 to 14 in fig. 15). Iron, lead, and zinc concentrations exceeded the freshwater toxicity criteria at the most surface-water sites (table 49).

Probable Sources

Probable sources are discussed for the 10 inorganic constituents whose concentrations exceeded the acute or chronic toxicity criteria for freshwater species (table 49). The sources of these inorganic contaminants in surface water in the Canal Creek area are difficult to identify because of the various pathways by which anthropogenic constituents can be transported to surface waters and because of the constant movement and redistribution of the surface water and sediment due to tidal influences. Possible transport pathways include discharge of industrial and municipal wastes, discharge of contaminated ground water, transport of contaminated soils to the surface water with storm runoff, atmospheric deposition, and tidal transport of contaminated surface water and sediment from outside the study area.

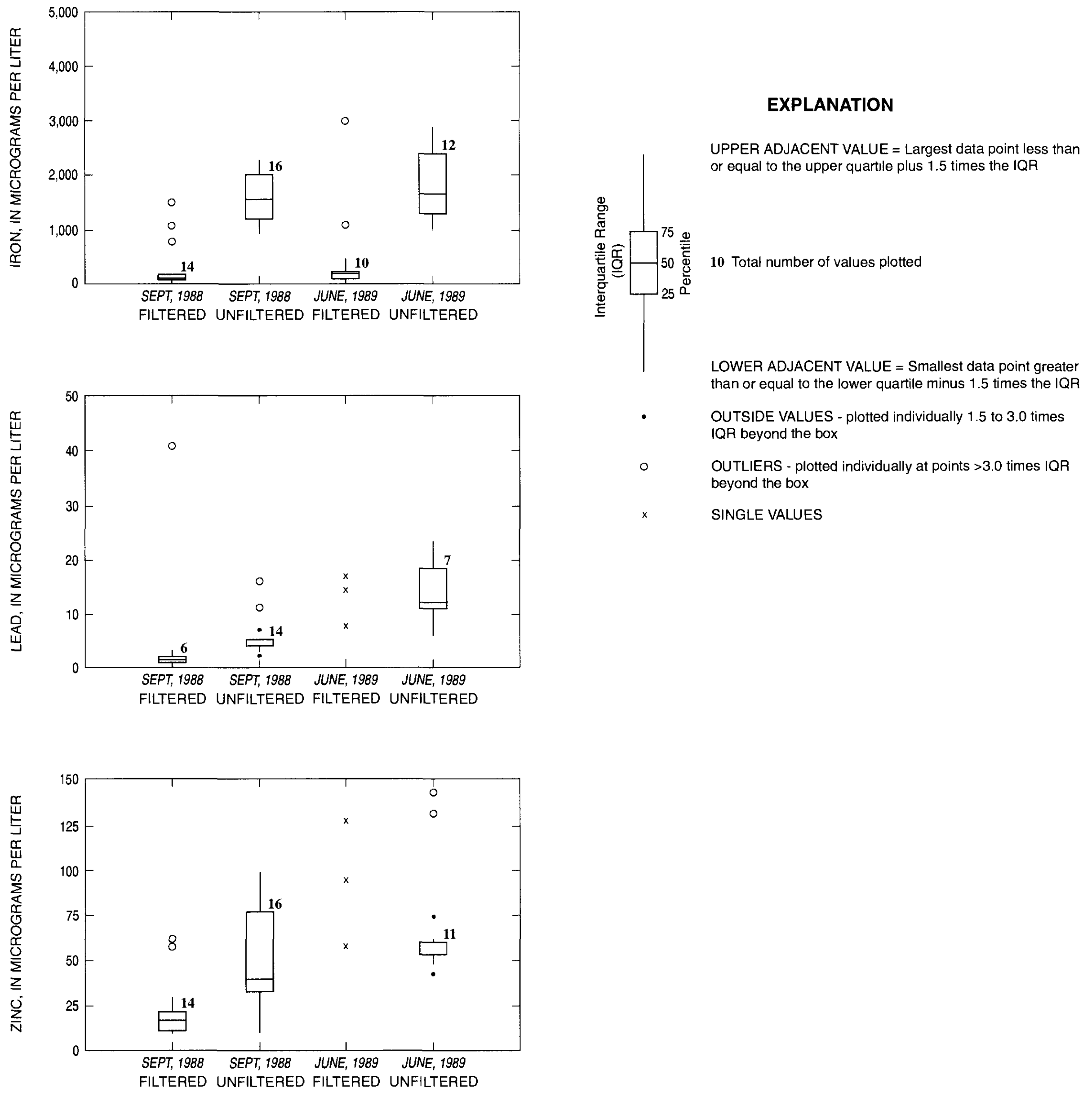


Figure 67. Concentrations of selected minor constituents in unfiltered and filtered surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland.

A probable source of the inorganic contaminants detected in the surface-water samples (table 49) is the remobilization of metals that accumulated in bottom sediments during periods of discharge of industrial wastewaters to the surface waters. Until the late 1970's or early 1980's, the primary method of waste disposal from the manufacturing, filling, and research plants in the Canal Creek area was by discharge of untreated wastes through sewers leading to Canal Creek and Kings Creek. These industrial wastewaters, which were known to contain various metals (U.S. Army Environmental Hygiene Agency, 1977), were discharged for more than 50 years and could have caused significant accumulation of metals in bottom sediments in the Canal Creek area. Previous investigators have measured elevated concentrations of various metals in the surface water and bottom sediment in Canal Creek and Kings Creek (see introduction of report). Zinc, cadmium, copper, mercury, and lead were detected in concentrations above background in the bottom sediments of Canal Creek and Kings Creek in one study (Nemeth, 1989, p. 245).

Municipal wastewater discharges to surface water are also known to be a significant source of inorganic contaminants, including cadmium, copper, chromium, lead, mercury, nickel, silver, and zinc (Helz and others, 1975; Elder, 1988, p. 5). The wastewater-treatment plant for the Edgewood area of APG is located immediately west of Beach Point (fig. 2), and the effluent is discharged to the Bush River near the mouth of Kings Creek (Nemeth, 1989, p. 725-728). In addition, the storm-sewer system for the study area discharges to Kings Creek near the wastewater-treatment plant (Nemeth, 1989, p. 728). The wastewater-treatment plant has operated from 1942 through the present, but the system was upgraded at least twice between the 1960's and 1980's. The plant processes sanitary and chemical wastes. During the late 1970's, about 1.3 Mgal/d of treated sewage was discharged to the Bush River from the wastewater-treatment plant (U.S. Army Environmental Hygiene Agency, 1977). Many of the surface-water samples that were collected for the present study and that contained metals at concentrations exceeding the toxicity criteria (table 49) were collected at the sites that surround Beach Point near the wastewater-treatment plant (sites 2 to 9 in fig. 15).

Discharge of contaminated ground water to surface water is another possible source of the surface-water contamination, although discharge of industrial and municipal wastewater has probably contributed a greater amount of metals to the surface water. Of the 10 inorganic constituents whose concentrations exceeded the toxicity criteria (table 49), 8 also were present in elevated concentrations in ground-water samples collected during this study. The eight constituents are beryllium, cadmium, copper, iron, lead, mercury, thallium, and zinc (table 18; figs. 36, 38, 39, 40). Because of tidal transport and mixing of the creek and estuary water, direct comparison cannot be made between surface-water sites where high concentrations of inorganic constituents were detected and areas of shallow ground-water contamination. Thus, the effect of ground-water discharge on the inorganic surface-water quality in the Canal Creek area is difficult to assess.

Several studies have shown that atmospheric deposition is an important pathway for metal contamination of surface water (Elder, 1988, p. 3). Lead is the most significant of the airborne contaminants because of its former widespread discharge into the atmosphere from exhausts of gasoline engines. Atmospheric deposition can also be a significant transport mechanism for cadmium and zinc (Elder, 1988, p. 3).

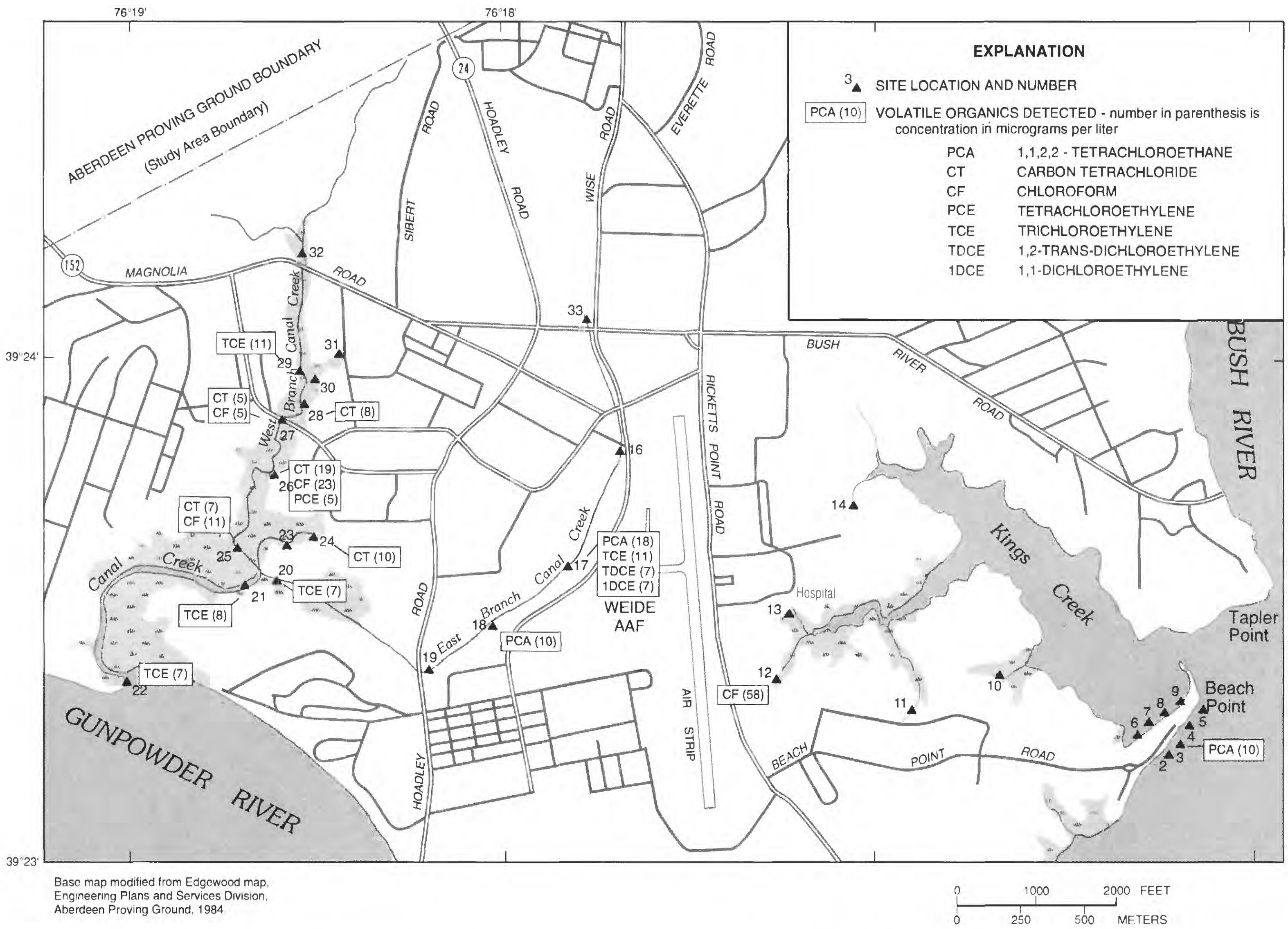
Organic Constituents

Distribution

Chlorinated VOC's were the most prevalent organic contaminants detected in surface-water samples that could be associated with past activities in the Canal Creek area. The distributions of the VOC's are summarized in figures 68 and 69 for the two sampling periods. All concentrations of VOC's in the surface-water samples were below the toxicity criteria for freshwater and saltwater aquatic life (U.S. Environmental Protection Agency, 1986). The VOC's that were detected most frequently and in the highest concentrations include 1,1,2,2-tetrachloroethane, carbon tetrachloride, chloroform, trichloroethylene, and 1,2-*trans*-dichloroethylene (figs. 68 and 69). The same VOC's were the major contaminants detected in ground water in the Canal Creek area (figs. 50 to 60), although concentrations were greater in the ground water than in the surface-water samples.

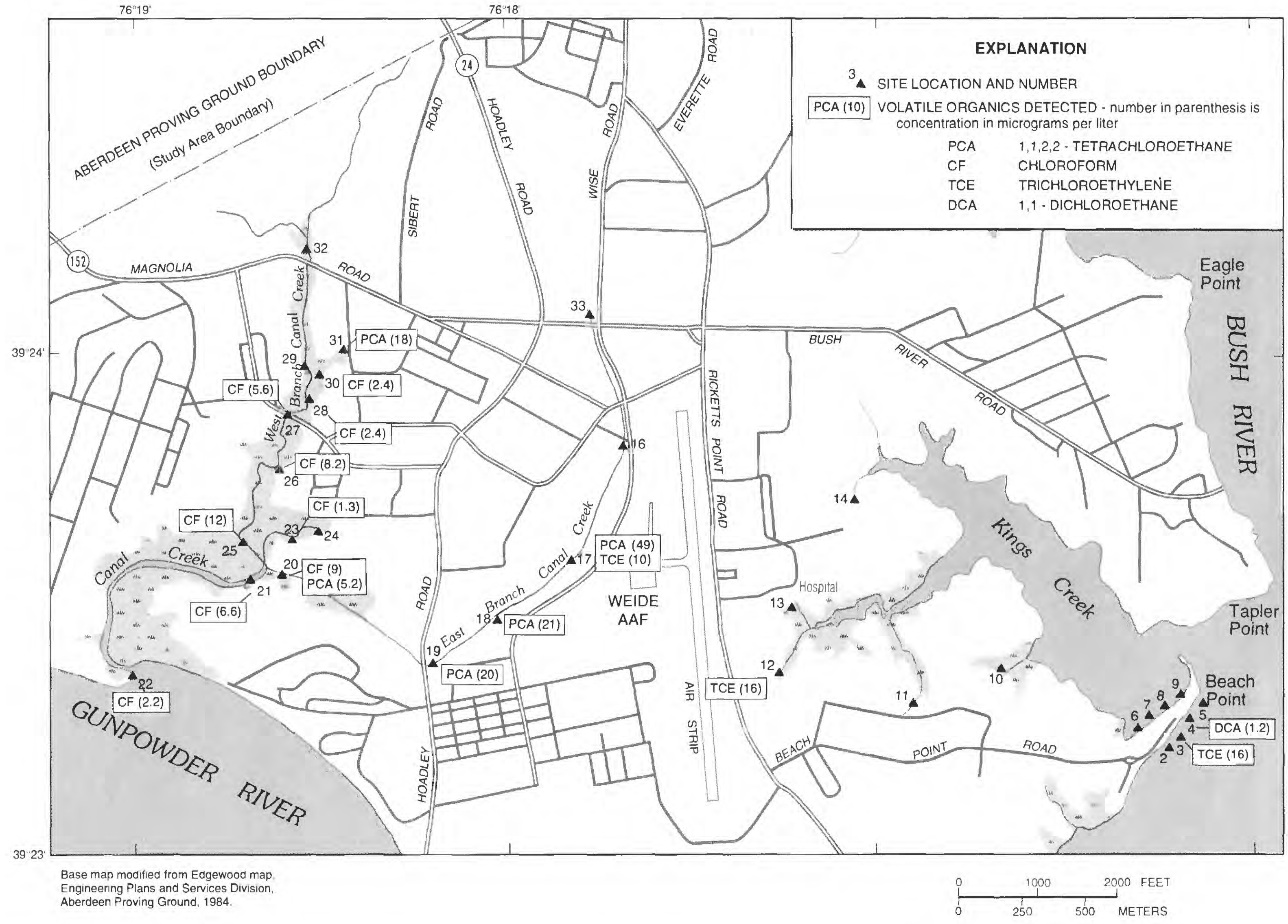
The concentrations of VOC's in the surface-water samples differed between replicate samples (Appendixes C2 and C4) and between the two sampling periods (figs. 68 and 69). The differences are probably due largely to the volatility of the compounds and to the tidal nature of the creeks and estuaries. In addition, differences in the relative proportions of ground-water input could cause differences between the concentrations measured in the surface-water samples during the two periods. During both sampling periods, VOC's were commonly detected in one sample in low concentrations but not detected in replicate samples (Appendixes C2 and C4). If replicate samples were collected at a site, the maximum concentration of each VOC measured at the site was used in figures 68 and 69.

Carbon tetrachloride and chloroform were detected at the most sites and in the highest concentrations along the West Branch Canal Creek, whereas 1,1,2,2-tetrachloroethane and trichloroethylene generally were more prevalent and in highest concentrations along the East Branch Canal Creek (figs. 68 and 69). The maximum concentrations of VOC's measured in the West Branch Canal Creek were 19 µg/L of carbon tetrachloride and 23 µg/L of chloroform; the maximum concentrations measured in the East Branch Canal Creek were 49 µg/L of 1,1,2,2-tetrachloroethane and 11 µg/L of trichloroethylene (figs. 68 and 69).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984

Figure 68. Distributions of volatile organic compounds in surface water in the Canal Creek area, September 1988.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 69. Distribution of volatile organic compounds in surface water in the Canal Creek area, June 1989.

The areal distributions of the VOC's in the West and East Branches of Canal Creek are similar to their areal distributions in the shallow ground water of the Canal Creek aquifer. Relatively high concentrations of carbon tetrachloride and chloroform were observed in the ground water (figs. 51 and 52) near the West Branch Canal Creek where substantial concentrations of these compounds were observed in the surface water (figs. 68 and 69). Carbon tetrachloride and chloroform concentrations were low or below detection limits in the ground water near the East Branch Canal Creek (figs. 57 and 58) and also in the surface-water samples collected from the East Branch Canal Creek (figs. 68 and 69). No relation is apparent between the distributions in ground water and surface water for 1,1,2,2-tetrachloroethane and trichloroethylene concentrations in Canal Creek. Relatively high concentrations of 1,1,2,2-tetrachloroethane and trichloroethylene were widespread in the ground water near both the West and East Branches of Canal Creek.

In Kings Creek and the Bush River, significant concentrations of VOC's were measured at two sites (figs. 68 and 69). At site 12, a relatively high concentration of chloroform (58 µg/L) was measured in September 1988 (fig. 68). In addition, 16 µg/L of trichloroethylene was measured in one sample collected at site 12 in June 1989, although a replicate sample collected at the site had less than 6.6 µg/L of trichloroethylene (Appendix C4). At site 3 in the Bush River adjacent to Beach Point, 10 µg/L of 1,1,2,2-tetrachloroethane and 16 µg/L of trichloroethylene were measured in September 1988 and June 1989, respectively (figs. 68 and 69).

Surface-water samples collected at Beach Point at sites 5 and 7 in June 1989 had low concentrations of practically every one of the 41 VOC's for which analyses were done (table 5 and Appendix C4). Many of these VOC's were not measured in any other ground-water or surface-water samples collected in the Canal Creek area; thus, the reported concentrations for all these compounds in the surface-water samples from sites 5 and 7 are highly suspect. Most likely, the laboratory mistakenly reported concentrations measured in one of their internal spiked samples (used for quality control) rather than the concentrations measured in the surface-water samples collected at sites 5 and 7. Results from one of the replicate samples collected at site 22 at the mouth of Canal Creek in September 1988 (fig. 68) are similarly suspect (Appendix C2). Low concentrations of practically all of the VOC's for which analyses were done were reported in one of the replicate samples collected at site 22, whereas trichloroethylene was the only VOC measured in the corresponding replicate in concentrations above the detection limits (Appendix C2 and fig. 68).

Several additional samples were collected for VOC analyses at four surface-water sites in December 1989 when a 3- to 4-in.-thick layer of ice covered most of the East and West Branches of Canal Creek (Appendix C5). VOC's are more soluble in cold water than in warm water, and volatilization to the atmosphere would be limited by the ice cover. Thus, higher concentrations of VOC's would be expected in surface water under ice cover than at other times of the year. Although some exceptions were found, the concentrations of VOC's in the December 1989 samples were generally greater than or equal to concentrations in samples collected at the same sites in September 1988 and June 1989 (Appendix C5). The results for the samples collected at the mouth of Canal Creek (site 22) are most notable (Appendix C5). Concentrations of carbon tetrachloride, chloroform, and 1,1,2,2-tetrachloroethane were 25, 38, and 11 µg/L, respectively, in the samples collected from underneath the ice at the mouth of the creek, whereas concentrations of these constituents were less than 10 µg/L in samples collected at site 22 during the other two sampling periods (Appendix C5). Concentrations in the replicate samples collected at the mouth of the river in December 1989 agree very closely (site 22 in Appendix C5); thus, confidence in the reported concentrations for this sampling date is high.

Other VOC's were tentatively identified or reported as unknowns for the surface-water samples collected in September 1988 (table 50) and June 1989 (table 51). Estimated concentrations of the TIOC's and unknown compounds ranged from 1 to 100 µg/L. Several of the TIOC's, such as hexane and acetone, are commonly used solvents in analytical laboratories and could have been introduced to the samples in the laboratories. The maximum concentration of unknown compounds (100 µg/L) was reported for a sample collected from site 12 in June 1989; however, a replicate sample collected at this site had concentrations of unknown compounds that were less than 10 µg/L (table 51). Unknown compounds also were detected in laboratory method blanks analyzed with the samples collected in June 1989 (table 51).

Of the semivolatile organic compounds for which quantitative analyses were done (table 6), phthalate esters--including butylbenzyl phthalate, *bis*(2-ethylhexyl) phthalate, and di-n-octyl phthalate--were the only semivolatile compounds detected in more than one surface-water sample (tables 52 and 53). The total concentration of phthalate esters exceeded the chronic toxicity value for freshwater

TABLE 49. Concentrations of constituents in surface-water samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland, as related to water-quality criteria for freshwater species

[All concentrations in micrograms per liter; replicate samples not included; ATV, acute toxicity value; CTV, chronic toxicity value; dashes indicate data not available]

Constituent	ATV	CTV	September 1988			June 1989		
			Number of sites where ATV was exceeded	Number of sites where CTV was exceeded	Maximum concentration observed	Number of sites where ATV was exceeded	Number of sites where CTV was exceeded	Maximum concentration observed
Beryllium	130	5.3	0	0	<10	0	14	44
Cadmium	3.9	1.1	0	2	2	6	7	6.6
Copper	18	12	0	0	12	3	3	44
Cyanide	22	5.2	2	5	80	--	--	--
Iron	1,000	--	22	--	8,000	28	--	7,700
Lead	8.2	3.2	8	18	41	18	25	43
Mercury	2.4	.012	0	1	1.5	0	3	2.4
Silver	4.1	.12	--	--	--	0	7	.8
Thallium	1,400	40	--	--	--	0	3	50
Zinc	320	47	0	13	160	1	24	390
Phthalate esters	940	3	0	4	58	0	9	41

Table 50. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for volatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, September 1988*

[All concentrations are in micrograms per liter; --, not available; R, replicate sample; (Re), repeat analysis by laboratory; MB, method blank]

Sample no.	Sampling date	Date of analysis	Volatile compound	Retention time (minutes)	Estimated concentration
			METHOD BLANKS		
MB1	--	9-24-88	None	--	--
MB2	--	9-28-88	None	--	--
MB4	--	10-04-88	None	--	--
MB5	--	10-11-88	None	--	--
MB6	--	10-13-88	None	--	--
			SURFACE-WATER SAMPLES		
CCSW-12	9-15-88	10-04-88	Unknown	--	13
CCSW-12R	9-15-88	9-29-88	Unknown	--	8
CCSW-18	9-13-88	9-28-88	Hexane	3.33	10
CCSW-19	9-13-88	10-13-88	Unknown	1.90	4
CCSW-19R	9-13-88	9-24-88	Unknown	28.0	4
CCSW-19R	9-13-88	9-24-88	1,5-Dimethyl-bicyclo-[3.2.2]nona-6,8-dien-3-one	8.85	2
CCSW-20(Re)	9-13-88	10-13-88	Acetone	2.62	3
CCSW-20(Re)	9-13-88	10-13-88	Unknown	10.89	11
CCSW-20(Re)	9-13-88	10-13-88	Unknown	11.06	4
CCSW-20(Re)	9-13-88	10-13-88	Unknown	12.05	3
CCSW-20(Re)	9-13-88	10-13-88	4-Methyl 2-pentanone	12.11	6
CCSW-21	9-13-88	9-24-88	Acetone	2.65	3
CCSW-21	9-13-88	9-24-88	Unknown	3.37	4
CCSW-21	9-13-88	9-24-88	1,4-Dioxane	10.93	14
CCSW-21	9-13-88	9-24-88	4-Methyl 2-pentanone	12.11	23
CCSW-21	9-13-88	9-24-88	2-Hexanone	15.48	3
CCSW-21	9-13-88	9-24-88	Xylene	20.36	2
CCSW-21	9-13-88	9-24-88	Unknown	20.60	4
CCSW-24(Re)	9-13-88	10-04-88	Hexane	3.01	5
CCSW-24(Re)	9-13-88	10-04-88	Fluorobenzene	7.20	31
CCSW-24(Re)	9-13-88	10-04-88	Difluorobenzene isomer	7.61	22
CCSW-24(Re)	9-13-88	10-04-88	Unknown	12.62	28
CCSW-24(Re)	9-13-88	10-04-88	Unknown	20.25	29
CCSW-25	9-13-88	9-28-88	Hexane	3.32	15
CCSW-28(Re)	9-13-88	10-13-88	Unknown	1.43	10
CCSW-28(Re)	9-13-88	10-13-88	Unknown	1.46	49
CCSW-28(Re)	9-13-88	10-13-88	Unknown	2.79	10
CCSW-29	9-13-88	9-24-88	Unknown	1.43	6
CCSW-29	9-13-88	9-24-88	Unknown	1.46	31
CCSW-29	9-13-88	9-24-88	Unknown	1.49	80
CCSW-29	9-13-88	9-24-88	thiobis-methane	2.79	4
CCSW-30	9-13-88	9-24-88	Acetone	2.62	3
CCSW-30	9-13-88	9-24-88	Unknown	2.79	9
CCSW-30	9-13-88	9-24-88	Unknown	4.85	3
CCSW-30R	9-13-88	9-24-88	Unknown	1.96	4
CCSW-30R	9-13-88	9-24-88	Unknown	2.76	7
CCSW-31	9-13-88	10-04-88	Unknown	1.46	42
CCSW-32	9-13-88	10-11-88	Unknown	1.85	4
CCSW-32R	9-13-88	9-24-88	Unknown	13.06	2
CCSW-32R	9-13-88	9-24-88	Unknown	25.71	2
CCSW-33	9-13-88	9-28-88	Unknown	3.17	3
CCSW-33	9-13-88	9-28-88	Unknown	10.70	1

Table 51. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for volatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, June 1989*

[All concentrations are in micrograms per liter; --, not available or not applicable; R, replicate sample]

Sample no.	Sampling date	Laboratory no.	Volatile compound	Retention time (minutes)	Estimated concentration
			METHOD BLANKS		
--	--	VBA014	Unknown	3.6	10
--	--	VBB014	Unknown	28.7	20
			SURFACE-WATER SAMPLES		
CCSW-2U	06-15-89	VBA007	Unknown	27.6	3
CCSW-3UR	06-15-89	VBA01	Napthalene	--	7
CCSW-3UR	06-15-89	VBA011	Unknown	27.2	5
CCSW-3UR	06-15-89	VBA011	Unknown	27.5	7
CCSW-3UR	06-15-89	VBA011	Unknown	27.7	40
CCSW-3UR	06-15-89	VBA011	Unknown	28.0	10
CCSW-3UR	06-15-89	VBA011	Unknown	28.9	20
CCSW-3UR	06-15-89	VBA011	Unknown	29.2	10
CCSW-3UR	06-15-89	VBA011	Unknown	29.4	20
CCSW-3UR	06-15-89	VBA011	Unknown	29.5	20
CCSW-6U	06-15-89	VBA008	Unknown	28.6	10
CCSW-6U	06-15-89	VBB006	Unknown	3.5	3
CCSW-9U	06-15-89	VBA001	Unknown	3.6	3
CCSW-12U	06-15-89	VBA012	Unknown	22.9	100
CCSW-12U	06-15-89	VBA012	Unknown	24.0	4
CCSW-12U	06-15-89	VBA012	Unknown	24.9	100
CCSW-12U	06-15-89	VBA012	Unknown	27.2	30
CCSW-12U	06-15-89	VBA012	Unknown	27.7	6
CCSW-12U	06-15-89	VBA012	Unknown	28.1	2
CCSW-12U	06-15-89	VBA012	Unknown	28.6	90
CCSW-12U	06-15-89	VBA012	Unknown	29.2	2
CCSW-12U	06-15-89	VBA012	Unknown	29.6	60
CCSW-12UR	06-15-89	VBA002	*cis*-1,2-Dichloroethene	--	6
CCSW-12UR	06-15-89	VBA002	Napthalene	--	9
CCSW-12UR	06-15-89	VBA002	Unknown	3.6	2
CCSW-12UR	06-15-89	VBA002	Unknown	27.1	4
CCSW-12UR	06-15-89	VBA002	Unknown	27.5	3
CCSW-12UR	06-15-89	VBA002	Unknown	27.6	6
CCSW-12UR	06-15-89	VBA002	Unknown	28.0	3
CCSW-12UR	06-15-89	VBA002	Unknown	28.3	4
CCSW-12UR	06-15-89	VBA002	Unknown	28.9	7
CCSW-14U	06-15-89	VBA010	Unknown	28.8	2

species (3 µg/L) in four samples in September 1988 and in nine samples in June 1989 (table 49); however, phthalate esters are common laboratory contaminants. Phthalate esters were present in laboratory method blanks analyzed with the surface-water samples in September 1988 and June 1989 (tables 52 and 53). Concentrations of the individual phthalate esters ranged from 15 to 310 µg/L in the method blanks and from 5 to 53 µg/L in the surface-water samples. Phthalate esters also were commonly detected in laboratory method blanks analyzed with ground-water samples (tables 46 and 47).

Other semivolatile organic compounds that were tentatively identified or reported as unknown compounds are listed in tables 54 and 55. Butyrolactone, which is also a laboratory contaminant, was most frequently reported as a semivolatile TIOC in the surface-water samples (tables 54 and 55).

Table 52. *Semivolatile organic compounds quantitated in surface-water samples collected at Aberdeen Proving Ground, Maryland, September 1988*

[All concentrations are in micrograms per liter; --, not applicable; R, replicate sample; MB, method blank.]

Sample no.	Sampling date	Date of analysis	Seimivolatile compound	Concentration
		METHOD BLANKS		
MB1	--	11-30-88	*bis*(2-Ethylhexyl) phthalate	310
MB1	--	11-30-88	Di-n-octyl phthalate	18
		SURFACE-WATER SAMPLES		
CCSW-19R	9-13-88	12-01-88	*bis*(2-Ethylhexyl) phthalate	53
CCSW-19R	9-13-88	12-01-88	Di-n-octyl phthalate	5
CCSW-22R	9-13-88	12-01-88	*bis*(2-Ethylhexyl) phthalate	31
CCSW-28	9-13-88	12-01-88	*bis*(2-Ethylhexyl) phthalate	42
CCSW-30	9-13-88	12-01-88	*bis*(2-Ethylhexyl) phthalate	19
CCSW-30R	9-13-88	12-01-88	*bis*(2-Ethylhexyl) phthalate	48
CCSW-32R	9-13-88	11-30-88	Phenol	2

Table 53. *Semivolatile organic compounds quantitated in surface-water samples collected at Aberdeen Proving Ground, Maryland, June 1989*

[All concentrations are in micrograms per liter; --, not applicable; R, replicate sample]

Sample no.	Sampling date	Laboratory no.	Semivolatile compound	Concentration
		METHOD BLANKS		
--	--	SA0005	Butylbenzyl phthalate	15
		SURFACE-WATER SAMPLES		
CCSW-22U	06-13-89	SAO001	Butylbenzyl phthalate	22
CCSW-22UR	06-13-89	SAN001	Butylbenzyl phthalate	11
CCSW-23U	06-13-89	SAN008	Butylbenzyl phthalate	17
CCSW-25U	06-13-89	SAO003	Butylbenzyl phthalate	11
CCSW-26U	06-13-89	SAN009	Butylbenzyl phthalate	20
CCSW-27UR	06-13-89	SAN005	Butylbenzyl phthalate	41
CCSW-28U	06-13-89	SAO004	Butylbenzyl phthalate	15
CCSW-29U	06-13-89	SAO006	Butylbenzyl phthalate	14
CCSW-30U	06-13-89	SAO002	Butylbenzyl phthalate	16
CCSW-33U	06-13-89	SAO009	Butylbenzyl phthalate	12

Unknown semivolatile compounds were reported for many of the surface-water samples for both sampling periods, and their estimated concentrations ranged from 2 to 460 μg/L (tables 54 and 55). In laboratory method blanks, concentrations of unknown semivolatile compounds ranged from 1 to 23 μg/L (tables 54 and 55).

Probable Sources

Because VOC's would be expected to volatilize quickly to the atmosphere from surface water, the presence of these compounds in the West and East Branches of Canal Creek, Kings Creek, and the Bush River (figs. 68 and 69) indicate a current and active source of contamination. Probable sources of the VOC's in the surface water include discharge of shallow contaminated ground water, current wastewater discharge, and dissolution of DNAPL's or desorption of compounds present in bottom sediments or marsh sediments.

Ground-water discharge is probably the major source of VOC's in the water column of the West Branch Canal Creek. Similarities are evident between the areal distribution of carbon tetrachloride and chloroform in the surface water and their areal distribution in the Canal Creek aquifer adjacent to the creek (figs. 51, 52, 68). Ground water in the Canal Creek aquifer in Region I flows toward and discharges to the West Branch Canal Creek and the lower reach of the East Branch Canal Creek (fig. 20). Because the eastern bank of the West Branch Canal Creek was used as a landfill and in the past (fig. 14), dissolution of DNAPL's or desorption of sorbed compounds from the creek-bottom or marsh sediments also could provide a source of surface-water contamination. Recent wastewater discharge is not a likely source of contamination along this creek because no site for wastewater discharge to the West Branch Canal Creek has been permitted in recent years (Nemeth, 1989, p. 796).

The East Branch Canal Creek near surface-water sampling sites 17, 18, and 19 (fig. 68) receives contaminated ground-water discharge from the surficial and Canal Creek aquifers in the paleochannel area (figs. 3 and 8). The major VOC's in the ground water (figs. 56 and 59) and surface water (figs. 68 and 69) in this area were 1,1,2,2-tetrachloroethane and trichloroethylene, indicating that ground-water discharge is a probable source of VOC's in the East Branch Canal Creek. In addition, large quantities of 1,1,2,2-tetrachloroethane in

Table 54. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for semivolatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, September 1988*

[All concentrations are in micrograms per liter; --, not applicable; R, replicate sample; MB, method blank]

Sample no.	Sampling date	Date of analysis	Semivolatile compound	Retention time (minutes)	Estimated concentration
			METHOD BLANKS		
MB7	--	11-30-88	Unknown	4.61	7
MB7	--	11-30-88	Butyrolactone	6.28	12
MB7	--	11-30-88	Unknown	6.48	8
MB7	--	11-30-88	Hexanedioic acid, dioctyl ester	25.46	370
MB8	--	12-01-88	Unknown	6.29	6
MB8	--	12-01-88	Unknown	6.53	23
			SURFACE-WATER SAMPLES		
CCSW-2	9-15-88	12-01-88	Unknown	4.67	45
CCSW-2	9-15-88	12-01-88	Unknown	6.40	76
CCSW-2	9-15-88	12-01-88	Unknown	6.44	41
CCSW-2	9-15-88	12-01-88	Unknown	6.54	17
CCSW-2	9-15-88	12-01-88	Unknown	12.61	3
CCSW-2	9-15-88	12-01-88	Unknown	13.45	5
CCSW-2	9-15-88	12-01-88	Unknown	25.49	133
CCSW-8	9-15-88	12-01-88	Unknown	4.63	31
CCSW-8	9-15-88	12-01-88	Butyrolactone	6.32	28
CCSW-8	9-15-88	12-01-88	Unknown	6.40	22
CCSW-8	9-15-88	12-01-88	Unknown	6.50	11
CCSW-12	9-15-88	12-01-88	Unknown	4.39	5
CCSW-12	9-15-88	12-01-88	Unknown	4.67	39
CCSW-12	9-15-88	12-01-88	Butyrolactone	6.34	20
CCSW-12	9-15-88	12-01-88	Unknown	6.54	14
CCSW-12	9-15-88	12-01-88	2-Ethyl 1-hexanol	8.69	5
CCSW-12	9-15-88	12-01-88	Unknown	8.96	4
CCSW-12	9-15-88	12-01-88	Unknown	9.40	17
CCSW-12	9-15-88	12-01-88	Unknown	10.66	3
CCSW-12	9-15-88	12-01-88	Unknown hydrocarbon	16.00	5
CCSW-12	9-15-88	12-01-88	2,4-Dimethyl-decane	18.48	7
CCSW-12	9-15-88	12-01-88	Unknown hydrocarbon	18.56	7
CCSW-13	9-15-88	12-01-88	Unknown	4.65	48
CCSW-13	9-15-88	12-01-88	Butyrolactone	6.29	9
CCSW-13	9-15-88	12-01-88	Unknown	6.54	36
CCSW-17	9-13-88	11-30-88	Unknown	4.61	22
CCSW-17	9-13-88	11-30-88	Butyrolactone	6.26	10
CCSW-17	9-13-88	11-30-88	Unknown	6.50	27
CCSW-17	9-13-88	11-30-88	Unknown	23.49	7
CCSW-20	9-13-88	11-30-88	Unknown	4.65	100
CCSW-20	9-13-88	11-30-88	Butyrolactone	6.30	17
CCSW-20	9-13-88	11-30-88	Unknown	6.52	30
CCSW-21	9-13-88	11-30-88	Unknown	4.63	74
CCSW-21	9-13-88	11-30-88	Butyrolactone	6.32	38
CCSW-21	9-13-88	11-30-88	Unknown	6.50	13
CCSW-22	9-13-88	11-30-88	Unknown	4.64	100
CCSW-22	9-13-88	11-30-88	Butyrolactone	6.30	29
CCSW-22	9-13-88	11-30-88	Unknown	6.38	7
CCSW-22	9-13-88	11-30-88	Unknown	6.50	16
CCSW-22R	9-13-88	11-30-88	Unknown	4.63	76

Table 54. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for semivolatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, September 1988--Continued*

Sample no.	Sampling date	Date of analysis	Semiolatile compound	Retention time (minutes)	Estimated concentration
			SURFACE-WATER SAMPLES--Continued		
CCSW-22R	9-13-88	11-30-88	Unknown	4.79	2
CCSW-22R	9-13-88	11-30-88	Butyrolactone	6.32	38
CCSW-22R	9-13-88	11-30-88	Unknown	6.40	27
CCSW-22R	9-13-88	11-30-88	Unknown	6.50	20
CCSW-22R	9-13-88	11-30-88	Unknown	25.44	160
CCSW-23	9-13-88	11-30-88	Unknown	4.63	64
CCSW-23	9-13-88	11-30-88	Butyrolactone	6.30	22
CCSW-23	9-13-88	11-30-88	Unknown	6.52	34
CCSW-23	9-13-88	11-30-88	Unknown	25.44	80
CCSW-28	9-13-88	11-30-88	Unknown	4.61	8
CCSW-28	9-13-88	11-30-88	Unknown	4.77	3
CCSW-28	9-13-88	11-30-88	Butyrolactone	6.28	16
CCSW-28	9-13-88	11-30-88	Unknown	6.50	30
CCSW-29	9-13-88	11-30-88	Unknown	4.63	55
CCSW-29	9-13-88	11-30-88	Butyrolactone	6.28	11
CCSW-29	9-13-88	11-30-88	Unknown	6.50	19
CCSW-30	9-13-88	11-30-88	Unknown	4.69	320
CCSW-30	9-13-88	11-30-88	Butyrolactone	6.32	41
CCSW-30	9-13-88	11-30-88	Unknown	17.06	8
CCSW-30	9-13-88	11-30-88	Unknown	25.44	72
CCSW-30R	9-13-88	11-30-88	Unknown	4.71	460
CCSW-30R	9-13-88	11-30-88	Butyrolactone	6.32	53
CCSW-30R	9-13-88	11-30-88	N,N-Diethyl-3-methyl benzamide	17.04	10
CCSW-30R	9-13-88	11-30-88	Hexanedioic acid, mono(2-ethylhexyl)este	25.44	80

DNAPL form are known to have been discharged to the East Branch Canal Creek from the clothing-impregnating plant that operated in building 73 in 1942 (fig. 13) (Nemeth, 1989, p. 60). Thus, residual DNAPL's in the bottom sediment are another likely source of the VOC's in the East Branch Canal Creek.

Low concentrations of VOC's were measured at the mouth of Canal Creek (site 22) in September 1988 and June 1989, and higher concentrations were measured in December 1989 when the creek was frozen along most of its length (table 49). This pattern indicates that VOC's could sometimes be transported from upstream sources to the Gunpowder River. In addition to known sources along the West and East Branches of Canal Creek, unknown contaminated areas along the lower reach of Canal Creek could act as a source of VOC's found at the mouth of Canal Creek.

The relatively high concentration of chloroform (58 μg/L) that was measured at site 12 in Kings Creek (fig. 68) could have resulted from recent wastewater discharge. A sewerline discharges immediately adjacent to this site, and wastewater treated with chlorine commonly contains chloroform. Chloroform was commonly detected in wastewaters in the Edgewood area in a study done during 1986-87 (Nemeth, 1989, p. 244). Ground-water discharge is not a likely source of the chloroform at this surface-water site. Kings Creek receives ground-water discharge from the surficial aquifer only (fig. 3), and the surficial aquifer is absent near surface-water site 12 (figs. 8 and 68).

Table 55. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for semivolatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, June 1989*

[All concentrations are in micrograms per liter; --, not available or not applicable; R, replicate sample]

Sample no.	Sampling date	Date of analysis	Semiolatile compound	Retention time (minutes)	Estimated concentration
			METHOD BLANKS		
--	--	SAO005	Unknown	52.4	5
--	--	SAO005	Unknown	57.1	3
--	--	SAO005	Unknown	57.3	5
--	--	SAO002	Unknown	57.3	1
			SURFACE-WATER SAMPLES		
CCSW-3U	06-15-89	SAP007	Unknown	57.3	3
CCSW-8U	06-15-89	SAP001	Unknown	57.1	3
CCSW-8U	06-15-89	SAP001	Unknown	57.3	4
CCSW-12U	06-15-89	SAP004	1-Methylnapthalene	--	70
CCSW-12U	06-15-89	SAP004	2-Methylnapthalene	--	58
CCSW-12U	06-15-89	SAP004	Diethyl phthalate	--	11
CCSW-12U	06-15-89	SAP004	Unknown	56.4	9
CCSW-12U	06-15-89	SAP004	Unknown	57.3	20
CCSW-12U	06-15-89	SAP004	Unknown	57.4	50
CCSW-12U	06-15-89	SAP004	Unknown	57.5	100
CCSW-12U	06-15-89	SAP004	Unknown	57.9	20
CCSW-12U	06-15-89	SAP004	Unknown	58.2	10
CCSW-12U	06-15-89	SAP004	Unknown	58.5	20
CCSW-12U	06-15-89	SAP004	Unknown	58.6	20
CCSW-12U	06-15-89	SAP004	Unknown	58.9	20
CCSW-12U	06-15-89	SAP004	Unknown	59.1	9
CCSW-12U	06-15-89	SAP004	Unknown	59.4	10
CCSW-12U	06-15-89	SAP004	Unknown	59.5	8
CCSW-12U	06-15-89	SAP004	Unknown	59.7	6
CCSW-12U	06-15-89	SAP004	Unknown	60.2	7
CCSW-12U	06-15-89	SAP004	Unknown	60.4	10
CCSW-12U	06-15-89	SAP004	Unknown	60.5	10
CCSW-12U	06-15-89	SAP004	Unknown	60.6	8
CCSW-12U	06-15-89	SAP004	Unknown	60.7	10
CCSW-12U	06-15-89	SAP004	Unknown	60.9	8
CCSW-13U	06-15-89	SAP003	Unknown	57.1	4
CCSW-13U	06-15-89	SAP003	Unknown	57.3	5
CCSW-13U	06-15-89	SAP003	Unknown	57.7	7
CCSW-14U	06-15-89	SAP005	Unknown	57.1	3
CCSW-14U	06-15-89	SAP005	Unknown	57.3	4
CCSW-17U	06-13-89	SAN003	Tetrachloroethane	--	10
CCSW-17U	06-13-89	SAN003	Unknown	57.1	2
CCSW-17U	06-13-89	SAN003	Unknown	57.3	3
CCSW-17UR	06-13-89	SAO007	Unknown	52.4	20
CCSW-17UR	06-13-89	SAO007	Unknown	52.5	6
CCSW-17UR	06-13-89	SAO007	Unknown	57.1	4
CCSW-17UR	06-13-89	SAO007	Unknown	57.3	6
CCSW-20U	06-13-89	SAO008	Unknown	52.4	4
CCSW-21U	06-13-89	SAN002	Unknown	57.2	2
CCSW-22U	06-13-89	SAO001	Unknown	52.4	6

Table 55. *Estimated concentrations of tentatively identified organic compounds and unknowns detected by library search for semivolatile organic compounds in surface-water samples collected at Aberdeen Proving Ground, Maryland, June 1989--Continued*

Sample no.	Sampling date	Date of analysis	Semivolatile compound	Retention time (minutes)	Estimated concentration
			SURFACE-WATER SAMPLES--Continued		
CCSW-22U	06-13-89	SAO001	Unknown	57.1	3
CCSW-22U	06-13-89	SAO001	Unknown	57.3	4
CCSW-23U	06-13-89	SAN008	Unknown	57.3	2
CCSW-23U	06-13-89	SAN008	Unknown	59.2	2
CCSW-24U	06-13-89	SAN004	Unknown	62.0	3
CCSW-24U	06-13-89	SAN004	Unknown	63.0	3
CCSW-25U	06-13-89	SAO003	Unknown	52.4	5
CCSW-25U	06-13-89	SAO003	Unknown	52.5	2
CCSW-25U	06-13-89	SAO003	Unknown	57.3	2
CCSW-26U	06-13-89	SAN009	Unknown	57.3	2
CCSW-27U	06-13-89	SAN007	Unknown	57.3	2
CCSW-28U	06-13-89	SAO004	Unknown	52.4	5
CCSW-28U	06-13-89	SAO004	Unknown	57.1	4
CCSW-28U	06-13-89	SAO004	Unknown	57.3	5
CCSW-29U	06-13-89	SAO006	Unknown	52.5	7
CCSW-30U	06-13-89	SAO002	Unknown	52.4	5
CCSW-30U	06-13-89	SAO002	Unknown	57.1	3
CCSW-30U	06-13-89	SAO002	Unknown	57.3	3
CCSW-33U	06-13-89	SAO009	Unknown	52.4	5
CCSW-33U	06-13-89	SAO009	Unknown	57.1	3
CCSW-33U	06-13-89	SAO009	Unknown	57.3	4

The concentrations of 1,1,2,2-tetrachloroethane and trichloroethylene that were measured in the Bush River by Beach Point (figs. 68 and 69) could be the result of ground-water discharge from the surficial aquifer. Ground-water samples collected from the surficial aquifer at Beach Point contained concentrations of 1,1,2,2-tetrachloroethane and trichloroethylene as high as 9,500 and 940 μg/L, respectively (table 27), and this shallow ground water discharges to Kings Creek and the Bush River.

SOIL CONTAMINATION

Appendixes D1 and D2 at the end of this report list the inorganic and organic chemical data for 50 soil samples that were collected at 46 sites in the Canal Creek area (fig. 16). No enforceable or recommended standards have been established for contaminant levels in soils. In addition, background levels for soils are difficult to define because concentrations in soils vary greatly with differences in geology, hydrology, land use, vegetation, and other factors.

Because of the lack of standards and background data, the extent of soil contamination in the Canal Creek area is discussed mainly as a comparison of the concentrations of constituents measured in the 50 soil samples relative to each other. Soil contamination is probable where high concentrations of constituents in the soils coincide with elevated concentrations of the same constituents in the underlying ground water. Soil samples were collected only in areas where the upper confining unit is thin or absent or where the surficial aquifer is present; these are the areas where contaminants in the soils possibly could be transported to the unconfined or semiconfined Canal Creek aquifer or to the surficial aquifer. These conditions are met in all the contaminated ground-water areas that were identified, except area IIB (figs. 6 and 19).

Historical information on use and disposal of inorganic and organic constituents was also used to assess whether or not soils were contaminated by site-related activities. The presence of some organic compounds could be derived only from an anthropogenic source, although many other organic compounds can be naturally occurring. The soil sample collected at site 1 (fig. 16), which is north of the manufacturing, filling, and research plants that operated in the Canal Creek area (fig. 13), is designated as a background sample for site-related contamination.

Inorganic Constituents

Distribution

The ranges and median concentrations of inorganic constituents measured in soil samples in the Canal Creek area are summarized in table 56. In this report, the inorganic constituents detected in the soils are divided into two broad classifications: (1) major and minor constituents, whose median concentrations were greater than about 150 μg/g, and (2) trace elements, whose median concentrations were less than about 150 μg/g. Two of the minor constituents (table 56) were not determined in all samples as requested.

The major and minor constituents were detected in all the analyzed soil samples (table 56). Median concentrations of iron, calcium, and magnesium were the highest among the major and minor constituents. Median concentrations of the major and minor constituents were lower in soils of the Canal Creek area than in other soils and surficial materials of the United States (table 56) (Sposito, 1989, p. 6). Sodium is the only major or minor constituent for which an anomalous concentration could be related to activies in the Canal Creek area. The maximum sodium concentration of 1,600 μg/g was measured in the soil sample collected from site 16 near the West Branch Canal Creek (fig. 16). This soil-sampling site is adjacent to well site 28 (fig. 2), where anomalously high concentrations of sodium were also measured in the shallow ground water of the Canal Creek aquifer (see ground-water section on major inorganic constituents).

Lead and arsenic were the most frequently detected trace elements in the soil samples (table 56). Chromium and zinc were detected relatively frequently, each occurring in 28 of the 50 soil samples (table 56). Two trace elements, boron and cadmium, were not detected in any of the soil samples (table 56). Selenium was detected in only one sample, and copper was detected in two samples. The median concentrations of antimony, lead, mercury, and zinc were greater in soils of the Canal Creek area than in other soils of the United States (table 56).

Elevated lead and zinc concentrations were measured in many of the same soil samples (figs. 70 and 71), and the areal distributions of both of these trace constituents are similar to their areal distributions in ground water (figs. 36 and 38). Relatively high lead concentrations (greater than or equal to 50 μg/g) were measured in soil and in ground water near well site 28 in area ID, well site 36 in area IIA, well site 120 in area IA, and well site 33 at Beach Point (figs. 19, 36, and 70). The maximum lead concentration in the soil, 1,100 μg/g, was measured near well site 28 (figs. 36 and 70). The lead concentrations in ground-water samples collected from well 28A ranged from 45 μg/L to greater than 91 μg/L and were consistently higher than lead concentrations observed in other ground-water samples collected during this study (Appendixes B1, B3, B5).

Zinc concentrations were elevated in ground water and soil in the vicinity of well sites 28 and 114 in area ID and well site 36 in area IIA (figs. 19, 38, and 71). Zinc concentrations in the soil often were greater than 100 μg/g in these areas; in contrast, the background concentration was less

Table 56. *Summary of concentrations of inorganic constituents detected in soil samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland, and median concentrations in other soils*

[All units in micrograms per gram dry soil; dashes indicate data not available]

Constituents	Number of samples analyzed	Number of samples detected	Minimum concentration	Maximum concentration	Site number of maxmium concentration	Median concentration	Median concentration in other soils [1]
			MAJOR AND MINOR CONSTITUENTS				
Calcium	50	50	170	58,000	CCSL-16	1,600	24,000
Magnesium	50	50	400	14,000	CCSL-15	1,500	9,000
Sodium	50	50	240	1,600	CCSL-16	320	12,000
Silica	50	50	51	1,600	CCSL- 6	320	310,000
Nitrogen, ammonia + organic	37	37	100	2,000	CCSL-15,17	800	2,000
Phosphorus	14	14	42	200	CCSL-26	170	430
Iron	50	50	1,400	55,000	CCSL-16	11,000	26,000
Managenese	50	50	63	3,000	CCSL-30A	200	550
			TRACE CONSTITUENTS				
Antimony	50	12	8.2	21	CCSL-16	10	.66
Arsenic	50	49	2.4	11	CCSL-12	4.6	7.2
Boron	50	0	<33	--	--	--	33
Cadmium	50	0	<3.0	--	--	--	.35
Chromium	50	28	24	140	CCSL-16	33	54
Copper	50	2	100	150	CCSL-34	--	25
Lead	50	50	2.1	1,100	CCSL-18	46	19
Mercury	50	15	.059	.91	CCSL-18	.25	.09
Selenium	50	1	--	1.2	CCSL-18	--	.39
Zinc	50	28	64	1,000	CCSL-37	120	60

[1] Constituent concentrations in soils and other surficial materials of the conterminous United States, from Sposito (1989, p. 6).

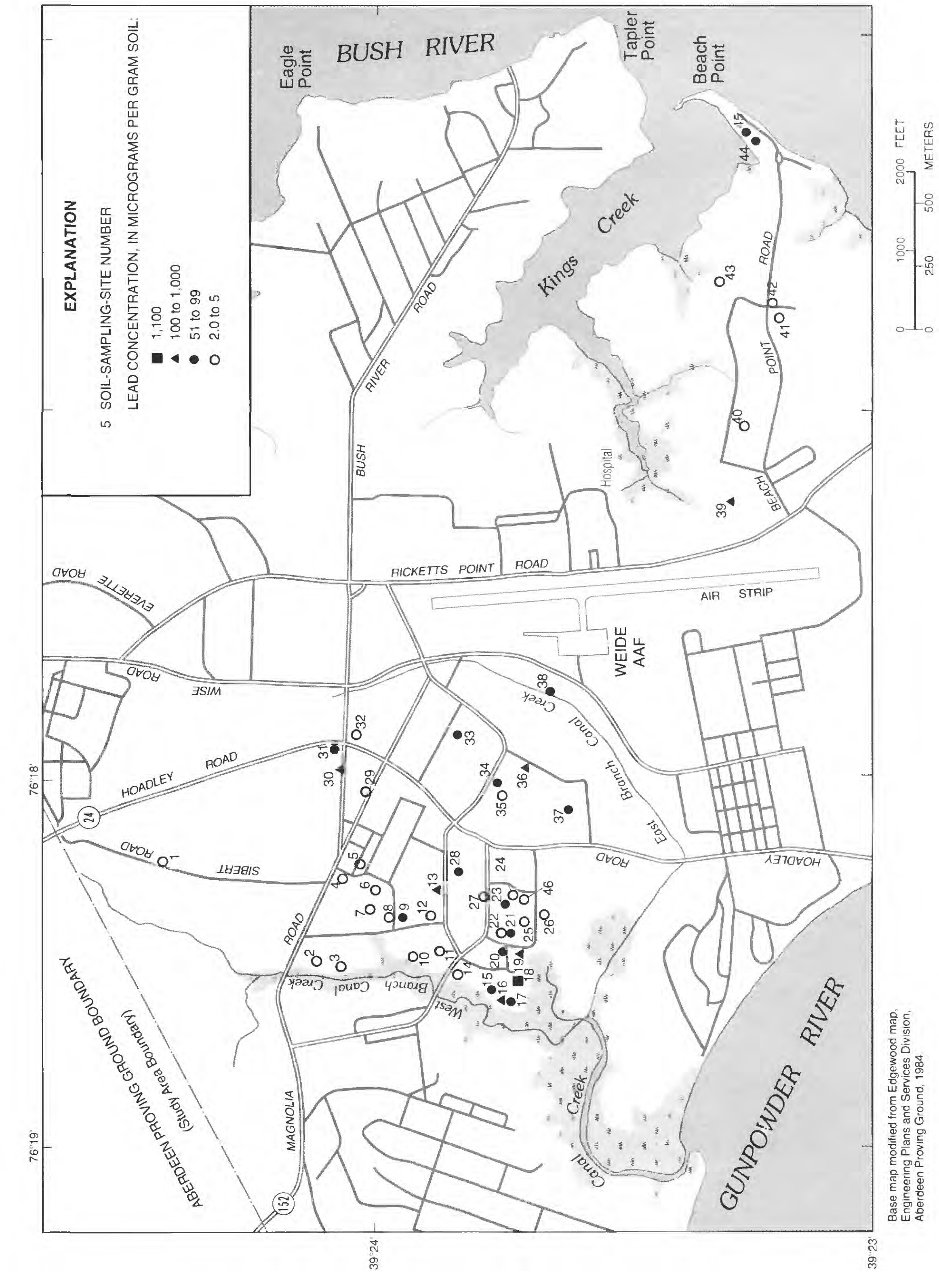
than 30 μg/g (fig. 71).

The arsenic concentration in the background sample collected at soil site 1 was 3.8 μg/g (Appendix D1), and the median concentration for the 50 soil samples collected in the Canal Creek area was 4.6 μg/g (table 56). This median arsenic concentration is lower than the median reported for other soils in the United States (7.2 μg/g); thus, arsenic concentrations in soils in the Canal Creek area are not unusually high (table 56). However, arsenic concentration was greater than the background soil concentration at several sites in area IIA near the East Branch Canal Creek, where elevated concentrations also were measured in ground water (figs. 19 and 35). Arsenic concentrations ranged from 6.2 to 9.6 μg/g in soil samples collected at sites 34, 35, 36, 37, and 38 in this area near the East Branch Canal Creek (fig. 16; Appendix D1).

Mercury was detected in only 15 of the 50 soil samples that were collected in the Canal Creek area (table 56), and 10 of these soil samples with measurable mercury concentrations were collected in area ID, near the West Branch Canal Creek (figs. 16 and 19). Mercury concentrations were not elevated in any of the ground-water samples collected in area ID (fig. 19 and table 18); thus, no relation is apparent between mercury distributions in the ground water and soil. The maximum mercury concentration measured in the soil was 0.91 μg/g (table 56).

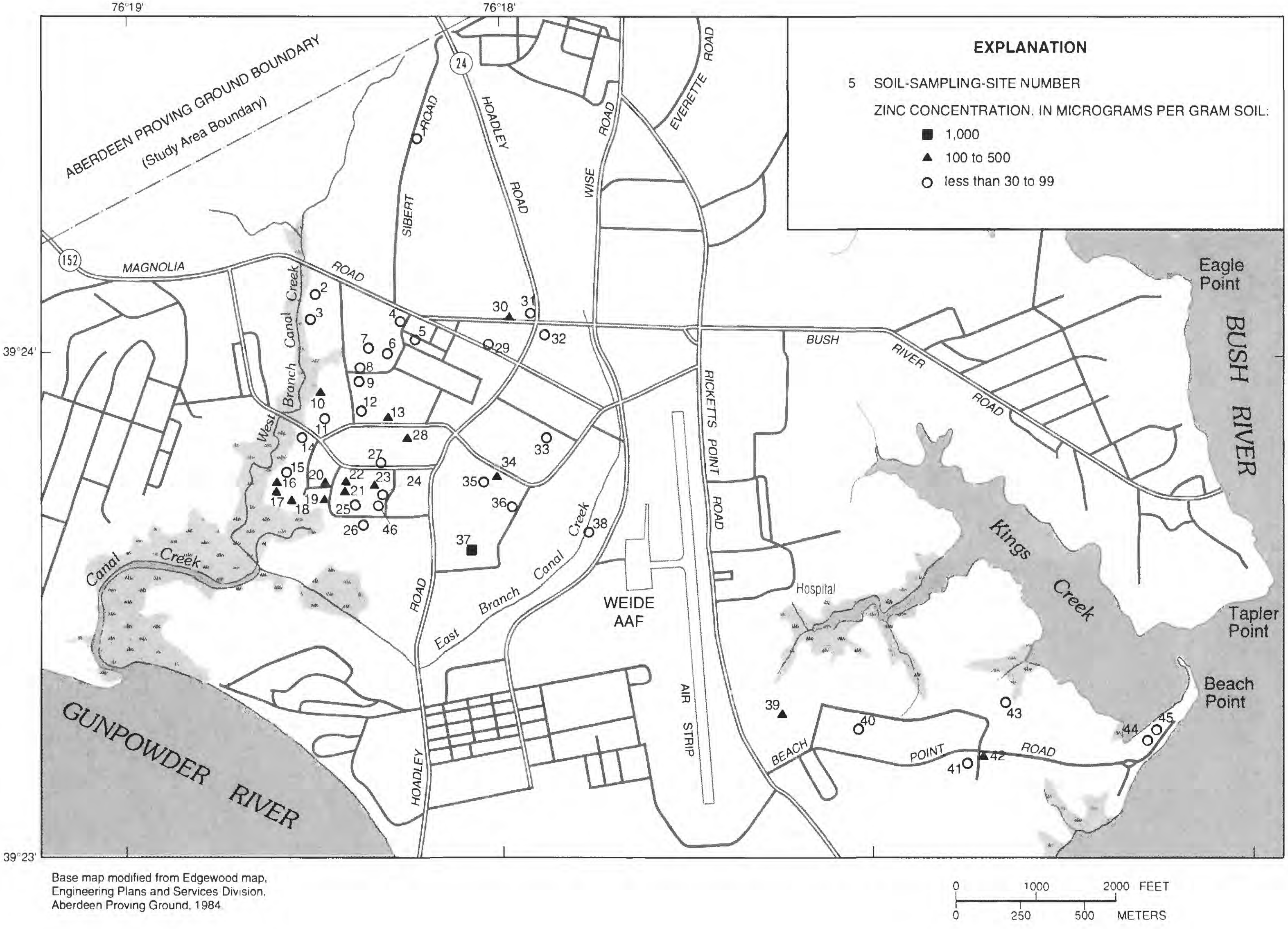
Probable Sources

Probable sources of the inorganic constituents were discussed in the ground-water contamination section of this report, and the sources are likely to be the same for ground water and soil. Mercury is the only inorganic constituent that was detected in elevated concentrations in soil and was not discussed in detail in the ground-water section. The WW2 chlorine plant that was near the West Branch Canal Creek (fig. 13) is the most likely source of the elevated mercury concentrations that were measured in the soil in area ID (fig. 19; Appendix D1). Chlorine was produced in this plant by means of a mercury cell process, which generated mercury as a waste product (Nemeth, 1989, p. 854), from shortly after WW2 until 1968. Demolition of the plant in 1969 would have disturbed and redistributed any mercury-contaminated soils (Nemeth, 1989, p. 855).



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984

Figure 70. Distribution of lead in soil in the Canal Creek area, September 1989.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984

Figure 71. Distribution of zinc in soil in the Canal Creek area, September 1989.

Previous investigators have found elevated mercury concentrations in the bottom sediments of West Branch Canal Creek near this plant (Nemeth, 1989, p. 855), but elevated mercury concentrations were not measured in the ground water in this area during the present study.

Organic Constituents

Distribution

Most of the organic contaminants identified in the soil samples are semivolatile organic compounds (table 57), whereas VOC's were the most prevalent organic contaminants in ground-water and surface-water samples collected in the Canal Creek area. Fluorinated hydrocarbons (trichlorofluoromethane and 1,1,2-trichloro-1,2,2-trifluoroethane) were the only two VOC's that were quantitatively or tentatively identified in the soil samples (Appendix D2 and table 57).

Four classes of semivolatile organic compounds were quantitatively identified in the soil samples: polycyclic aromatic hydrocarbons (PAH's), polychlorinated biphenyls (PCB's), pesticides, and phthalate esters. PAH's are the most prevalent of the semivolatile organic compounds identified in the soil samples (table 57). Concentrations of the PAH's ranged from 0.05 to 0.89 μg/g (table 57). Fluoranthene, pyrene, benzo[k]fluoranthene, and chrysene were the most frequently detected PAH's, each occurring in 16 to 19 samples (table 57).

Although PCB's were detected in only one soil sample, the concentration was the highest observed for any of the semivolatile compounds (table 57). A concentration of 330 μg/g of PCB 1260 (table 57) was measured in the sample collected from soil site 16 (fig. 16), which is between well sites 27 and 28 along the West Branch Canal Creek (fig. 2).

One pesticide compound (2,2-*bis*(para-chlorophenyl)-1,1-dichloroethene) and one phthalate ester (di-n-butyl phthalate) were each detected in three soil samples. Concentrations of the pesticide and phthalate ester were relatively low, ranging from 0.10 to 0.60 μg/g (table 57).

All the unknown compounds and all except one of the TIOC's (1,1,2-trichloro-1,2,2-trifluoroethane) were detected by library search for semivolatile compounds, rather than in the volatile fraction (Appendix D2). The semivolatile organic compounds that were tentatively identified by library search are mostly fatty acids or fuel-related alkanes with high molecular weights (such as tetradecane and hexadecane) (Appendix D2). The sum of all unknowns and TIOC's detected in each soil sample ranged in concentration from 0.2 to 16 μg/g (table 57).

Probable Sources

PAH's, which were the most common class of organic compounds present in soil samples in the Canal Creek area (table 57), are ubiquitous components of sediments throughout the world (Laflamme and Hites, 1978, p. 289). PAH's can originate from natural and anthropogenic sources. The most common source of PAH's is deposition of airborne particulates formed by combustion (Laflamme and Hites, 1978, p. 296; Smith and others, 1988, p. 64). Combustion sources include burning of fossil fuels, municipal-waste incineration, and forest fires (Smith and others, 1988, p. 64). In addition, some PAH's are produced commercially for use in chemical manufacturing processes, such as production of pesticides, smokeless powders, dyes, plastics, and lubricants (Smith and others, 1988, p. 64).

On the basis of a review of the literature on background soil concentrations of PAH's, Durda and others (1991, p. 7-7) state that the concentrations of individual PAH's in urban/industrial soils can be 100 μg/g or higher. Concentrations of PAH's in soil samples from the Canal Creek area were much lower than 100 μg/g--the maximum concentration measured was 0.89 μg/g (table 57). Thus, the PAH's detected in soils of the Canal Creek area have probably resulted from general human activity and are not related to any specific manufacturing or waste-disposal activity. Because of all the construction that has taken place in the Canal Creek area since 1917, many of the soil samples consisted partially of fill material. The fill material commonly contained pieces of asphalt and incinerator slag that are probable sources of PAH's.

Although all manufacture, sale, and distribution of PCB's in the United States has been prohibited since 1979, PCB's were once widely used as plasticizers, as hydraulic lubricants in gas turbines and vacuum pumps, as components of heat-transfer systems, and as dielectric fluids in electrical capacitors and transformers (Smith and others, 1988, p. 25-26). The site from which PCB-contaminated soil was collected (site 16, fig. 16) is by a landfill area along the West Branch Canal Creek (fig. 14) and where the WW2 chlorine plant (fig. 13) was demolished. Thus, PCB's could be present in this fill material from the remains of old machinery, capacitors, and building materials.

The compound 2,2-*bis*(para-chlorophenyl)-1,1-dichloroethene (table 73) is a biodegradation product of the insecticide DDT, which was widely used

Table 57. *Summary of concentrations of organic constituents detected in soil samples collected in the Canal Creek area, Aberdeen Proving Ground, Maryland*

[All units in micrograms per gram dry soil unless otherwise noted; **Analysis type**: V, quantitative analysis for volatile organics; S, quantitative analysis for semivolatile organics; VL plus SL, sum of unknown compounds and tentatively identified organic compounds (TIOC'S) detected by library search for volatile and semivolatile organics; dashes indicate data not available]

Constituents	Analysis type	Number of samples analyzed	Number of samples detected	Minimum concentration	Maximum concentration	Site number of maxmium concentration	Median
INDICATORS							
Organic carbon, total (g/kg)	--	28	28	1.0	48	CCSL-18	8.9
Organic halides, total	--	44	1	--	200	CCSL- 1	--
Phenols, total	--	50	43	.20	3,200	CCSL-24	1.3
POLYCYCLIC AROMATIC HYDROCARABONS (PAH'S)							
Acenapthylene	S	50	1	--	.22	CCSL-12	--
Anthracene	S	50	4	.09	.26	CCSL-28	.11
Benzo[a]anthracene	S	50	7	.17	.55	CCSL-12	.25
Benzo[b]fluoranthene	S	50	4	.38	.82	CCSL-12	.40
Benzo[k]fluoranthene	S	50	16	.09	.45	CCSL-12	.14
Benzo[g,h,i]perylene	S	50	2	.27	.51	CCSL-12	--
Benzo[a]pyrene	S	50	2	.51	.89	CCSL-12	--
Chrysene	S	50	16	.18	.84	CCSL-12	.24
Dibenzofuran	S	50	1	--	.14	CCSL-28	--
Fluoranthene	S	50	19	.11	.76	CCSL-12	33
Fluorene	S	50	1	--	.15	CCSL-28	--
Indeno[1,2,3-c,d]pyrene	S	50	1	--	.50	CCSL-12	--
2-Methylnapthalene	S	50	1	--	.09	CCSL-28	--
Napthalene	S	50	2	.11	.19	CCSL-28	--
Phenanthrene	S	50	15	.05	.44	CCSL-31	.22
Pyrene	S	50	19	.10	.72	CCSL-12	.21
POLYCHLORINATED BIPHENYLS (PCB'S))							
PCB 1260	S	50	1	--	330	CCSL-16	--
PESTICIDES							
2,2-*bis*(Para-chlorophenyl)-1,1-dichloroethene	S	50	3	.40	.60	CCSL-31	49
FLUORINATED HYDROCARBONS							
Trichlorofluoromethane	V	50	2	.01	.03	CCSL-15	--
PHTHALATE ESTERS							
Di-n-butyl phthalate	S	50	3	.10	.22	CCSL- 5	.21
UNKNOWNS + TIOC'S							
	VL + SL	50	45	.2	16	CCSL-15, 18	.25

in the United States from the early 1940's through the 1960's (Smith and others, 1988, p. 26-27). Residues of DDT and its degradation products are commonly detected in the environment (Smith and others, 1988, p. 26).

The relatively low concentrations of fluorinated hydrocarbons and phthalate esters that were detected in three or fewer soil samples (table 57) are likely derived from laboratory contamination. However, no quality-control data were received from the laboratory, and this possible source can not be confirmed. Because fluorinated hydrocarbons are present in refrigerants, sample contamination by trichlorofluoromethane and 1,1,2-trichloro-1,2,2-trifluoroethane could have resulted during refrigerator storage of the samples. Phthalate esters were common contaminants in quality-control samples analyzed with ground-water and surface-water samples collected during this study (tables 46, 47, 53, 54).

EVALUATION OF SELECTED GROUND-WATER PUMPING ALTERNATIVES

The ground-water flow system underlying the Canal Creek study area was modeled to evaluate the hydrologic and chemical effects of several pumping alternatives. The results of the pumpage scenarios were used to evaluate the effectiveness of pump-and-treat remediation and the potential for offsite contamination of public water-supply wells.

Simulation of Ground-Water Flow

Model Description

Simulation is the calculation, by use of a digital computer, of the effects of a physical process. The computer program MODFLOW (McDonald and Harbaugh, 1988) was used as the basis for the model developed to simulate ground-water flow within the study area. MODFLOW is a three-dimensional, finite-difference ground-water-flow computer program that requires the study area to be discretized into a rectangular gridded mesh. The program also requires input of initial and boundary conditions, hydraulic parameters, and external stresses, such as pumpage withdrawal. By solving the equation of ground-water flow, as written in finite-difference form, the program calculates average heads for each active cell of the gridded mesh.

The model grid (fig. 72) consists of 47 rows oriented southwest to northeast from the Gunpowder River to Otter Point Creek, and 41 columns oriented northwest to southeast from the Fall Line to the Bush River. Grid spacing varies from 400 ft per side in the primary area of interest around Canal Creek to 2,025 ft per side near the model boundaries. Grid spacing in the primary area of interest was chosen on the basis of spatial distribution of observation wells in the Canal Creek aquifer. Grid spacing is larger near the model boundaries to minimize the number of cells in areas where fine-scale definition of ground-water flow was not of interest.

Vertically, the flow model consists of three layers representing the surficial aquifer (layer 1), the Canal Creek aquifer (layer 2), and the lower confined aquifer (layer 3) (fig. 73). The aquifers are separated by the upper and lower confining units, which are represented in the flow model as a vertical leakance between layers. Vertical leakance is calculated by dividing vertical hydraulic conductivity of the confining unit by confining-unit thickness. This approach is known as a quasi three-dimensional representation of confining units. This approach requires the assumption that, because of the large contrast in hydraulic conductivity between aquifers and confining units, ground-water flow is predominantly horizontal in aquifers and predominantly vertical through confining units. The confining units are low-conductivity vertical connections between aquifers except in their outcrop areas, where they are an extension of layers 1 and 2.

Boundary conditions

Boundaries for the Canal Creek flow model were chosen to coincide with identifiable hydrogeologic features and are specific to each of the aquifers modeled (fig. 74). The surficial aquifer (layer 1) is bordered to the northeast, southeast, and southwest by surface-water bodies (Otter Point Creek, Bush River, and Gunpowder River), which are represented in the model as constant heads (fig. 72). The northwest boundary of layer 1 is the updip limit of the surficial aquifer (fig. 74).

The northeast and southwest boundaries of the Canal Creek aquifer (layer 2) coincide with Otter Point Creek and the Gunpowder River, where the aquifer subcrop area extends under these surface-water bodies (fig. 74). The upper confining unit has probably been eroded to some extent by the Bush River (Oliveros and Vroblesky, 1989, p. 25). In these areas, the Canal Creek aquifer could be hydraulically connected to the Bush River. The downdip extent of the Canal Creek aquifer is not known, but much of the water in the aquifer probably discharges by vertical leakage through the confining unit to the Bush River (Oliveros and Vroblesky, 1989, p. 35). For these reasons, the southeast boundary of the model was placed at the Bush River. The northwest boundary of layer 2 is the updip limit of the outcrop area of the Canal Creek aquifer (fig. 74) and is represented in the model as a no-flow boundary.

The northwestern boundary of the lower confined aquifer is roughly parallel with the Fall Line (fig. 74) and is modeled as a no-flow boundary. The areal extent of the lower confined aquifer to the northeast, southeast, and southwest is not known. Measured heads in the lower confined aquifer were 0.1 to 8.0 ft higher than those in the Canal Creek aquifer (Oliveros and Vroblesky, 1989, p. 43). Because of this upward head gradient between the Canal Creek and lower confined aquifers, the amount of upward ground-water flow within the model area is probably significant. Thus, the lateral flux of ground water out of the model area defined by layers 1 and 2 is assumed to be minimal. The northeast, southeast, and southwest boundaries in layer 3 were placed in the same location as the layer 2 boundaries on the basis of this information and the fact that these boundaries are some distance from the primary area of interest. Sensitivity

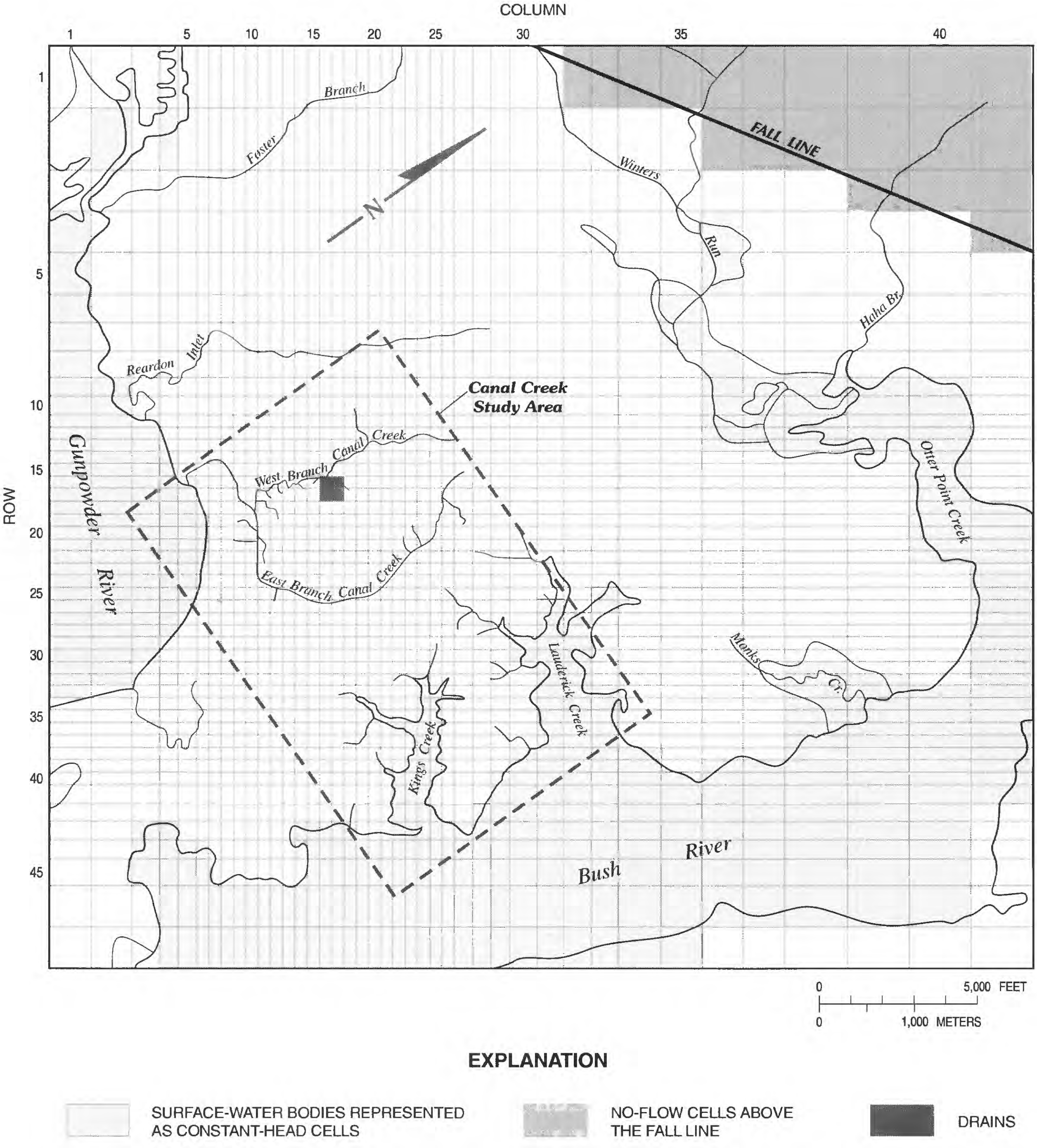


Figure 72. Extent of modeled area and grid boundaries.

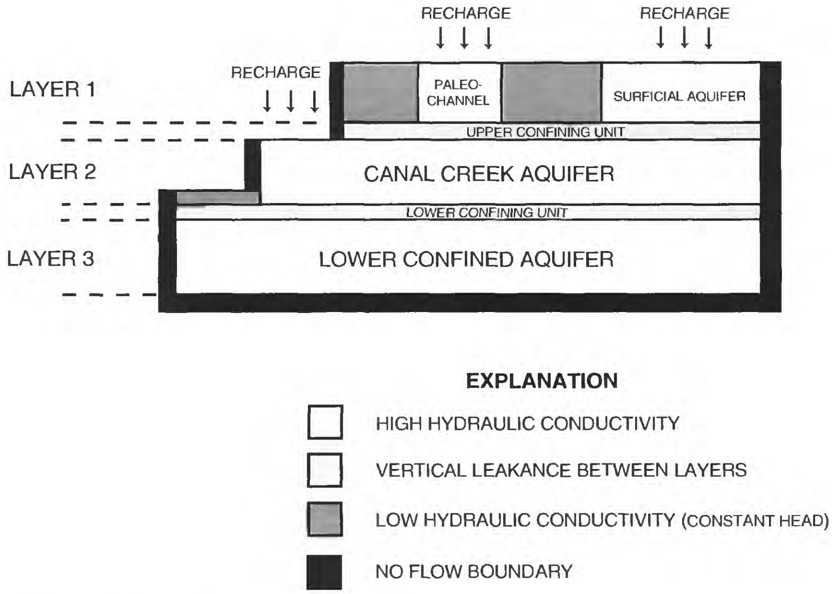


Figure 73. Schematic diagram of model layers and boundaries.

analysis presented later in this section show that, in the Canal Creek area, the model was not sensitive to changes in the proximity of these lateral boundaries.

Little information concerning the confining units or aquifers below the lower confined aquifer is available. The extent of ground-water flow between the lower confined aquifer and underlying Potomac Group aquifers is unknown. For the purposes of this report, the bottom of the lower confined aquifer is considered to be the lower, no-flow boundary of the model.

The upper boundary of the model is represented by the water-table surface in areas where the surficial aquifer, paleochannel, and Canal Creek aquifer crop out and as a constant-head boundary in areas where the upper and lower confining units crop out (fig. 74). The outcrop areas were determined from previous investigations (Oliveros and Vroblesky, 1989), from information obtained during well drilling, and from soil maps of Harford County, Md. (Smith and Matthews, 1975). As previously discussed, Otter Point Creek, the Bush River, and the Gunpowder River were simulated as constant-head boundaries.

Data requirements and input

The surficial aquifer and paleochannel sediments are unconfined in the model area. Transmissivity for an unconfined layer is calculated in the model from horizontal hydraulic conductivity and the simulated saturated thickness. Input data include horizontal hydraulic conductivity and altitude of the cell bottom. For layer 1, a horizontal hydraulic conductivity of 30 ft/d was determined from slug tests at wells 1B (11 ft/d) and 20B (44 ft/d) (Oliveros and Vroblesky, 1989, p. 25). Saturated thickness is calculated by the model from the simulated water table and the bottom altitude of the layer. The altitude of the bottom of the surficial aquifer is shown in figure 75. The interpreted contours were digitized and interpolated over the grid by use of ARC/INFO to obtain a bottom altitude for each model cell. A formatted model-input file was then downloaded from ARC/INFO.

Vertical leakance between layers 1 and 2 was calculated by dividing the confining unit's vertical hydraulic conductivity by the thickness. Although the vertical hydraulic conductivity of sediments in the Canal Creek area was not measured, the vertical hydraulic conductivity of cores from similar confining-unit sediments 3 mi away on Graces Quarters is about 1 x 10^{-6} ft/d (Fred Tenbus, U.S. Geological Survey, oral commun., 1989). This value was used in initial simulations for most of the modeled area. Where the upper confining unit is missing in the paleochannel, a vertical hydraulic conductivity of 1 ft/d was used in the model to calculate flux beween layers 1 and 2. The thickness of the upper confining unit is shown in figure 6.

The Canal Creek aquifer is an unconfined water-table aquifer where it crops out (fig. 74); elsewhere, the Canal Creek aquifer is confined. In the model, the Canal Creek aquifer is a layer that is represented by unconfined and confined conditions. Transmissivity is calculated by the model from the horizontal hydraulic conductivity and saturated

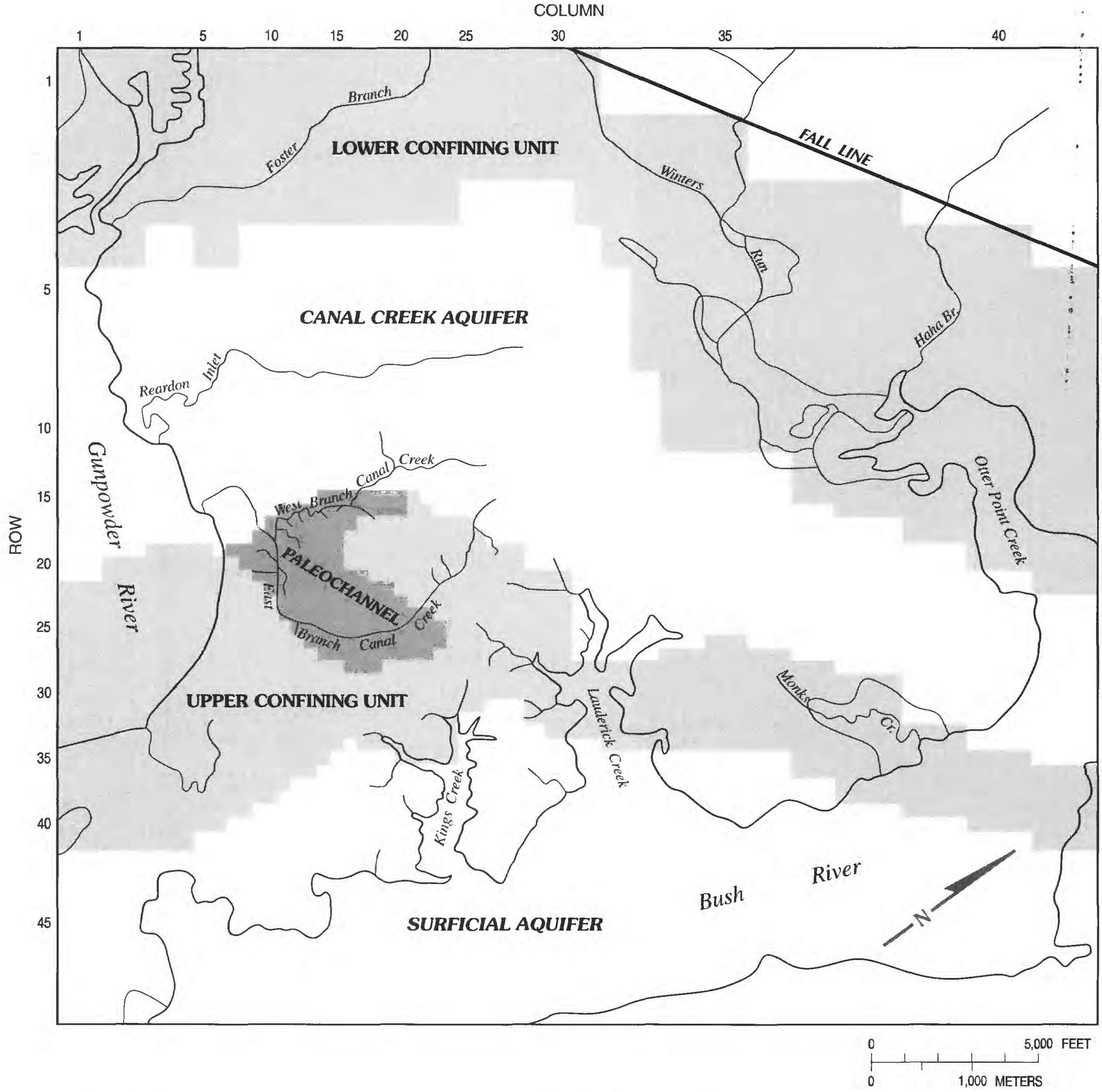
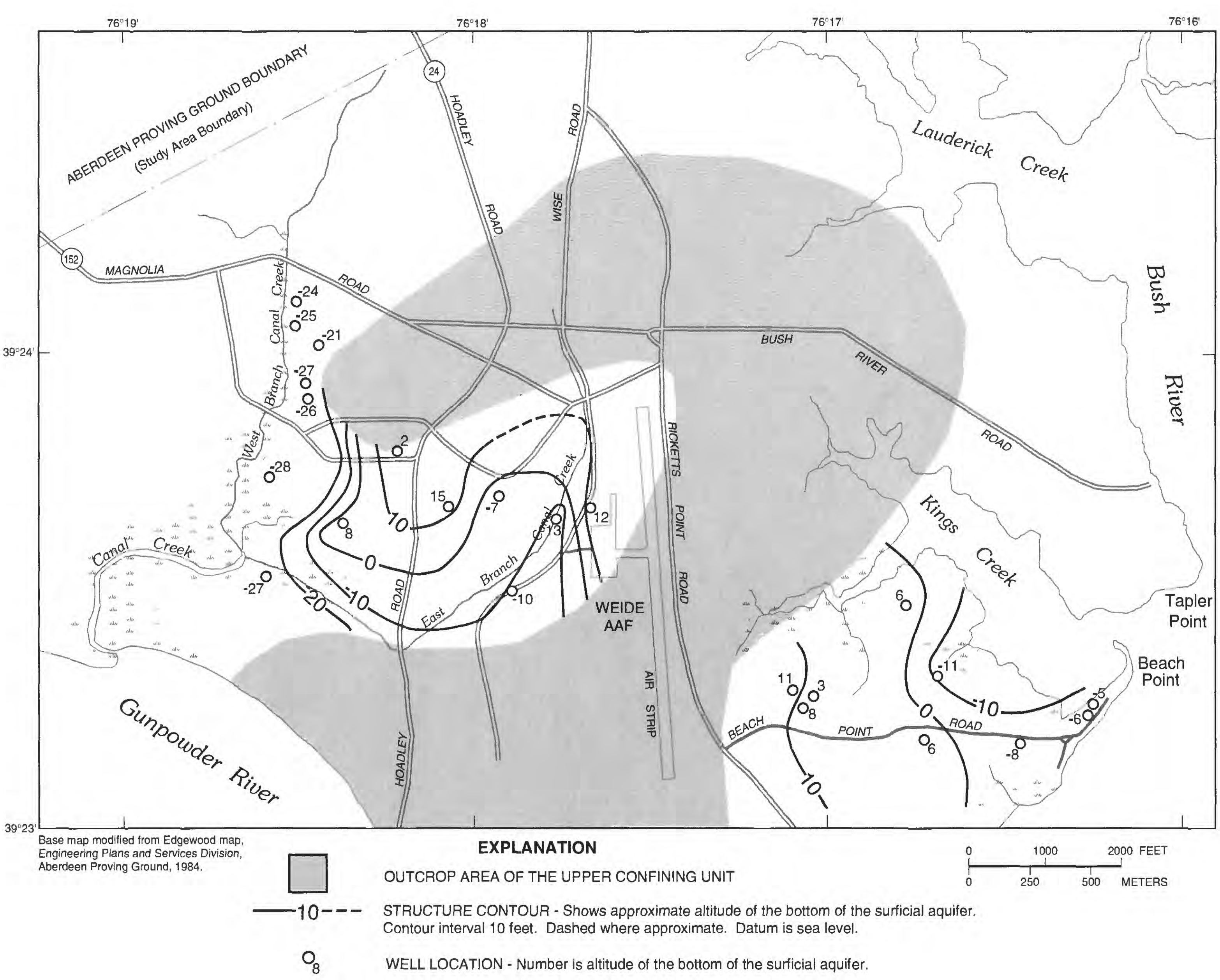


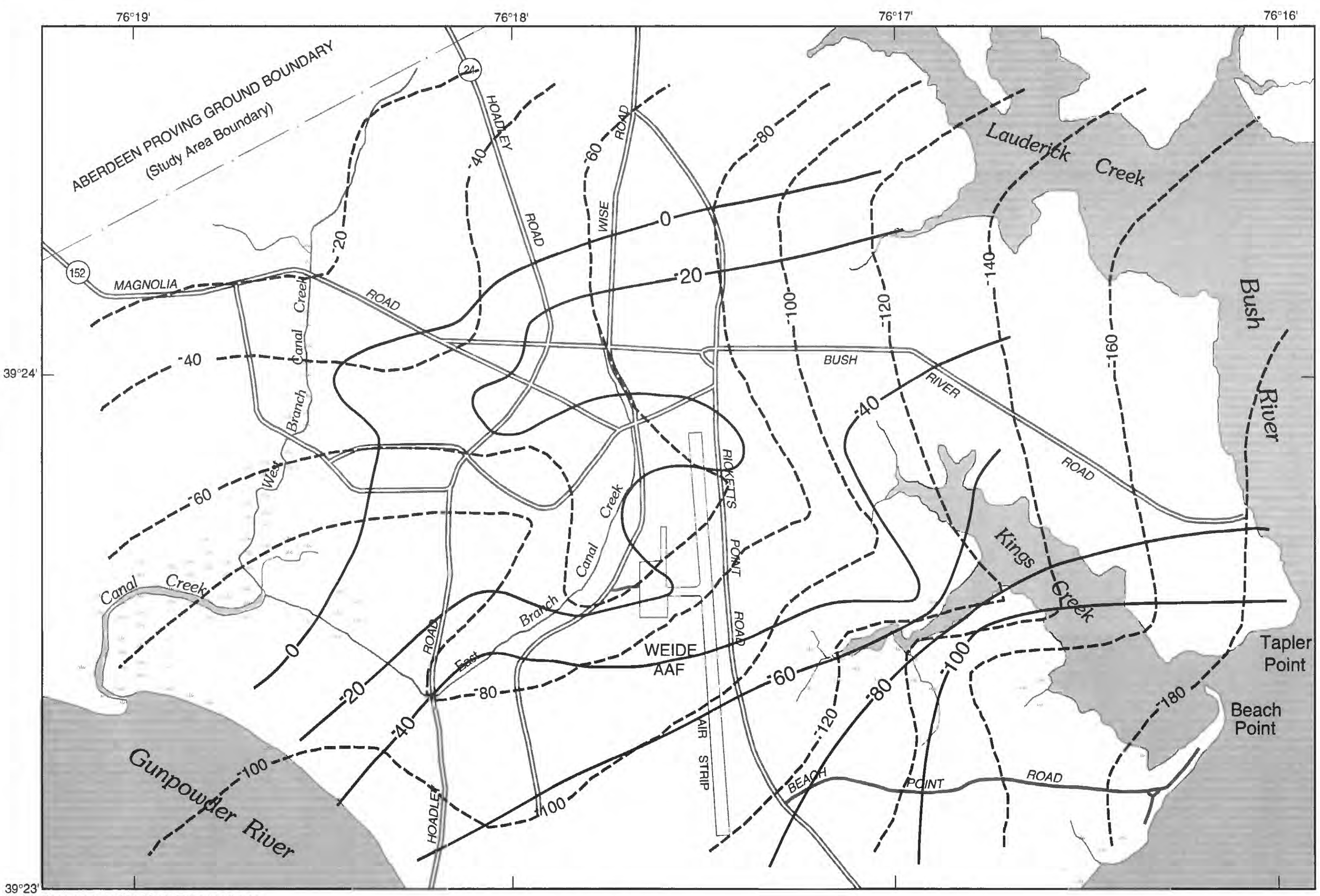
Figure 74. Outcrop areas and model representation of aquifers and confining units.

thickness in unconfined areas of the Canal Creek aquifer and from the horizontal hydraulic conductivity and layer thickness in confined areas. Input data are horizontal hydraulic conductivity and top and bottom altitudes of the layer. Horizontal hydraulic conductivities for the Canal Creek aquifer, as determined from slug tests, range from 6 to 176 ft/d (table 58). Because horizontal hydraulic conductivity in the Canal Creek area generally increases from northwest to southeast, three conductivity zones were used for the initial model simulations. To the northwest, in the outcrop area of the Canal Creek aquifer, 20 ft/d was used. In the central area, under the outcrop area of the upper confining unit, 30 ft/d was used. In the southeast, under the outcrop area of the surficial aquifer, 40 ft/d was used. The altitudes of the top and the bottom of the Canal Creek aquifer are shown in figure 76.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 75. Altitude and configuration of the bottom of the surficial aquifer, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

-20 STRUCTURE CONTOUR - Shows approximate altitude of the top of the Canal Creek aquifer. Contour interval 20 feet. Datum is sea level.

-80 STRUCTURE CONTOUR - Shows approximate altitude of the bottom of the Canal Creek aquifer. Contour interval 20 feet. Datum is sea level.

Figure 76. Altitude and configuration of the top and the bottom of the Canal Creek aquifer, Aberdeen Proving Ground, Maryland. (Modified from Oliveros and Vroblesky, 1989, fig. 18.)

Table 58. *Horizontal hydraulic conductivities for the Canal Creek aquifer, as determined from slug tests, Aberdeen Proving Ground, Maryland*

[From Oliveros and Vroblesky, 1989, p. 3]

Well no.	Horizontal hydraulic conductivity (feet per day)
CC-1C	21
CC-2A	152
CC-4B	24
CC-5C	23
CC-7A	34
CC-7B	6
CC-8C	68
CC-8D	18
CC-18A	176
CC-18B	11
CC-26B	15

Leakance between layers 2 and 3 was calculated from the same vertical hydraulic conductivity as used between layers 1 and 2 (1×10^{-7} ft/d). The thickness of the lower confining unit is shown in figure 77.

The lower confined aquifer is confined throughout the model area, and transmissivity is considered constant in each cell. Transmissivity, which is the only parameter input for layer 3, is calculated by multiplying horizontal hydraulic conductivity by layer thickness. The horizontal hydraulic conductivity of the lower confined aquifer was determined from five slug tests (table 59). An average for the five slug tests, 30 ft/d, was used for the entire layer. The thickness of the lower confined aquifer is shown in figure 78.

Recharge to the surficial and Canal Creek aquifers is primarily from vertical infiltration of precipitation in the outcrop areas of the aquifers. The lower confined aquifer is recharged updip of the outcrop area of the Canal Creek aquifer by leakage through the overlying lower confining unit. Annual rainfall ranges from 39 to 45 in/yr in the study area (Durda and others, 1991, p. 2-7). Only part of that rainfall enters the ground-water system as recharge; most is lost as runoff or is evapotranspired at the surface. Recharge to the outcrop areas of the surficial and Canal Creek aquifers in the Canal Creek flow model was estimated to be 13.5 in/yr on the basis of the recharge rate used in a previous study at nearby O-Field (Vroblesky and others, 1989, p. 129).

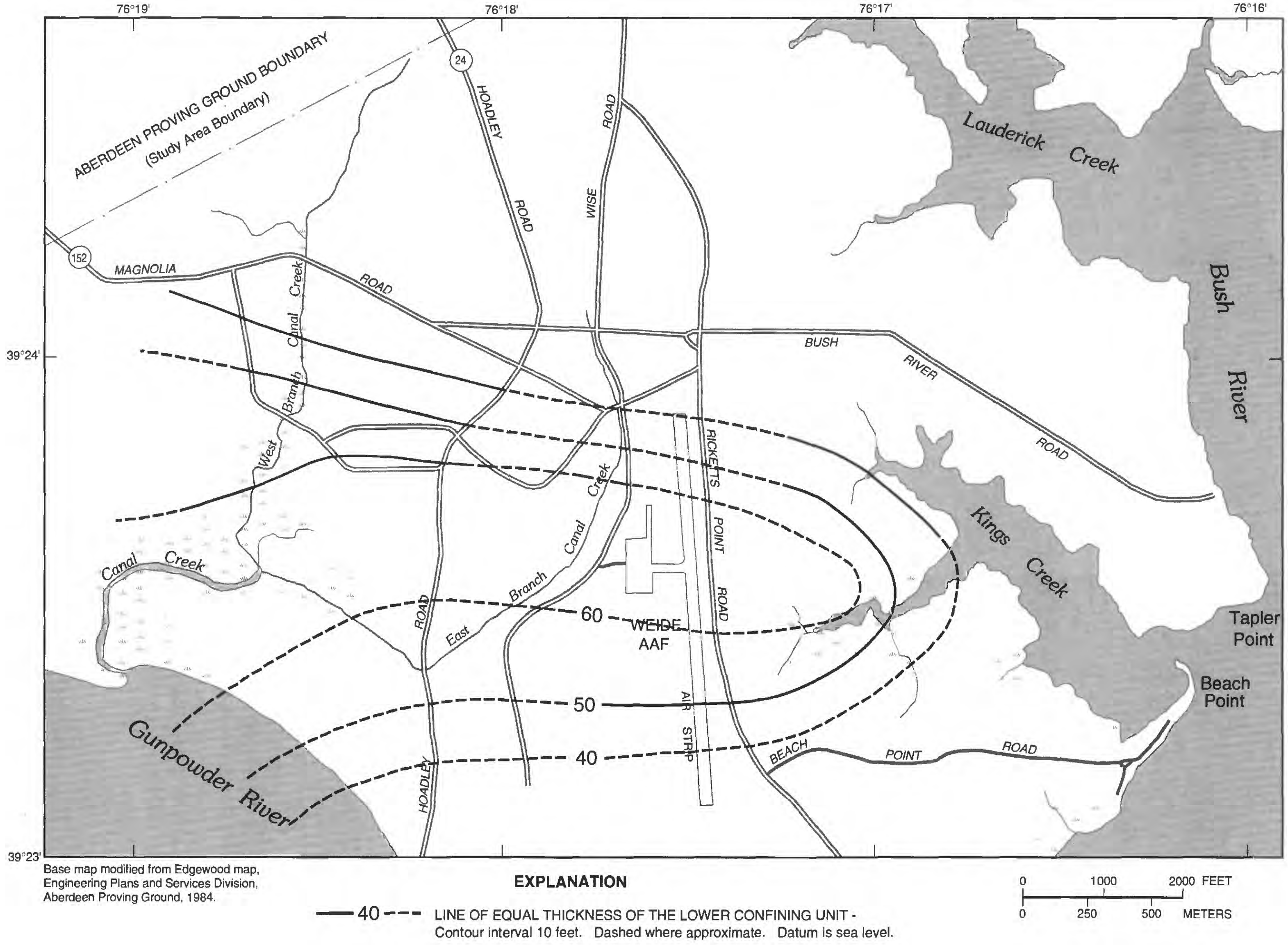
Table 59. *Horizontal hydraulic conductivities for the lower confined aquifer, as determined from slug tests, Aberdeen Proving Ground, Maryland*

Well no.	Horizontal hydraulic conductivity (feet per day)
CC-6C	53
CC-17C	24
CC-28C	16
CC-139	34
CC-140	37

Because of a depression in the potentiometric surface, four model cells near the West Branch Canal Creek (fig. 72) were simulated as a ground-water drain by use of the drain package of the modular model. A ground-water drain simulates removal of water from an aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or altitude, as long as the head in the aquifer is above that fixed altitude (McDonald and Harbaugh, 1988, p. 9-1). No water is removed if head in the aquifer falls below that level. Model input includes location, altitude, and conductance between the drain and the aquifer.

A depression in the potentiometric surface has existed for at least as long as water-level measurements have been made (fig. 8). It is located where the upper confining unit is very thin at the surface and excavation for sewer lines in the early 1900's probably disturbed the clayey sediments. This combination of factors created a depression in the potentiometric surface and opened up a pathway for ground-water to discharge to the West Branch Canal Creek. In 1988, the site was reexcavated to replace leaky sewer lines (Gary Nemeth, U.S. Army Environmental Hygiene Agency, oral commun., 1990), slightly enlarging the area of the depression.

Canal Creek and Reardon Inlet (fig. 72) were simulated in the model by use of the river package. The river package simulates leakage between surface-water features and ground-water systems (McDonald and Harbaugh, 1988, p. 6-1). Model input includes location, stage, riverbed conductance, and riverbed altitude.

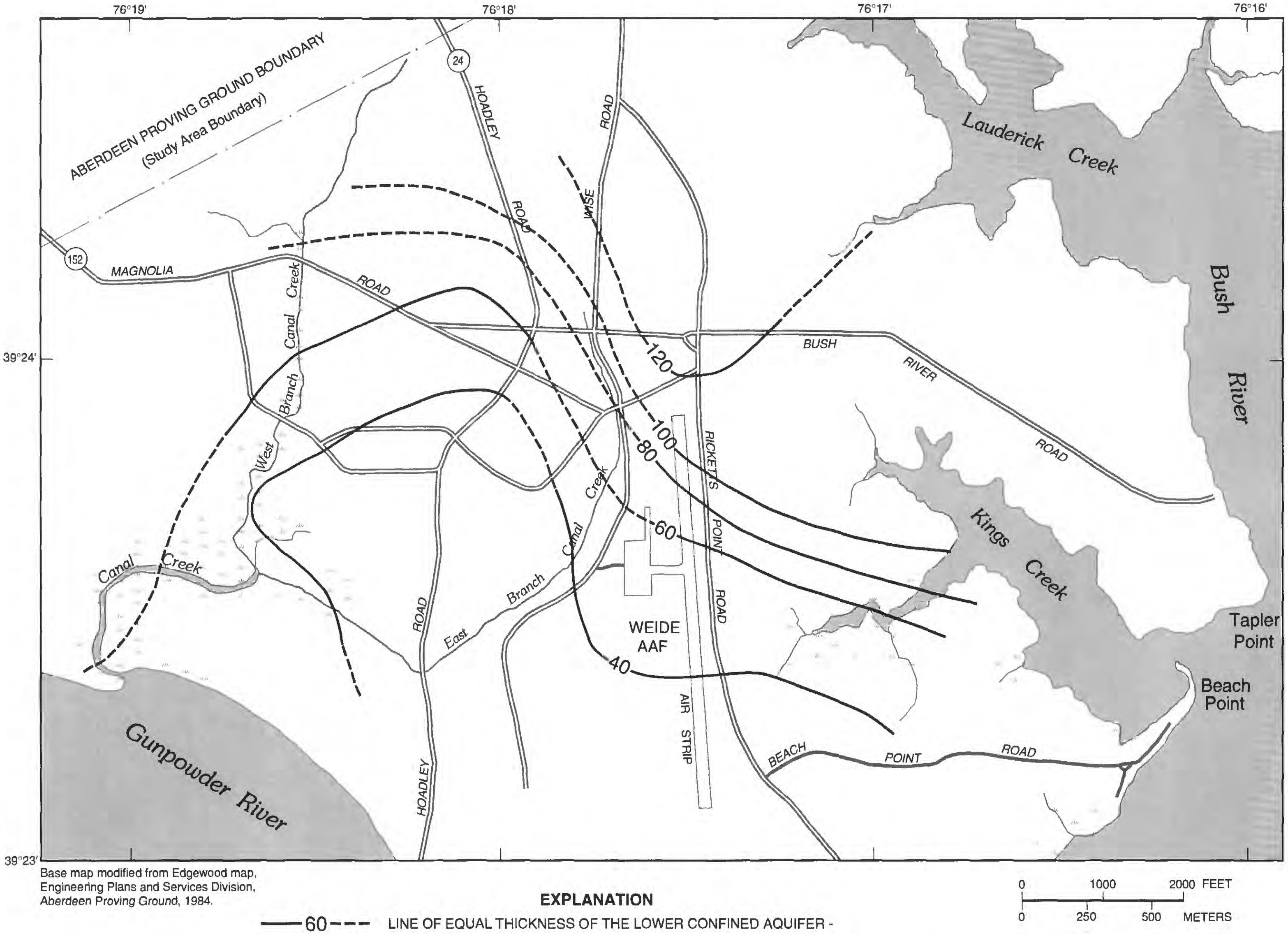


Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

—40 - - - LINE OF EQUAL THICKNESS OF THE LOWER CONFINING UNIT - Contour interval 10 feet. Dashed where approximate. Datum is sea level.

Figure 77. Thickness of the lower confining unit, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

——60– – – LINE OF EQUAL THICKNESS OF THE LOWER CONFINED AQUIFER - Contour interval 20 feet. Dashed where approximate. Datum is sea level.

Figure 78. Thickness of the lower confined aquifer, Aberdeen Proving Ground, Maryland.

Model Calibration

Unstressed conditions

From about 1950-68, ground water was pumped from onsite wells screened in the Canal Creek and lower confined aquifers. Since about 1968, no onsite or nearby wells have been pumped. Currently, the ground-water flow system is in a state of equilibrium that probably approximates the prepumping conditions. Therefore, it was assumed that the model could be calibrated to current, steady-state conditions. A long-term hydrograph of the water level in the Canal Creek aquifer during pumping and after pumping had stopped in 1968 is shown in figure 12.

The model was calibrated by systematic adjustment of the initial model values of hydraulic conductivity, transmissvity, and leakance until simulated water levels approximated water levels measured in observation wells in the study area. Simulated water levels were compared to water levels measured in October 1989 from 23 surficial aquifer wells and 55 Canal Creek aquifer wells and to water levels measured in April 1989 from 25 lower confined aquifer wells. Water levels measured in October 1989 represent an average altitude of water levels in the Canal Creek aquifer (fig. 10). April 1989 water levels were used for the lower confined aquifer because of an abundance of data for this time period from offsite wells screened in the lower confined aquifer. Water levels in the lower confined aquifer did not vary significantly between April and October 1989 (fig. 11), and the median water level in the Canal Creek aquifer for April 1989 differed from that in October 1989 by less than 0.5 ft (fig. 10).

Model calibration and sensitivity analysis were aided by calculation of descriptive statistics, particularly the root mean square error (RMSE), for each model run. The RMSE of the difference between simulated and measured water levels decreases as the total sum of the squared differences between them is reduced. During calibration, the RMSE for the 103 wells used in the model was reduced from approximately 10 ft to 2.0 ft. The calibration procedure also included the comparison of maps of simulated and measured potentiometric surfaces for each aquifer.

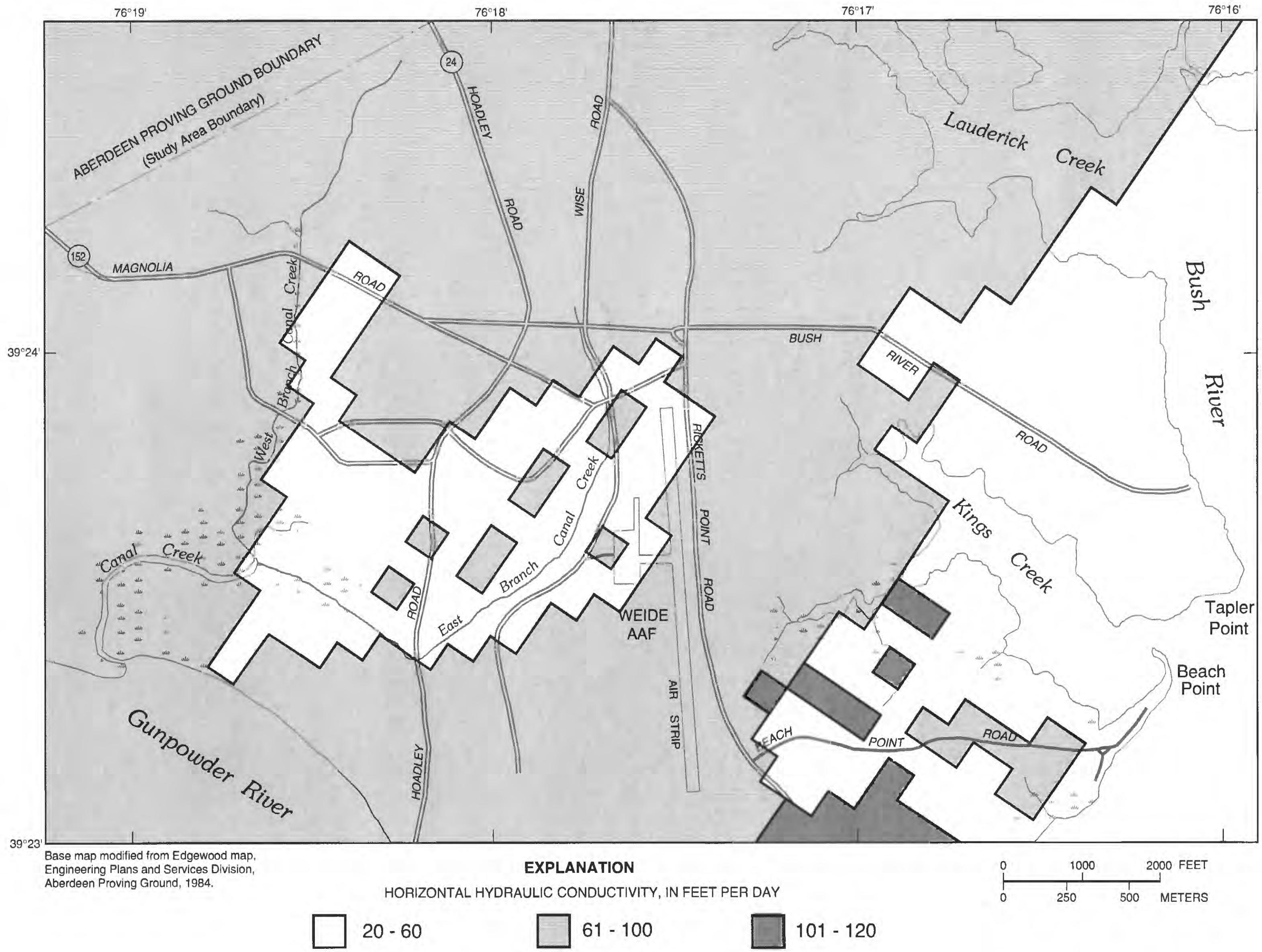
Changes to model parameters were made during calibration by use of ARC/INFO. After each model run, simulated water levels were entered into an ARC/INFO data base and compared to those from April and October 1989. Potentiometric-surface maps for each aquifer were constructed from the water levels measured in 103 observation wells. These potentiometric-surface maps were then discretized to obtain an interpreted head for each model node. For each model cell where a significant difference between simulated and interpreted head was found, a change was made to the model parameters for that cell to improve subsequent simulations. For example, for each model cell where the simulated water levels in layer 2 were 5 to 10 ft too high, the hydraulic conductivity might have been increased by 10 ft/d; for each model cell where simulated water levels were 10 to 15 ft too high, the hydraulic conductivity might have been increased by 15 ft/d. This process continued until adjustments were made to the hydraulic conductivity for all cells in layer 2 with a significant difference in water levels. This approach was justified because the lithology of these sediments is highly varied, both vertically and horizontally (Owens, 1969, p. 80), and because head gradients are a reflection of differences in hydraulic parameters. The model was then run with the new values for hydraulic conductivity in layer 2, and the simulation was again evaluated as previously described. Sensititvity analysis, however, subsequently indicated that small changes (multiples of 0.5 to 1.5) of calibrated hydraulic conductivity produced insignificant changes in simulated heads.

Calibration results

Horizontal hydraulic conductivity used in the model for the surficial aquifer is shown in figure 79. Hydraulic conductivities used in the calibrated model generally were higher than initial estimates. Hydraulic conductivities range from 20 to 100 ft/d in the paleochannel part of the surficial aquifer and from 20 to 120 ft/d in the eastern part. The amount of variation is greater in the paleochannel and south of Kings Creek, where more aquifer and water-level data were available. This variation in hydraulic conductivity was expected for all three aquifers because of the variations in lithology of the fluvial sediments that make up the aquifers.

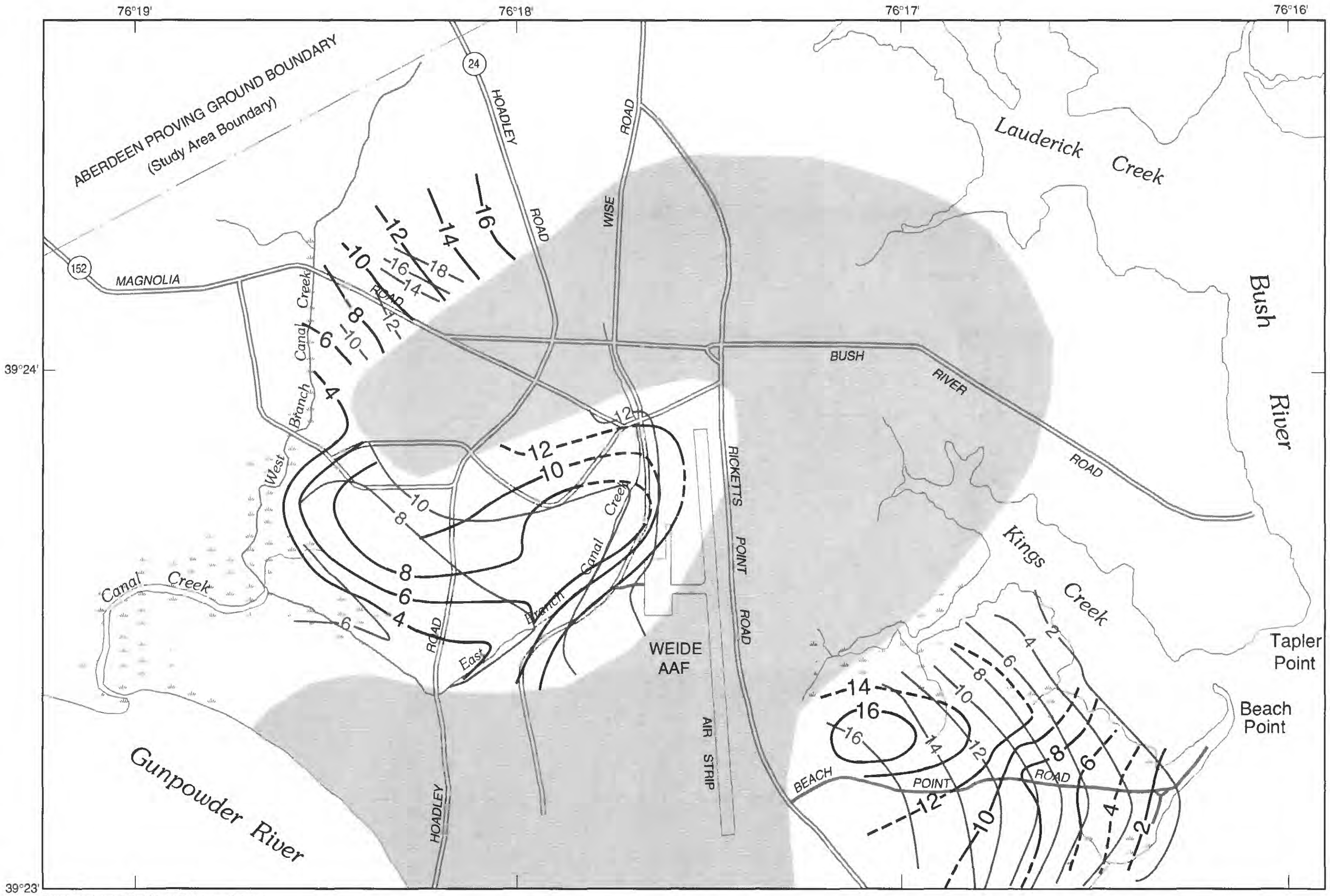
A map showing the relation of the simulated water-table altitudes to the interpreted water-table altitudes in the surficial aquifer is shown in figure 80. Simulated water levels generally approximate interpreted water levels. The RMSE between model-simulated water levels and water levels measured in October 1989 in 23 surficial aquifer wells is 2.5 ft.

Vertical-leakance values used in the model to simulate flow through the upper confining unit are shown in figure 81. In most areas where the upper confining unit is present, vertical leakance is approximately 1×10^{-9} ft/d. Within the paleochannel,



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 79. Hydraulic conductivity in the surficial aquifer, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

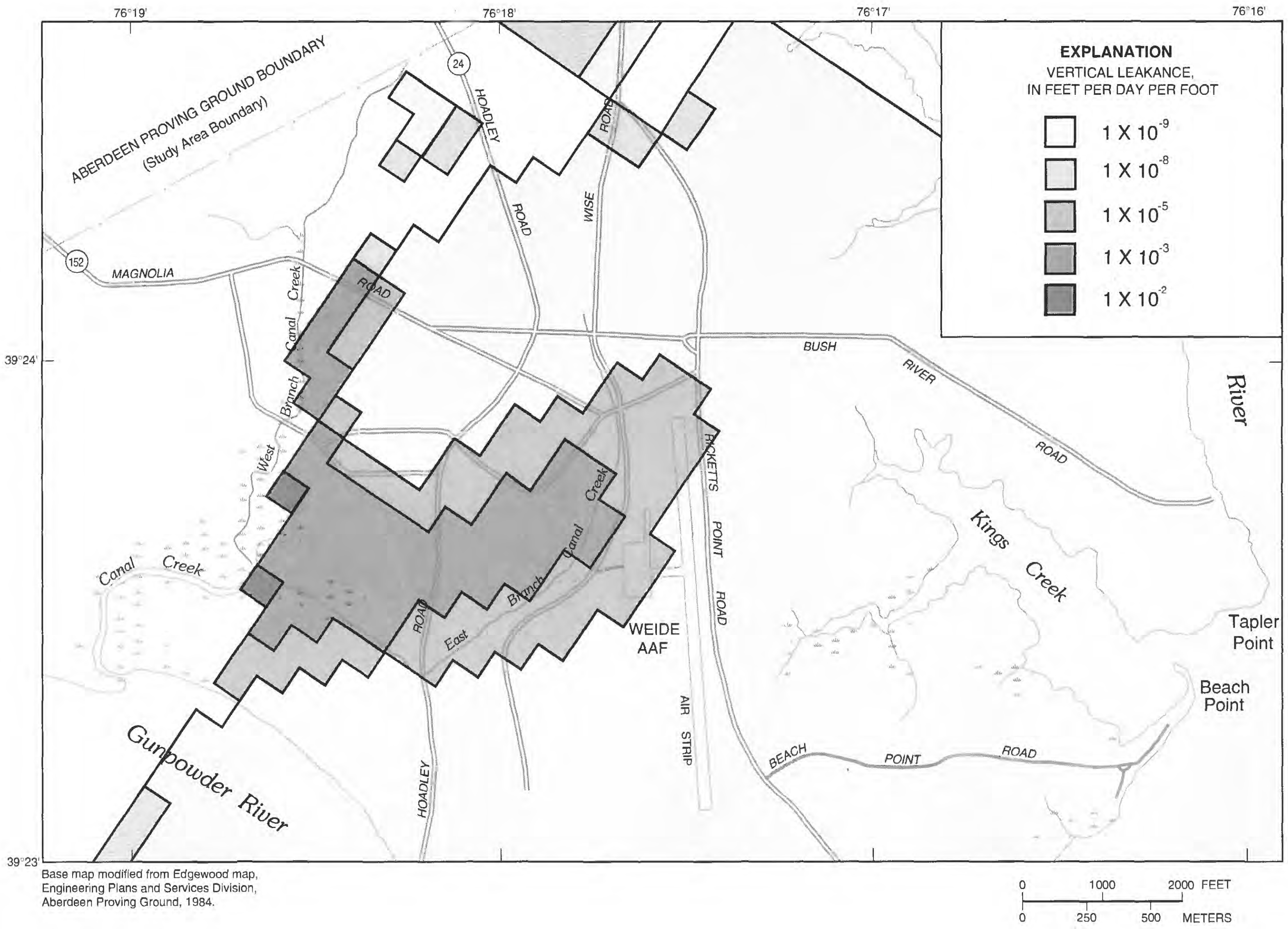
▨ OUTCROP AREA OF THE UPPER CONFINING UNIT

—10- - - OBSERVED WATER-TABLE CONTOUR - Shows altitude of the water table based on measurements from October 1989. Dashed where approximate. Contour interval 2 feet. Datum is sea level.

—10— SIMULATED WATER-TABLE CONTOUR - Shows altitude of the simulated water table. October 1989. Contour interval 2 feet. Datum is sea level.

0 1000 2000 FEET
0 250 500 METERS

Figure 80. Altitudes of the simulated and observed water-table surfaces in the surficial aquifer, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 81. Vertical leakance values used to simulate flow through the upper confining unit, Aberdeen Proving Ground, Maryland.

vertical leakance is approximately 1 x 10^{-3} ft/d. Vertical-leakance values in the calibrated model are generally lower than initial estimates.

Hydraulic conductivities used in the model range from 20 to 140 ft/d in the Canal Creek aquifer (fig. 82). Variations in calibrated hydraulic conductivities are similar to variations in hydraulic conductivities determined from slug tests (table 58).

A map showing the altitudes of the simulated potentiometric surface and the interpreted potentiometric surface for the Canal Creek aquifer is presented in figure 83. Simulated water levels generally approximate observed water levels. The largest difference between simulated and observed water levels is in the eastern part of the study area, where water level and aquifer data were limited. The RMSE between model-simulated water levels and water levels measured in October 1989 in 55 Canal Creek aquifer wells is 1.3 ft.

Vertical-leakance values used to simulate the lower confining unit are shown in figure 84. In most of the study area, vertical leakance ranges from 1 x 10^{-5} to 1 x 10^{-7} ft/d. Vertical leakance is greater in areas under the Bush River, Kings Creek, and the Gunpowder River, ranging from 1 x 10^{-2} to 1 x 10^{-4} ft/d (fig. 84). These higher values were based on the assumption that some erosion of the confining unit has taken place beneath the Bush River, Kings Creek, and the Gunpowder River, as previously discussed. In general, vertical-leakance values are within an order of magnitude of original estimates.

Transmissivities used in the model for the lower confined aquifer are shown in figure 85. The calibrated transmissivities are not much different from the initial values. In the study area transmissivity ranges from 400 to about 5,000 ft^2/d. The initial hydraulic conductivity used to calculate transmissivity was 30 ft/d; hydraulic conductivities used for the calibrated model range from 10 to 45 ft/d. Most of the variation in transmissivity is a result of differences in aquifer thickness.

A map showing the altitudes of the simulated and interpreted potentiometric surfaces for the lower confined aquifer is given in figure 86. For the most part, simulated water levels are 2 to 3 ft higher than interpreted water levels. The RMSE between simulated water levels and water levels measured in April 1989 in 25 lower confined aquifer wells is 3.1 ft.

Stressed conditions

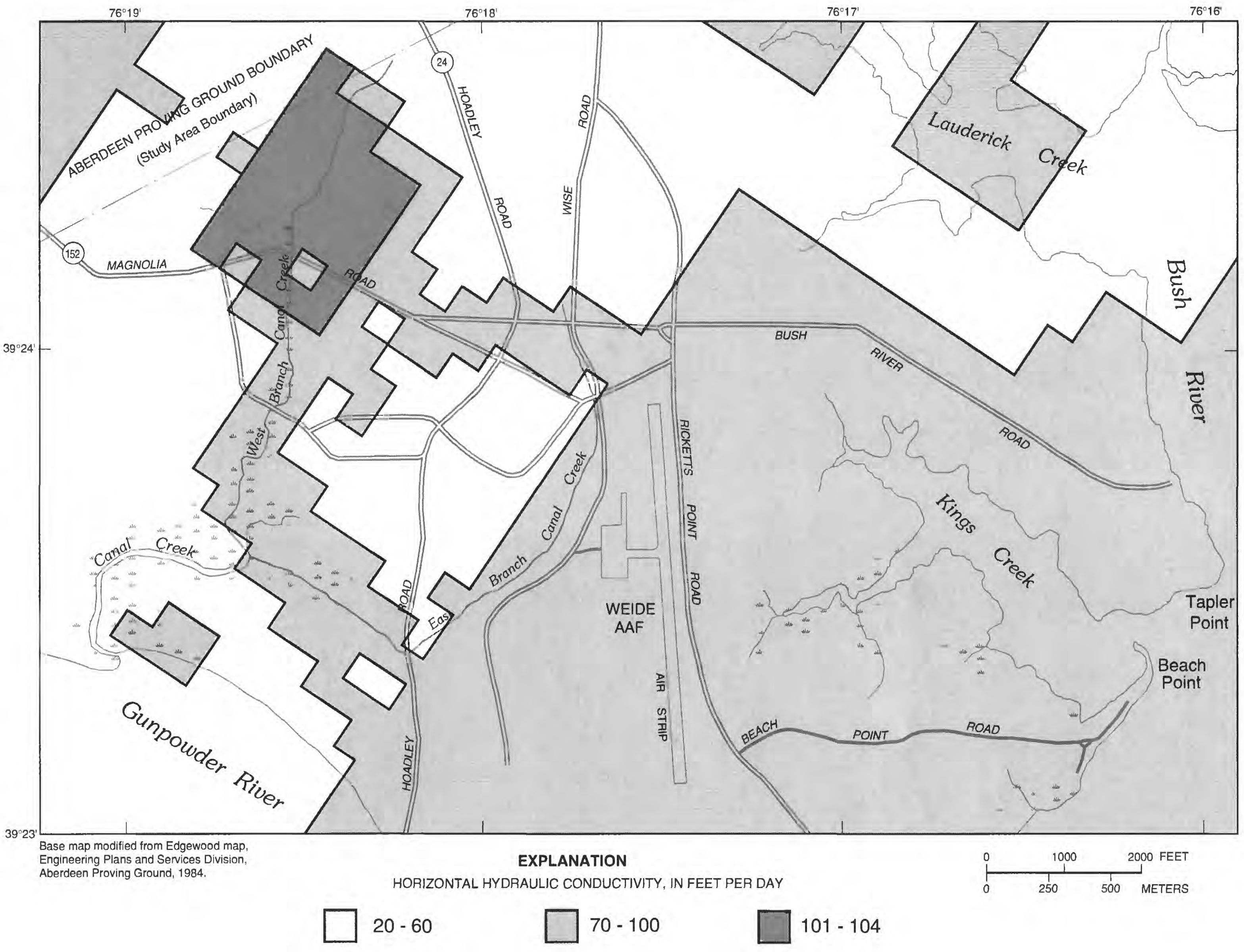
Detailed records are not available of the pumpage during about 1950-68 from the Canal Creek and lower confined aquifers. The records that were located are hand-written copies of pumpage records from 1950 and 1957 that are probably incomplete.

During model calibration, an attempt was made to match the drawdown recorded for well HA Ed 24 (fig. 12) in the pumpage records that were available. The amount of drawdown in the well could not be simulated without making excessive changes to simulated hydraulic parameters. The possibility exists that a well (such as well 23N, fig. 2) near the observation well was pumping at the time, or that the pumpage records are inaccurate. Because of this uncertainty, changes were not made to hydraulic parameters in response to simulations based on historical pumpage data. However, the pumpage records are used to infer the movement of contaminant plumes from suspected source areas to present-day locations. The directions of ground-water flow over time and the estimated migration of contaminant plumes are discussed in the section, "Pumping Alternatives."

Sensitivity Analysis

After calibration, the sensitivity of the model to changes in model parameters was tested. Hydraulic conductivity, transmissivity, leakance, recharge, lateral boundaries, drain and riverbed conductance, and drain altitude were varied one at a time within a reasonable range. In addition, several simulations were done while two model parameters were varied at the same time. Water levels from the sensitivity simulations were compared to water levels from the calibrated model by use of the RMSE. Comparisons were made for all cells in the study area. The model is sensitive to changes in a model parameter if small changes in the parameter produce large changes in water levels (large RMSE); the model is not sensitive if large changes in a parameter produce little water-level change (small RMSE).

The model was sensitive to changes in the hydraulic conductivity of the Canal Creek aquifer. The RMSE between simulated water levels was 2.5 ft when the hydraulic conductivity was divided by 2. When the hydraulic conductivity was doubled, the RMSE between simulated water levels was 1.3 ft, and several cells went dry. If the hydraulic conductivity was increased by more than a factor of 2, cells went dry until the model failed to converge.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

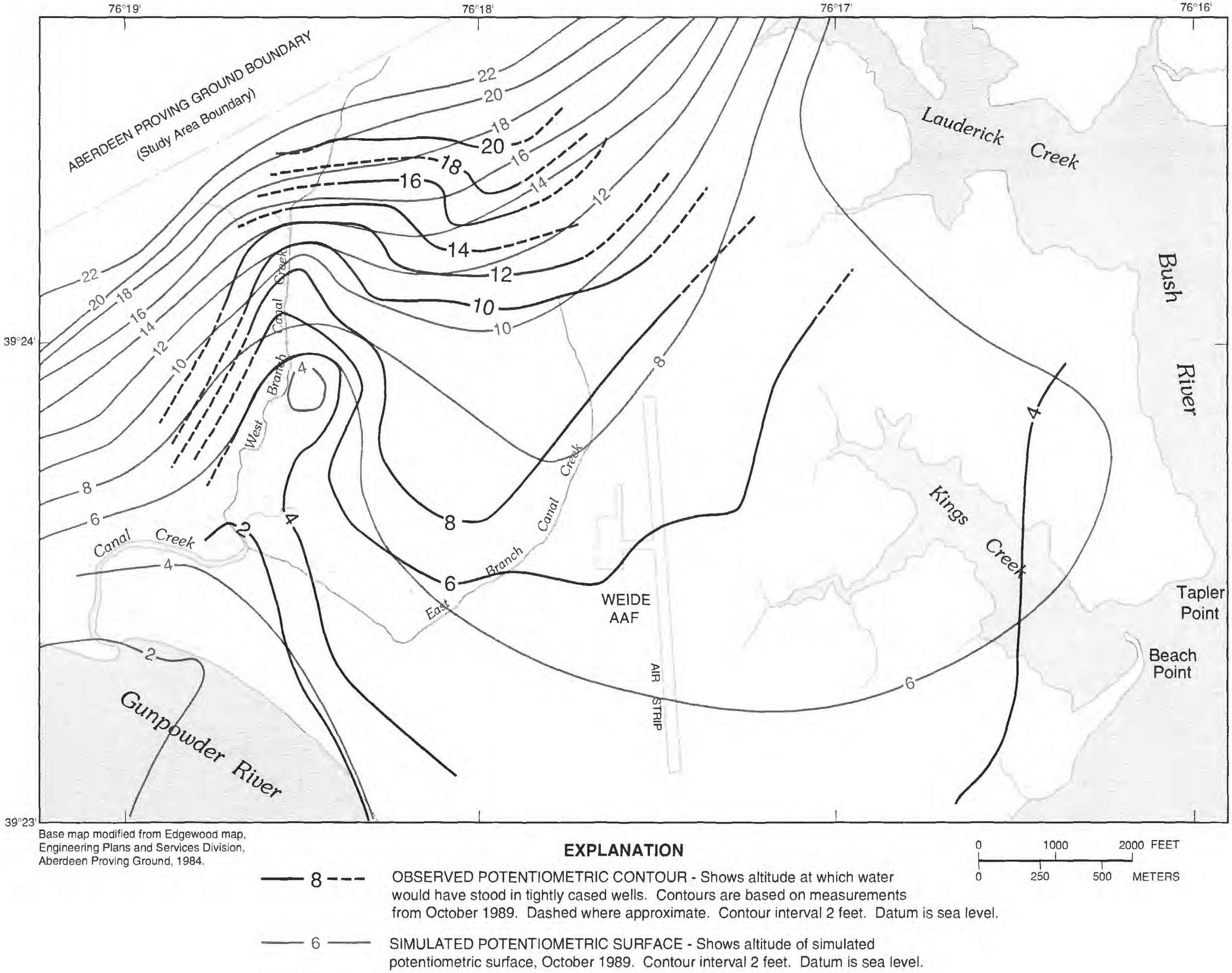
HORIZONTAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

☐ 20 - 60

▨ 70 - 100

■ 101 - 104

Figure 82. Hydraulic conductivity in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland.



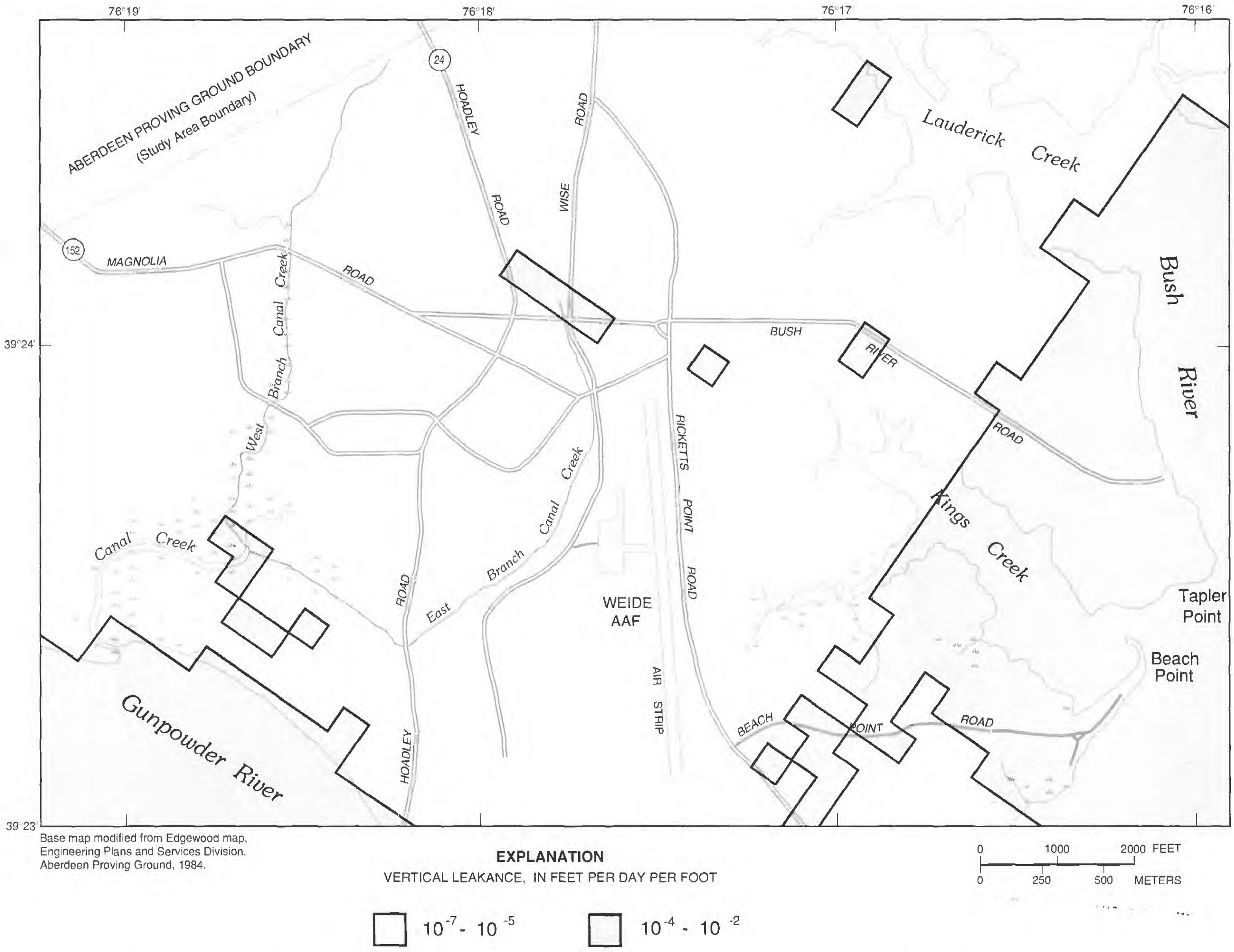
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

8 - - - OBSERVED POTENTIOMETRIC CONTOUR - Shows altitude at which water would have stood in tightly cased wells. Contours are based on measurements from October 1989. Dashed where approximate. Contour interval 2 feet. Datum is sea level.

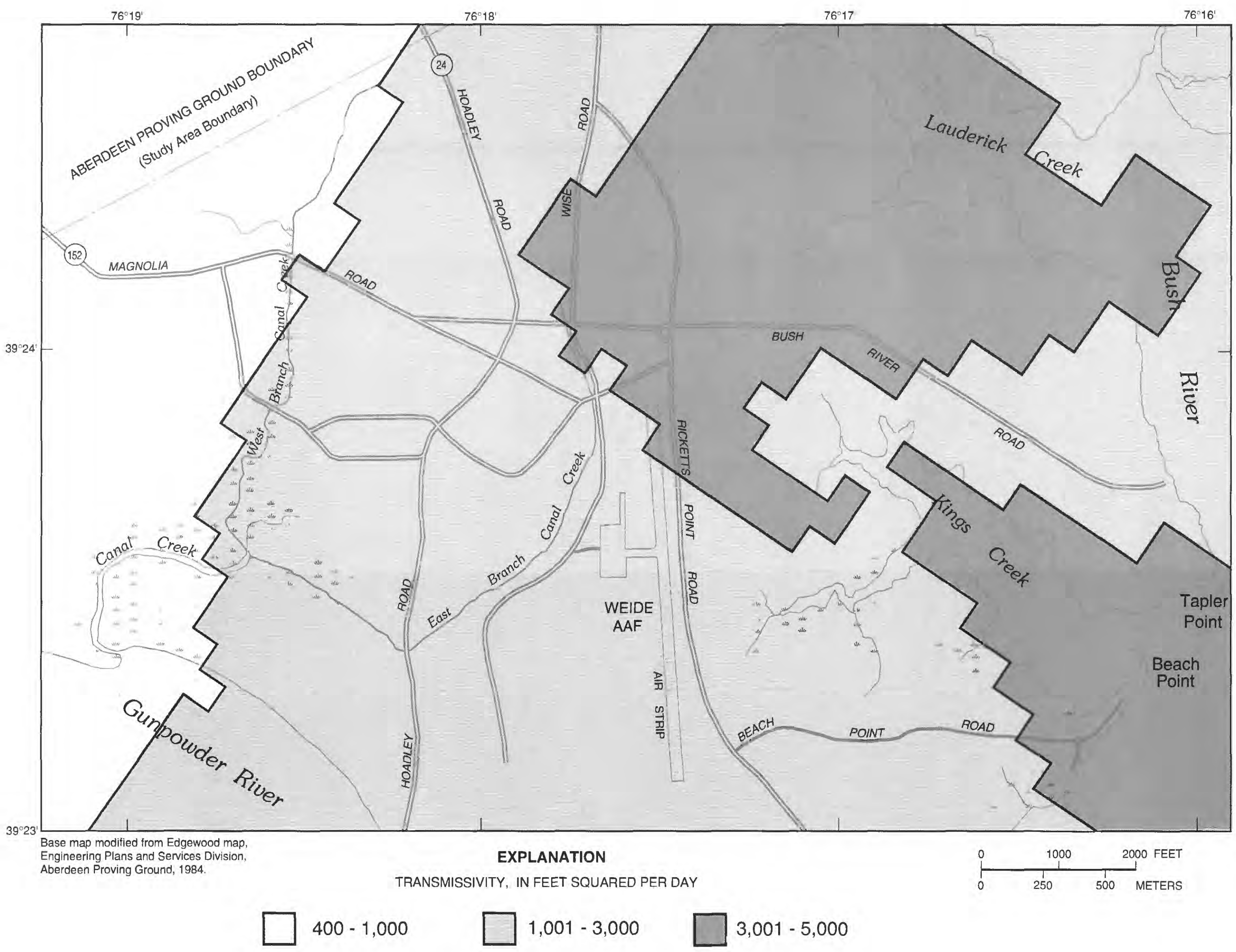
6 SIMULATED POTENTIOMETRIC SURFACE - Shows altitude of simulated potentiometric surface, October 1989. Contour interval 2 feet. Datum is sea level.

Figure 83. Altitudes of the simulated and observed potentiometric surfaces in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 84. Vertical leakance values used to simulate flow through the lower confining unit, Aberdeen Proving Ground, Maryland.



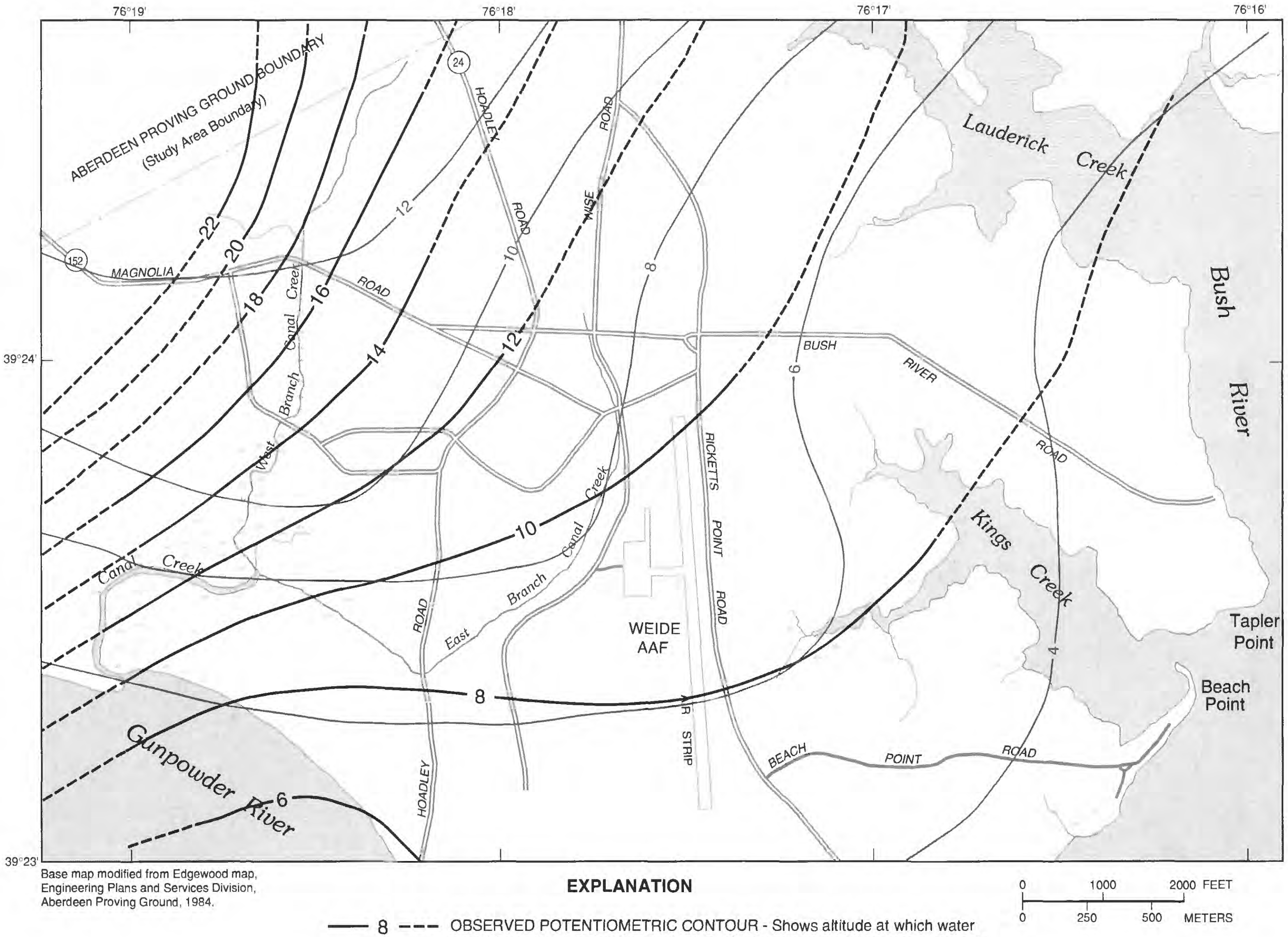
Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

- ☐ 400 - 1,000
- ▨ 1,001 - 3,000
- ■ 3,001 - 5,000

Figure 85. Transmissivity in the lower confined aquifer, Aberdeen Proving Ground, Maryland.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

EXPLANATION

— 8 - - - OBSERVED POTENTIOMETRIC CONTOUR - Shows altitude at which water would have stood in tightly cased wells. Contours are based on measurements from April 1989. Dashed where approximate. Contour interval 2 feet. Datum is sea level.

— 8 — SIMULATED POTENTIOMETRIC CONTOUR - Shows altitude of simulated potentiometric surface, April 1989. Contour interval 2 feet. Datum is sea level.

Figure 86. Altitudes of the simulated and observed potentiometric surfaces in the lower confined aquifer, Aberdeen Proving Ground, Maryland.

Other parameters tested were vertical leakance between layers 2 and 3 and the transmissivity of layer 3. When leakance was increased by a factor of 10, or transmissivity was decreased by a factor of 10, the RMSE between simulated water levels was about 1.9 ft. When leakance was decreased by a factor of 10, or transmissivity increased by a factor of 10, the RMSE was about 1.0 ft. When the hydraulic conductivity of the surficial aquifer was increased by a factor of 10, the RMSE between simulated water levels was 2.6 ft; however, decreasing the hydraulic conductivity by a factor of 10 resulted in only a 0.2-ft RMSE.

An RMSE of 0.5 ft resulted from varying recharge by plus or minus 2 in/yr, from multiplying vertical leakance between layers 1 and 2 by 0.1 or 10, and from multiplying riverbed conductance by 0.5 or 2. Multiplying drain conductance by 0.5 or 2 and varying drain altitude by plus or minus 2 ft resulted in an RMSE of less than 0.2 ft in each case.

Decreasing the distance from the center of the study area to the southwest and southeast model boundaries by 600 ft resulted in an RMSE of 0.25 ft between simulated water levels. The maximum change in water levels in the area of primary interest was 0.1, 0.4, and 0.6 ft for the surficial, Canal Creek, and lower confined aquifers, respectively. This indicates that the model boundaries are far enough away so as not to affect simulations of ground-water flow in the primary area of interest. The northwest boundary was not tested because it is a no-flow boundary at the Fall Line; the northeast boundary was not tested because it is more than twice as far from the primary area of interest as any of the other boundaries and is not likely to influence ground-water flow.

Simulations were done in which hydraulic conductivities in layer 2 and vertical leakances between layers 1 and 2 were varied simultaneously; simulations also were done in which hydraulic conductivities in layer 2 and vertical leakances between layers 2 and 3 were varied. The results are shown in figure 87. Model sensitivity to changes in the hydraulic conductivity in layer 2 can be seen in the elongation of the water-level contours. A small change to the hydraulic conductivity in layer 2 results in greater water-level changes than a similar change to vertical leakance. Figure 87 also shows that RMSE at calibration was at a minimum with respect to these matrices.

Major Assumptions and Limitations

A ground-water-flow model is a practical tool for understanding the ground-water-flow system and simulating ground-water flow. However, during model setup and calibration, many assumptions are made about the flow system and conditions affecting it. As a result of these assumptions, the model has certain limitations.

The Canal Creek flow model is a simplification of a complex flow system. Lateral and vertical changes in the fluvial deposits that constitute the hydrogeologic framework could create flow paths tens to hundreds of feet long that neither the model nor the data collected to date can accurately describe. The model is best suited to describing generalized flow patterns (on the order of hundreds to thousands of feet) within the study area. This generalized flow is assumed to be horizontal within layers and vertical between layers. Outside of the study area, near the model boundaries, the small amount of hydrogeologic information available could result in larger errors in the simulation of ground-water flow. Within the study area, more information was available for the Canal Creek aquifer than for the surficial and lower confined aquifers. As a result, the model is calibrated in greater detail for the Canal Creek aquifer than for the surficial and lower confined aquifers.

In addition, pumping alternatives should be evaluated with the knowledge that the model was not calibrated to any known pumping stress. In particular, aquifer storage coefficients were not used to calibrate the steady-state, unstressed model. However, it was necessary to modify the model to include aquifer storage coefficients for the pumpage scenarios, in which transient conditions exist. Thus, the results from pumpage scenarios are based upon the calculations of a modification to the calibrated model for the Canal Creek aquifer.

Pumping Alternatives

The ground-water-flow model (McDonald and Harbaugh, 1988) and particle tracker postprocessor to the model (Pollock, 1989) were used to evaluate the development of contaminant plumes and the hydrologic effects of three ground-water pumping alternatives in the Canal Creek study area. The pumping alternatives are (1) no pumpage, to evaluate the hydrologic effects if no remedial action were taken, (2) pumping of existing wells on base, to evaluate the hydrologic effects of a pump-and-treat remedial action, (3) and pumping of wells offsite, to determine if offsite public-supply wells could become contaminated.

All of the alternatives were simulated under steady-state conditions. Estimated porosities of 0.3 for each aquifer and 0.4 for each confining unit were used for particle tracking. The contaminant plumes used in the simulations are a composite of

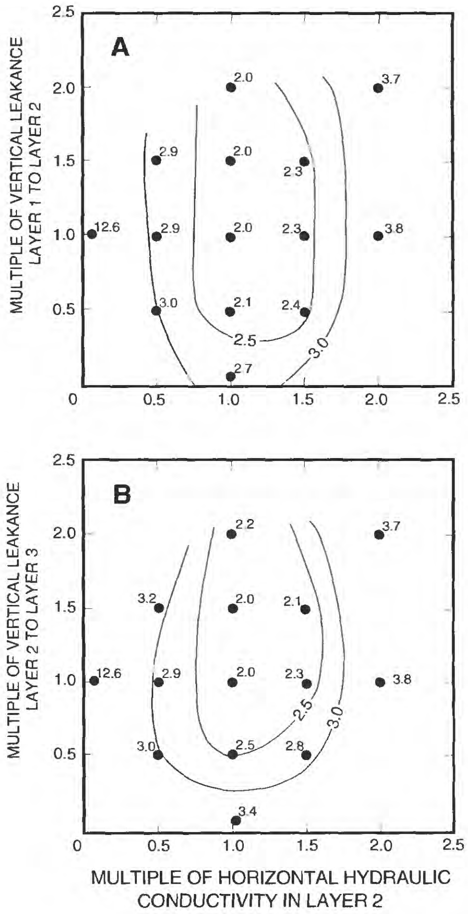


Figure 87. Root mean square error of water levels for changes of horizontal hydraulic conductivity and vertical leakance from calibrated values.

several individual contaminant plumes discussed earlier in this report. The extent of the contaminant plumes shown here (fig. 88) should be considered the general extent of contamination in the Canal Creek aquifer in 1989.

The ground-water-flow model and particle tracker describe only advective flow of conservative constituents; other physical, chemical, and biological processes that affect the nonconservative contaminants present in the Canal Creek aquifer are not described in the model. Although other transport processes could affect contaminant migration (particularly traveltime), advection is the primary transport process for mobile contaminants (Freeze and Cherry, 1979, p. 389). Thus, the ground-water-flow model and particle tracker can be used to identify advective contaminant flow directions and discharge points.

Development of Contaminant Plumes

Suspected contaminant source areas were described in previous sections of this report; however, the existing historical data are too uncertain to quantify the sources and volumes of all contaminants introduced into the ground-water-flow system in the Canal Creek study area. In addition, a detailed account of historical pumping is not available. The timing of events that led to the current size and location of contaminant plumes is complex. Without additional specific information, a detailed simulation of plume development would be impossible. The discussion presented here is intended to give a general idea of how the current contaminant plumes evolved. It is based on simulations with wells known to be pumping during about 1950-68 and on suspected source areas previously defined in this and other reports.

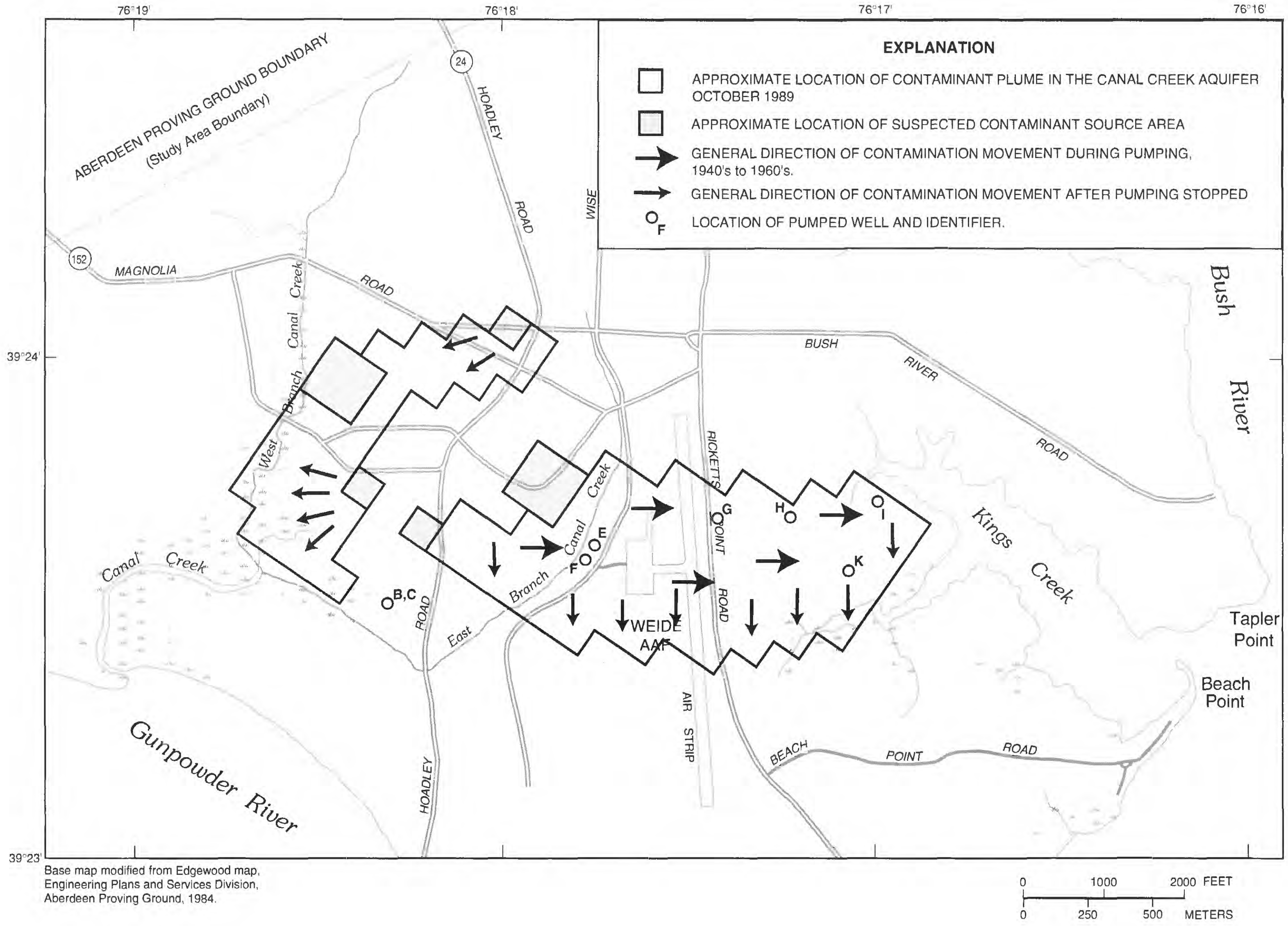
Records indicate that wells C, F, G, H, I, and K in the Canal Creek aquifer, and wells B and E in the lower confined aquifer (fig. 88) were pumped. Not all of the wells were pumped at the same time. Pumpage was probably about 1 Mgal/d. This value was estimated from the typical pumping rate of wells known to be in use at the time.

The simulated directions of contaminant movement during pumping and after pumping had stopped are shown in figure 88. During pumping, ground-water flow was generally to the east (toward the pumped wells) in the eastern part of the study area. In the eastern part of the study area, contaminants probably migrated relatively quickly from the surficial aquifer and into the Canal Creek aquifer through the paleochannel. Flow velocities were increased because of increased hydraulic gradients. Once pumping had stopped, ground-water-flow directions changed, and the contaminant plume in the eastern part of the study area moved to the south. Hydraulic gradients were reduced and flow velocities decreased after pumping had stopped.

Flow directions in the western part of the study area probably changed very little during the period of pumping. However, not enough data exists to evaluate the effect of pumping on the western plume. Much of the ground-water flow in that area is influenced by the disturbed sediments near the pilot plant on the West Branch Canal Creek.

No Pumpage

The no-pumpage scenario is based on the assumption that any remedial action at the site would not result in a change in ground-water-flow directions or hydraulic gradients. In general, ground-water levels would remain similar to those shown on figures 80, 83, and 86.



Base map modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984.

Figure 88. Simulated historical development of contaminant plumes in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland.

Pathline analysis

Pathlines of advective particles that start in contaminant plumes in the Canal Creek aquifer are depicted in figure 89. The contaminant plumes continue to move in the same directions as they have since pumping stopped in the 1960's. Particles in the western plume follow pathlines that discharge to Canal Creek and the Gunpowder River. Ground water in the eastern plume will eventually discharge to the Gunpowder River. Near the East Branch Canal Creek, simulated particle velocity (assuming a porosity of 0.3) is about 75 ft/yr. Near Kings Creek, simulated particle velocity is much lower, about 25 ft/yr. This velocity difference can also be inferred from the higher potentiometric gradient near the East Branch Canal Creek (fig. 83). Particle velocity in the western plume could be as high as 100 ft/yr. The simulated pathlines and velocities account only for advection; other transport processes would retard the movement of contaminants to some degree.

Chemical effects

If no remedial action is taken, the bulk of the contaminant plumes are likely to continue moving in the current direction of ground-water flow. Ground-water contaminants near the West Branch Canal Creek would generally continue flowing toward and discharging to the West Branch Canal Creek (fig. 89). Infiltration of recharge water could cause a decrease in contaminant concentrations over a long period of time. However, the dilution effect of infiltrating rainwater could be counteracted by dissolution of DNAPL's that could still be present in the sediments and by leaching of trace metals from contaminated soils.

No significant contaminant-retardation mechanisms seem to be occurring in the ground water in this western plume. Sorption is not believed to be a significant process in the aquifer sediments for the VOC's (Lorah and Vroblesky, 1989, p. 83), although sorption or coprecipitation with iron and manganese oxides could attenuate some of the trace elements that were found in elevated concentrations. Because oxic conditions generally are maintained in the ground water in this relatively shallow flow system of the Canal Creek aquifer (fig. 25), biodegradation of the chlorinated VOC's does not seem to be a significant process.

The bulk of the contaminants in the eastern plume will generally spread to the south and cause presently uncontaminated areas between the plume and the Gunpowder River to become contaminated (fig. 89). Eventually, the ground water will discharge to the Gunpowder River. Eastward movement of the contaminants in the eastern plume will be slower than movement of contaminants to the south because hydraulic gradients are lower in the eastern direction.

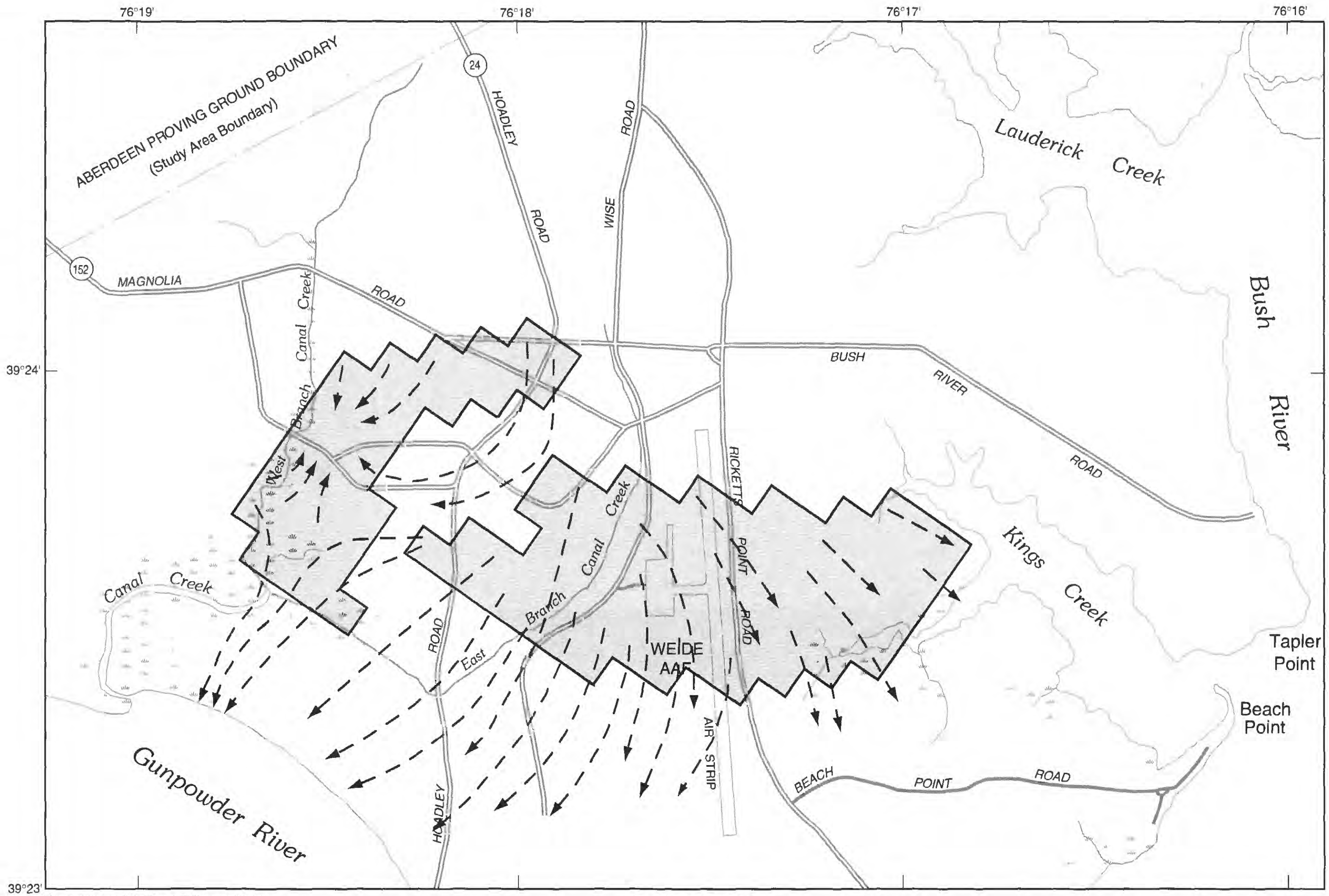
Contaminant concentrations at the leading edge of the eastern plume are likely to decrease from dilution caused by mixing with previously uncontaminated water. Some of the VOC's are biodegrading under anaerobic conditions in this eastern plume, but intermediate degradation products, including 1,2-*trans*-dichloroethylene and vinyl chloride, seem to be accumulating in the ground water. DNAPL's are probably present in the aquifer sediments, especially near the East Branch Canal Creek where the clothing-impregnating plant discharged large quantities of solvent (fig. 14). Dissolution of DNAPL's would continue to provide a source of VOC's to the ground water.

Pumpage From Existing Wells

Simulations in which existing wells F, G, H, I, and K in the Canal Creek aquifer were withdrawal points for a pump-and-treat remedial action were run at full (2.0 Mgal/d), half (1.0 Mgal/d), and quarter (0.5 Mgal/d) capacity. Pumping capacities (table 60) were determined from well records obtained from the U.S. Army. The condition of these wells, all drilled in the 1940's, is not known. Rehabilitation of the wells could be necessary to achieve the capacity used in the simulations.

Table 60. *Simulated pumping rates from the Canal Creek aquifer, Aberdeen Proving Ground, Maryland*

	Pumping rate, in gallons per minute		
Well	**Full capacity**	**Half capacity**	**Quarter capacity**
F	175	88	44
G	200	100	50
H	300	150	75
I	400	200	100
K	300	150	75
Total, in million gallons per day)	2.0	1.0	0.5



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

▨ APPROXIMATE LOCATION OF CONTAMINANT PLUME IN THE CANAL CREEK AQUIFER, OCTOBER 1989.

← – – SIMULATED PARTICLE PATHLINE.

Figure 89. Simulated particle pathlines in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under no pumping alternative.

Simulated head

Simulated head in the Canal Creek aquifer for the three pumpage scenarios is shown in figures 90, 91, and 92. If pumping is simulated at 0.5 Mgal/d (fig. 90), a small cone of depression forms around wells G, H, I, and K. Simulated heads in the cone are less than 2 ft, about 4 ft below heads for nonstressed conditions. The potentiometric gradient toward the eastern part of the study area is increased; however, the depression near the West Branch Canal Creek is not affected.

The cone of depression deepens to 4 ft below sea level when simulated pumping is 1.0 Mgal/d (fig. 91). The cone increases in size and affects water levels in more than half of the study area.

The cone of depression deepens to 14 ft below sea level when simulated pumping is 2.0 Mgal/d (fig. 92), and it enlarges to underlie half of the study area. Water levels in most of the study area, including those near the West Branch Canal Creek, are affected.

Pathline analysis

Pathlines for particles started in the contaminant plumes at a simulated pumping rate of 0.5 Mgal/d are shown in figure 93. Most of the particles that start in the eastern plume move toward wells G, H, I, and K, although a few move toward the Gunpowder River. Particles in the immediate vicinity of well F move toward the well; however, most of the ground-water flow is past well F toward wells with higher pumping rates. Traveltimes along pathlines in the center of the plume are 5 to 15 years. Along the longer pathlines to the south, traveltimes are 75 to 150 years. Particles starting in the western plume move either toward the pumped wells, the West Branch Canal Creek, or the Gunpowder River. Traveltimes are 2 to 15 years along pathlines toward the West Branch Canal Creek and 15 to 100 years toward the Gunpowder River.

At a simulated pumping rate of 1.0 Mgal/d, all of the particles that start in the eastern plume reach the pumped wells (fig. 94). Traveltimes range from 1 to 50 years. The pumped wells capture more particles from the western plume than they capture when the pumping rate is 0.5 Mgal/d. Traveltimes are 10 to 75 years. Traveltimes of the particles from the western plume that continue to discharge to the West Branch Canal Creek and the Gunpowder River are 2 to 75 years.

At a pumping rate of 2.0 Mgal/d, all of the particles in both plumes, except those in the immediate vicinity of the pilot plant, discharge to the pumped wells (fig. 95). Traveltimes range from days in the vicinity of the wells to 60 years along the longest pathlines.

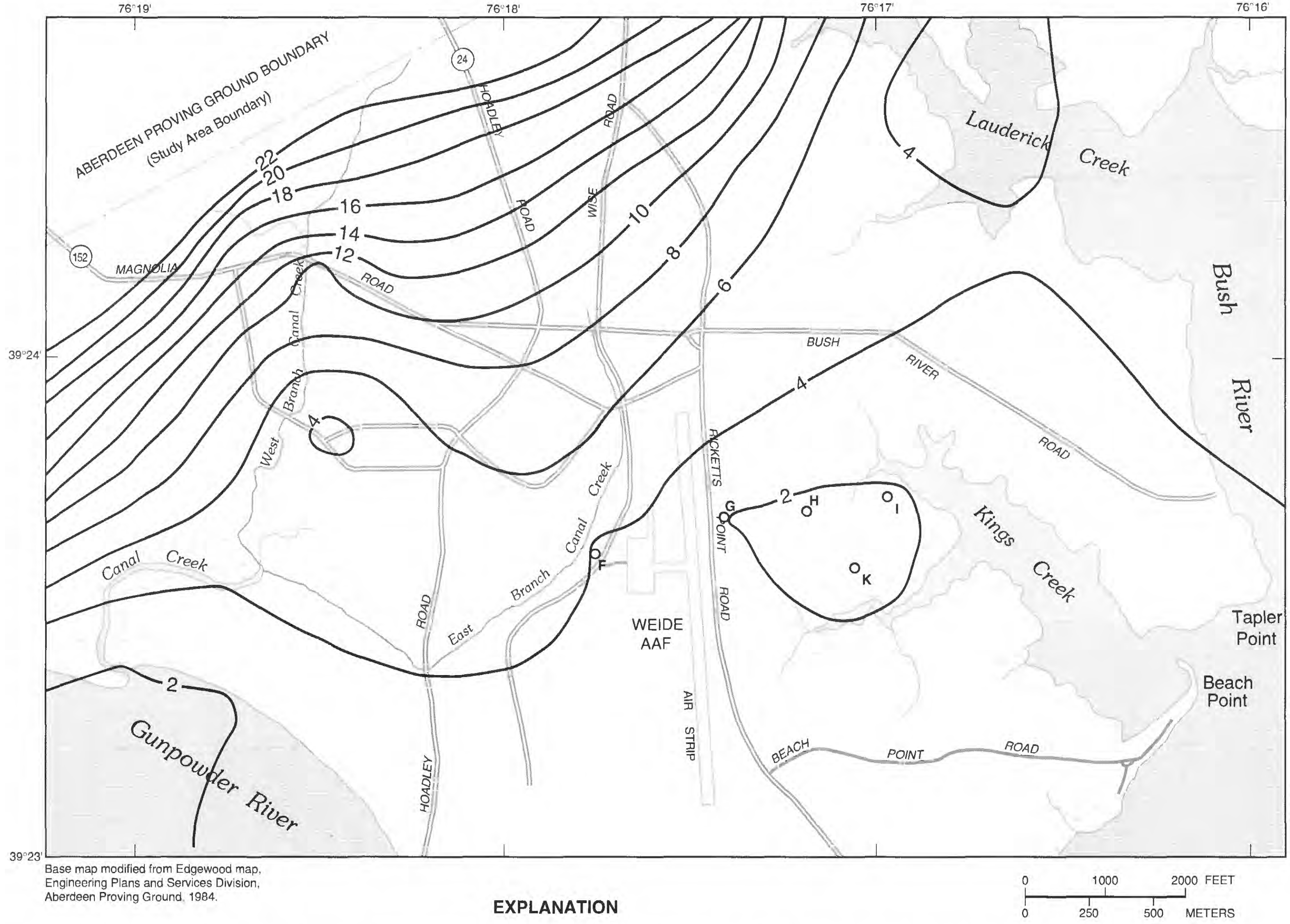
Chemical effects

The water-level decline in the Canal Creek aquifer produced by a pumping rate of 0.5 Mgal/d from existing wells would probably keep a large part of the eastern plume from spreading (fig. 93). However, contaminants would continue to discharge to the West Branch Canal Creek and the Gunpowder River. Even at a pumping rate of 2.0 Mgal/d, a section of the West Branch Canal Creek would continue to receive contaminated ground-water discharge (fig. 95).

Although pumping of existing wells at 2.0 Mgal/d is likely to prevent the contaminant plumes from spreading, decades would be required for complete removal of contaminated ground water from the aquifer. Advective transport of ground water from the western plume to the pumped wells would take as long as 60 years; transport of nonconservative contaminants to the pumped wells would probably take much longer. If pumping wells were added within the western plume area, the contaminated ground water in this plume could probably be withdrawn more efficiently. However, possible movement of surface water from the West Branch Canal Creek into the Canal Creek aquifer would need to be considered if pumping wells were placed in the western plume.

Contaminant concentrations in the ground water would be expected to decline as a result of pumpage because uncontaminated water would be drawn into the plume areas at a faster rate. However, because dissolution of DNAPL's would continue adding dissolved contaminants to the ground water during pumping, the pumpage time required to remediate the ground water would be longer than could be predicted from advective transport of contaminants. Desorption of organic and inorganic species from the aquifer sediments could also contribute low concentrations of contaminants to the ground water during pumping and could cause an increase in the required pumping times.

Pumping would probably cause an increase in the transport rate of dissolved oxygen to the ground water in the eastern contaminant plume. Because the chlorinated VOC's seem to be biodegrading only under anaerobic conditions in the ground water of the Canal Creek area, pumping could result in a decrease in biodegradation rates.



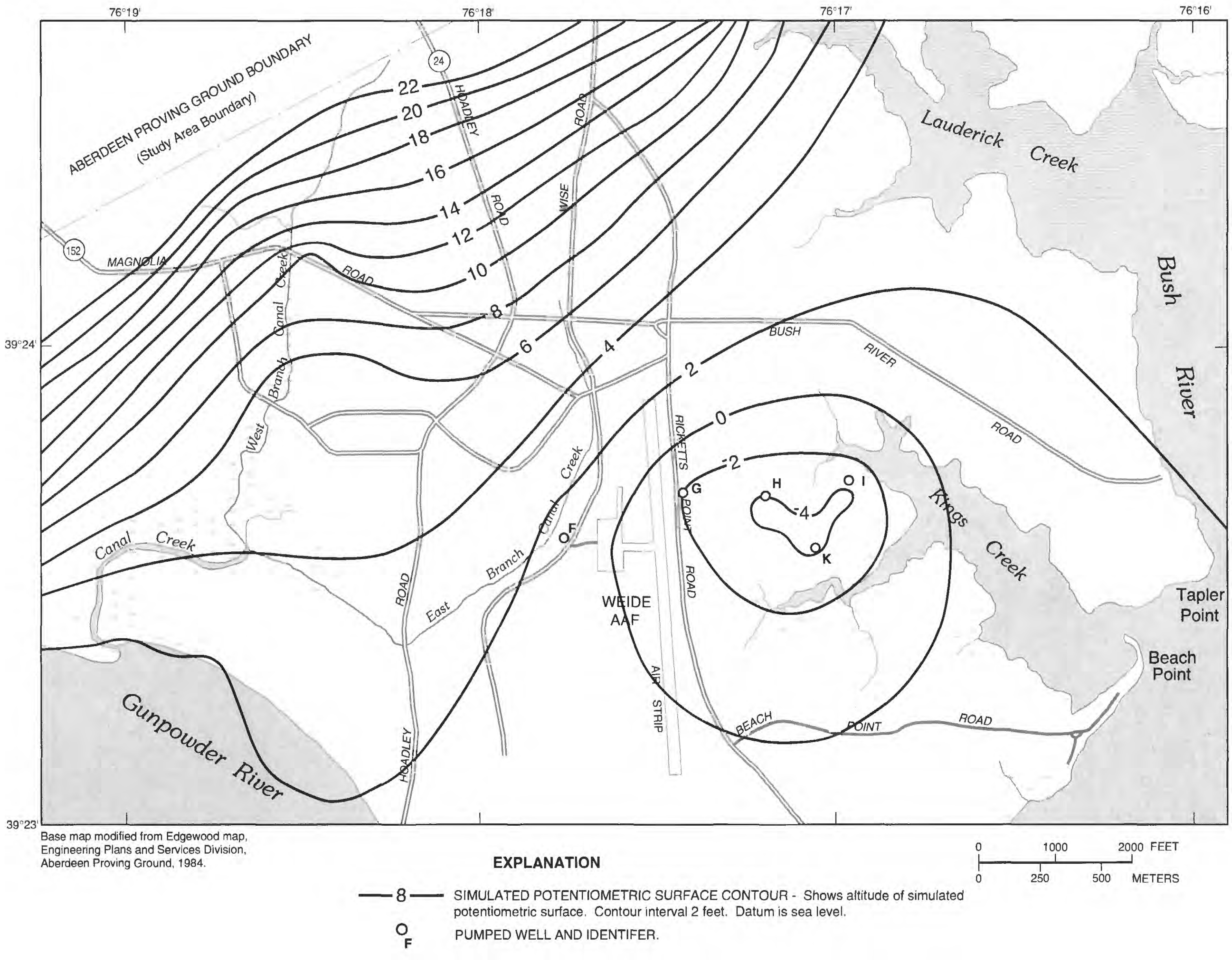
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

EXPLANATION

—— 8 —— SIMULATED POTENTIOMETRIC CONTOUR - Shows altitude of simulated potentiometric surface. Contour interval 2 feet. Datum is sea level.

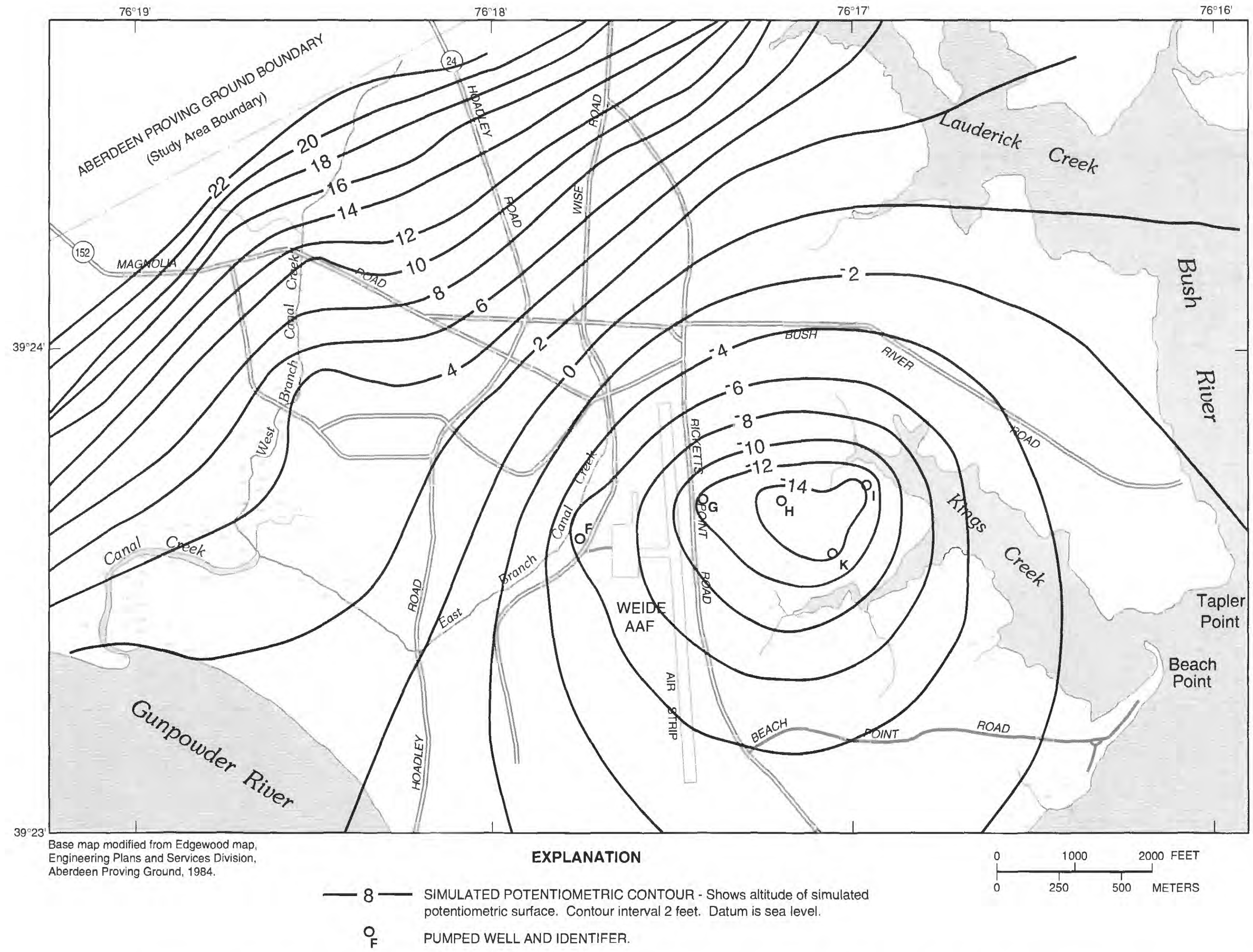
○F PUMPED WELL AND IDENTIFER.

Figure 90. Simulated potentiometric surface in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 0.5 million gallons per day.



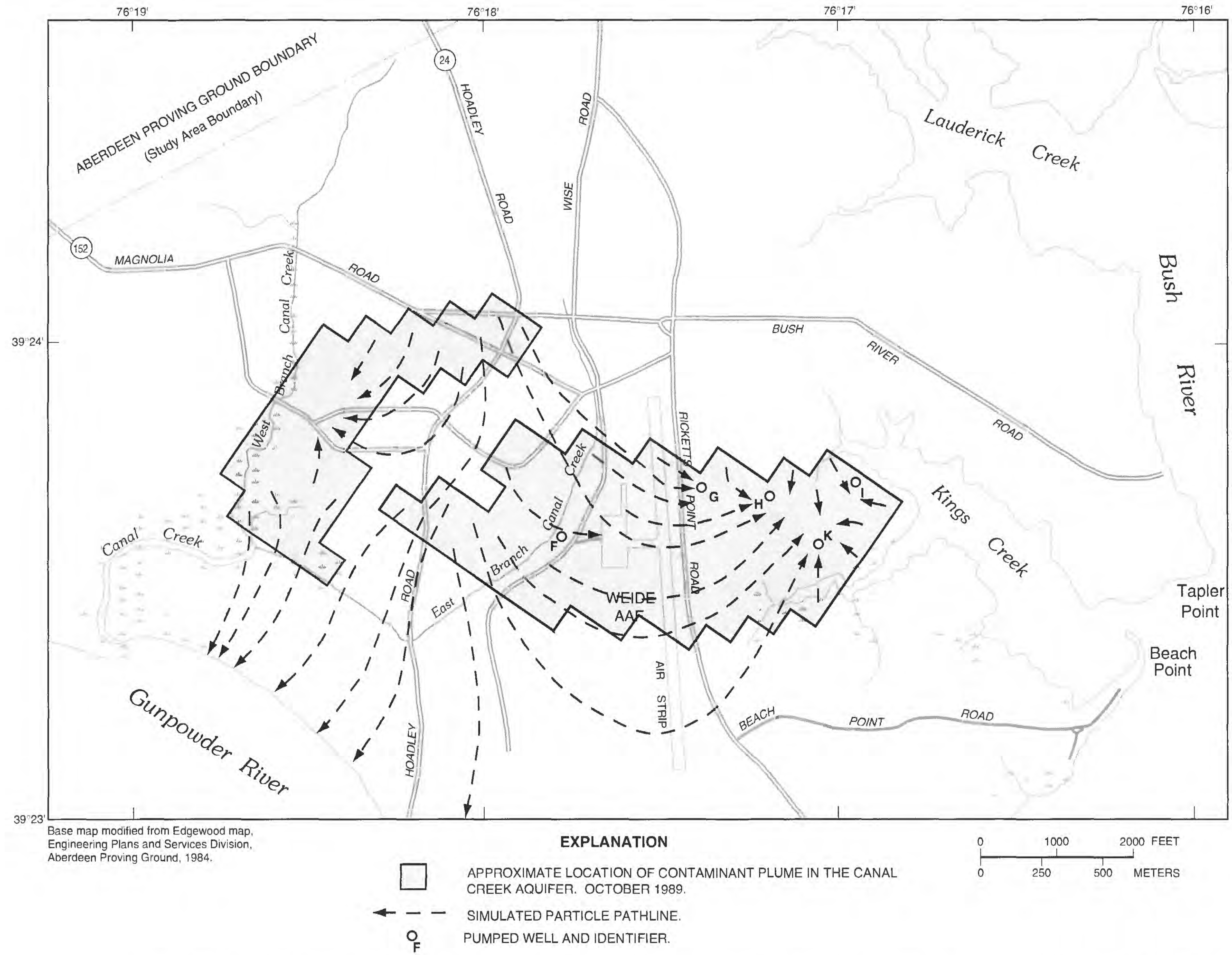
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 91. Simulated potentiometric surface in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 1.0 million gallons per day.



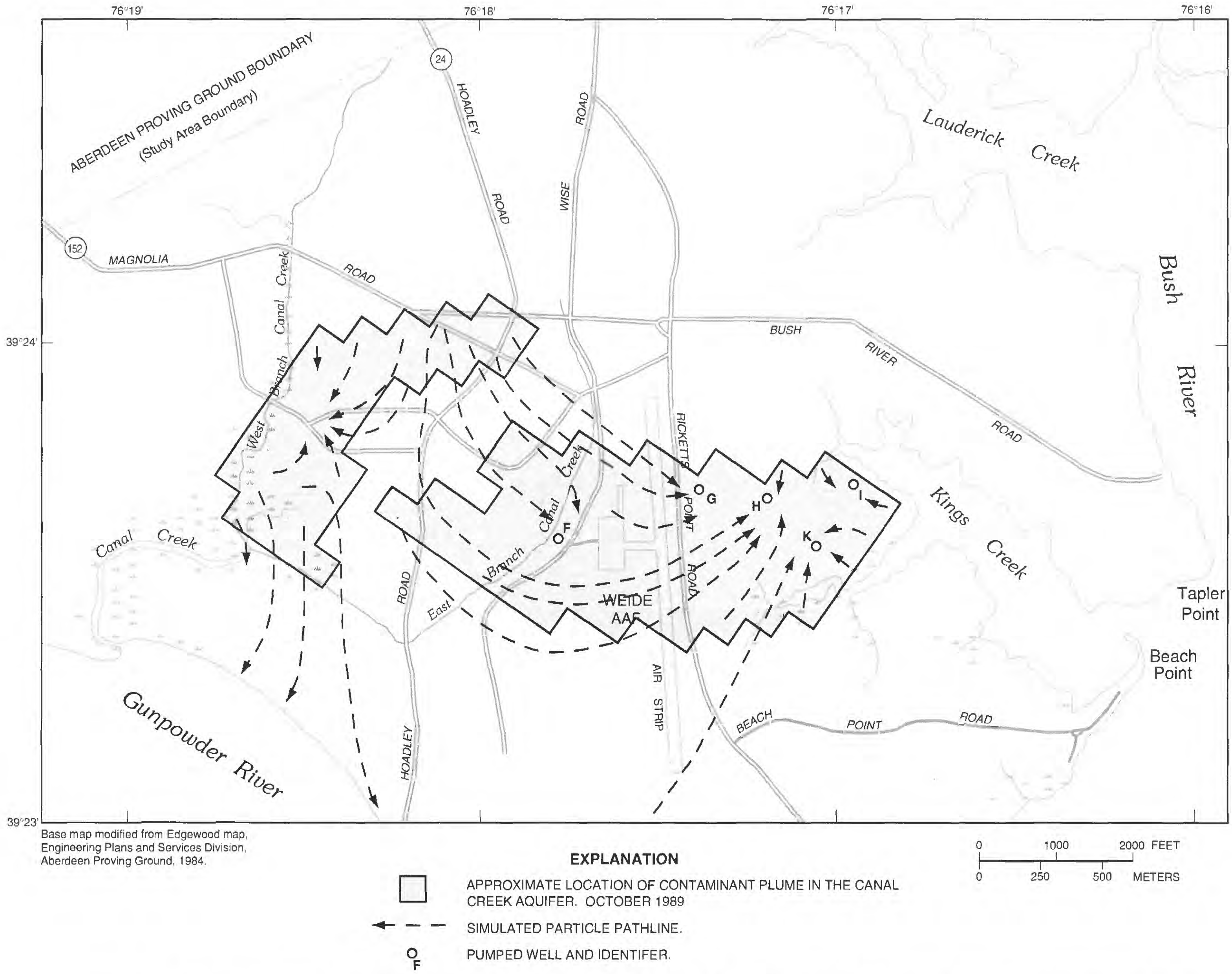
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 92. Simulated potentiometric surface in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 2.0 million gallons per day.



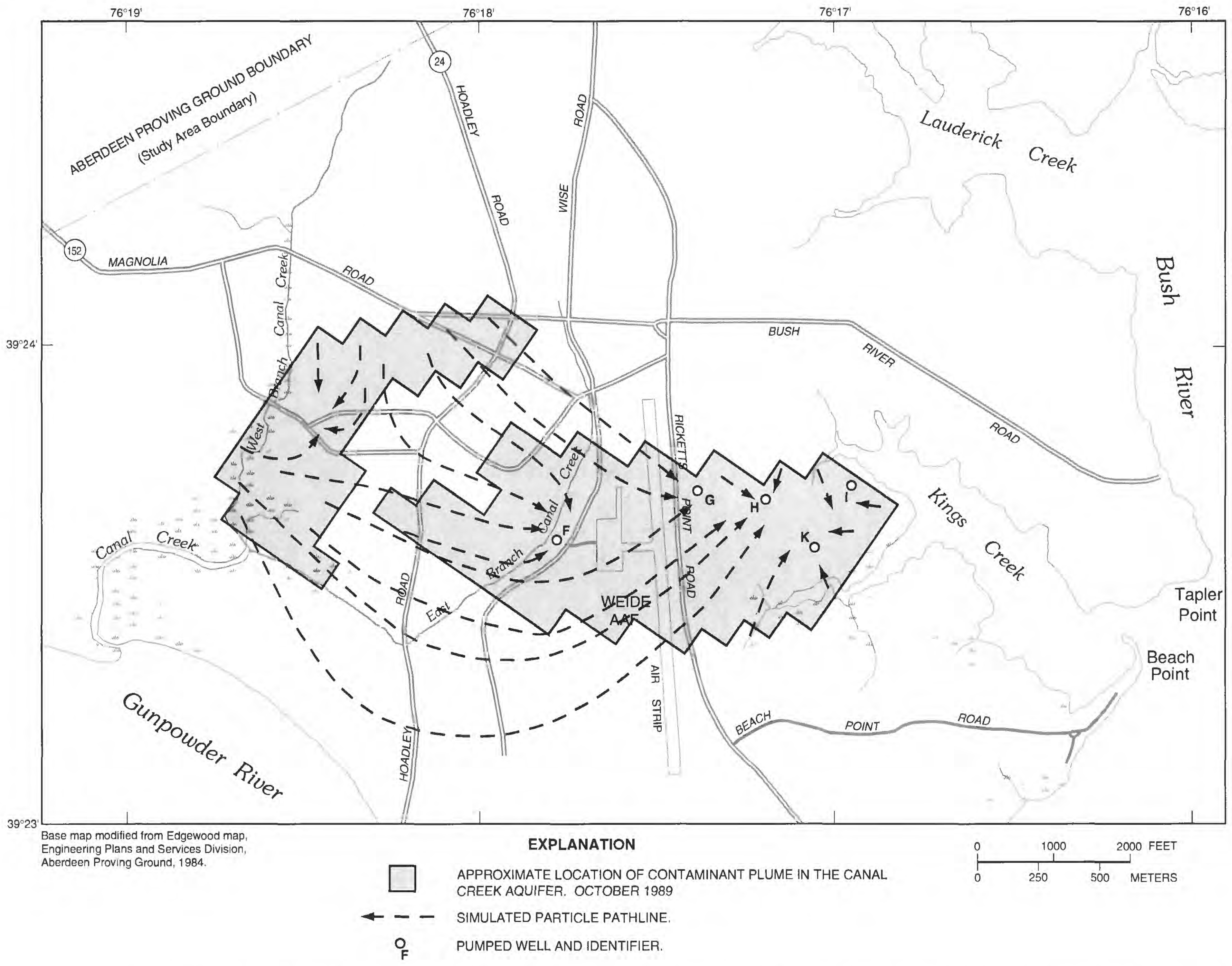
Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 93. Simulated particle pathlines in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 0.5 million gallons per day.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 94. Simulated particle pathlines in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 1.0 million gallons per day.



Base map modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984.

Figure 95. Simulated particle pathlines in the Canal Creek aquifer, Aberdeen Proving Ground, Maryland, under pumping alternative of 2.0 million gallons per day.

Pumpage From Offsite Wells

Harford County owns four production wells screened in the lower confined aquifer; these wells are about half a mile northwest of the Canal Creek area of APG, on Trimble Road. In the Canal Creek model, the wells are located in row 6, column 26 (fig. 72). These wells were installed to investigate the possible use of water from the lower confined aquifer as a supplement to public-water supplies. The wells have not been used because of low yield. Local water managers are also concerned that pumping might cause contaminants to move into the lower confined aquifer from the Canal Creek aquifer (David Drummond, Maryland Geological Survey, oral commun., 1991).

Simulated head

The purpose of this scenario was to simulate the effects of pumpage from the Trimble Road wells; however, at simulated pumping rates higher than 150,000 gal/d, water levels in the model cells containing the pumped wells were below the bottom of the aquifer. During an aquifer test in April 1988, the production wells were pumped at approximately 300,000 gal/d (David Drummond, Maryland Geological Survey, oral commun., 1991). Minor changes in model transmissivity and leakance were made to try and simulate this pumping rate, but the changes had little effect. One possible explanation for the difficulty in simulating a higher pumping rate is leakage into the lower confined aquifer from below, a condition that is not simulated in the model. In the model, the bottom of the lower confined aquifer is considered a no-flow boundary. Information on the lower confined aquifer is scanty; even less is known about deeper aquifers and confining units.

At higher pumping rates (greater than 150,000 gal/d), water levels were below the bottom of the aquifer in the immediate vicinity of the wells; however, the simulations were still run to demonstrate the effects of pumping in the areas surrounding the wells. In these areas, simulated water levels adequately represented conditions observed during the aquifer test. Water levels in model cells more than a half mile away from the pumped well were not affected by simulated pumping rates of 250,000 gal/d. During the aquifer test, water levels in two observation wells half a mile away from the pumped well were not affected by the pumping; the water level in a third well declined by less than half a foot (David Drummond, Maryland Geological Survey, oral commun., 1991).

Pathline analysis

Particle movement was simulated backward from the wells to their recharge areas and forward from the location of the contaminant plumes in the Canal Creek aquifer. In each case, the pumping had no effect on particles in the area of the contaminant plumes. The recharge area for the wells (pumping at 150,000 gal/d) is between the wells and the APG boundary, near Reardon Inlet. Particles started in the contaminant plumes in the Canal Creek aquifer move forward to their discharge areas in Canal Creek and the Gunpowder River in the same manner as in the "no pumpage" scenario.

Particles in the contaminant plumes were not affected by simulated pumpage at rates as high as 250,000 gal/d, even though water levels in the immediate vicinity of the pumping wells were below the bottom of the aquifer. Pathline analysis from a larger scale ground-water-flow model of the Harford County Coastal Plain (prepared by the Maryland Geological Survey) supports this finding (David Drummond, Maryland Geological Survey, oral commun., 1991).

Chemical effects

There is no evidence that pumping from the lower confined aquifer at the Trimble Road site will have any effect on ground-water flow in the Canal Creek aquifer. Unless the lower confining unit is breached, such as by a paleochannel, pumping the Trimble Road wells at their stated capacity is unlikely to cause contamination to move into the lower confined aquifer.

SUMMARY AND CONCLUSIONS

An investigation begun by the U.S. Geological Survey in 1985 has shown that ground water, surface water, and soil are contaminated in the Canal Creek area of Aberdeen Proving Ground, Md. The Canal Creek area has been used since 1917 for production-scale and pilot-scale manufacturing of military-related chemicals, for filling of chemical munitions, and for various support activities such as fabrication and cleaning of military equipment and metal plating. A total of 33 historical sites were identified in this study as possible significant sources of contamination. Most of these sites were located between the West and East Branches of Canal Creek, and chlorinated organic solvents were the most common wastes generated.

Ground-water contamination is widespread in two aquifers that are composed of unconsolidated Coastal Plain sediments: the Canal Creek aquifer and the overlying surficial aquifer. No contamination was detected in the lower confined aquifer, which is separated from the Canal Creek aquifer by a 35- to 65-ft-thick clay unit. One large contaminant plume, referred to here as the "western plume," extends parallel to the West Branch Canal Creek; another plume, referred to here as the "eastern plume," extends eastward from the East Branch Canal Creek. Other smaller contaminated areas also exist in the study area.

Chlorinated volatile organic compounds (VOC's) are the most prevalent ground-water contaminants, although dissolved solids and 13 inorganic constituents were found in excessive concentrations; that is, concentrations were greater than limits given in Federal drinking-water regulations. Excessive concentrations of the inorganic constituents generally were less widespread throughout the study area and less consistent between the four ground-water sampling periods than concentrations of VOC's.

Contaminated ground water was found to contain concentrations of dissolved solids, chloride, iron, fluoride, manganese, and aluminum that exceed secondary maximum contaminant levels (SMCL's); the trace elements antimony, arsenic, beryllium, cadmium, lead, mercury, nickel, and thallium were present in concentrations that exceed primary maximum contaminant levels (MCL's). In addition, zinc and copper were present in the ground water in concentrations that are elevated compared to background concentrations in the study area.

Sources of elevated concentrations of dissolved solids and chloride in the ground water include brackish-water intrusion from the tidal creeks or estuaries and brines used in chlorine manufacturing. Seepage from phossy water ponds is a possible source of elevated dissolved-solids and chloride concentrations in one area, but no historical information could be found on the chloride content of the wastewater discharged to these ponds. Iron and manganese are derived mainly from natural dissolution of minerals and oxide coatings in the aquifer sediment. The elevated concentrations of several of the other minor constituents, including aluminum, antimony, arsenic, and thallium, could be at least partly derived from natural sources.

Anthropogenic sources of the minor inorganic contaminants include (1) aluminum and zinc oxides and chlorides used as catalysts in manufacturing processes, (2) aluminum and zinc compounds used in the filling of smoke, pyrotechnic, and incendiary munitions, (3) metal-plating wastes, and (4) manufacturing and filling of munitions with arsenicals such as lewisite and adamsite. Many of the trace elements, including antimony, lead, cadmium, and thallium, could have been present as impurities in the aluminum, zinc, and iron compounds used in various manufacturing and filling activities.

Because of their widespread distribution and relatively high concentrations, the VOC's 1,1,2,2-tetrachloroethane, trichloroethylene, chloroform, 1,2-*trans*-dichloroethylene, and carbon tetrachloride are considered to be the major ground-water contaminants. Trichloroethylene and 1,1,2,2-tetrachloroethane were the most prevalent contaminants and were detected in about 70 percent of the 93 samples collected from the Canal Creek aquifer during the second sampling period (July-September 1988). Maximum concentrations of the five major VOC's ranged from 650 to 5,800 μg/L during the second sampling period. Concentrations and areal distributions of the major VOC's in the ground water did not change significantly during the study. Additional VOC's that were quantitatively or tentatively identified in the ground water include benzene, chlorinated benzenes, pentachloroethane, and unknown compounds.

Semivolatile organic compounds are not as widely distributed in the ground water as VOC's are. Phthalate esters, which were the most commonly detected semivolatile compounds, are common laboratory contaminants. Nitrobenzene, 1,2,3-trichlorobenzene, and 1,2,4-trichlorobenzene, which were present in the ground water at three or fewer sites, are semivolatile contaminants that were used in military activities. In addition, low concentrations (3.0 to 24 μg/L) of two mustard-degradation products, dithiane and 1,4-oxathiane, were present in the ground water at two well sites. Other semivolatile contaminants that were tentatively reported in some ground-water samples include hexachloroethane, 1,2-dibromoethene, tribromoethene, naphthalene compounds, various compounds related to petroleum fuels, and unknown compounds.

Specific sources of the major organic contaminants found in the ground water are difficult to define because organic solvents were the most commonly used and disposed of chemicals in the Canal Creek area and because many of the manufacturing, filling, and waste-disposal sites were concentrated in a relatively small area. VOC's were used as cleaning, degreasing, and decontaminating agents and as raw products in manufacturing processes.

Some of the historical facilities that are believed to have been primary sources of the VOC's in the ground water include (1) an incendiary bomb and experimental filling plant in building 99, (2) machine shop and metal-plating activities in several buildings (60, 88, 101, and 103), (3) munitions filling, bomb-body degreasing, and equipment cleaning in building 84, (4) pilot-scale manufacturing and research work with chemical agents in the building 87 complex ("pilot-plant"), (5) manufacturing of tear agents in building 58, (6) impregnite manufacturing and clothing impregnating in building 103, and (7) a clothing-impregnating plant in building 73.

Two processes that have affected the distribution, movement, and fate of the VOC's are the sinking of dense nonaqueous-phase liquids (DNAPL's) into the aquifers and microbial degradation. Most of the VOC's present in the ground water have a density greater than that of water in their free-product form and are classified as DNAPL's. DNAPL's released at or near the land surface from spills or waste-disposal sites could have migrated downward into the Canal Creek aquifer where the near-surface clay layer is absent or thin, such as in the outcrop area of the upper confining unit near the West Branch Canal Creek and in the paleochannel area near the East Branch Canal Creek. The apparent persistence of the VOC's in the ground water for decades could be partly accounted for by the continuous dissolution of residual DNAPL's in the aquifers.

Many of the chlorinated VOC's are resistant to microbial degradation under aerobic conditions, but they can be slowly degraded under anaerobic conditions. Microbial degradation products, including 1,2-*trans*-dichloroethylene and vinyl chloride, are widespread only in anaerobic parts of the Canal Creek aquifer in the eastern plume. The ground water is anaerobic near and to the east of the East Branch Canal Creek, where a thick confining unit overlies the Canal Creek aquifer; dissolved oxygen is transported into the aquifer at a slower rate than it is consumed by biogeochemical reactions in this deep, confined part of the aquifer. Near the West Branch Canal Creek, ground water in the Canal Creek aquifer flows in a relatively shallow, unconfined flow system for which recharge rates are rapid. Oxic conditions are maintained in this region of the Canal Creek aquifer, and no significant biodegradation of the VOC's is evident.

Concentrations of 10 inorganic constituents exceeded the acute or chronic toxicity criteria for freshwater aquatic life in surface-water samples collected from the West and East Branches of Canal Creek, Kings Creek, and the Bush River near Beach Point. These inorganic constituents are beryllium, cadmium, copper, cyanide, iron, lead, mercury, silver, thallium, and zinc. Iron, lead, and zinc were detected more frequently than the other inorganic constituents in concentrations that exceed the toxicity criteria. A probable source of the inorganic contaminants detected in the surface water is the remobilization of metals that accumulated in stream bottom sediments from discharge of untreated industrial wastewaters and from discharge of treated sanitary and chemical wastes from a wastewater-treatment plant.

The same VOC's that were major ground-water contaminants were detected in surface-water samples, and discharge of shallow contaminated ground water is probably the major source of these surface-water contaminants. Dissolution of DNAPL's that could still be present in stream bottom sediments is another likely source of the VOC's in the surface water. Phthalate esters, which are common laboratory contaminants, were the only organic compounds detected in the surface-water samples in concentrations that exceeded the toxicity criteria.

Soil samples collected in the Canal Creek area had relatively high concentrations of some trace elements, including lead, zinc, and arsenic, at sites where the same constituents were observed in elevated concentrations in the shallow ground water. Thus, sources of these trace elements are probably the same for the soil and ground water, and leaching of trace elements from the soils is a pathway for contamination of shallow ground water.

Semivolatile organic compounds were the most prevalent organic contaminants in the soil samples, unlike the ground-water and surface-water samples, which mainly contained VOC's. Polycyclic aromatic hydrocarbons, which are ubiquitous contaminants in soils throughout the world from combustion sources, were the most common type of semivolatile organic compound detected in the soil samples. A polychlorinated biphenyl (PCB) compound was detected in one soil sample at a relatively high concentration of 330 μg/g. Relatively low concentrations (0.40 to 0.60 μg/g) of a biodegradation product of the insecticide DDT were detected in three soil samples, and a number of fatty acids and fuel-related hydrocarbons were tentatively identified.

Ground-water flow in the study area was simulated by use of a modular, three-dimensional, finite-difference ground-water-flow model. The model consists of three layers representing the surficial, Canal Creek, and lower confined aquifers. The upper and lower confining units are represented as a vertical leakance between layers. Because more data are available for the Canal Creek aquifer than for the surficial or lower confined aquifers, the model simulates the Canal Creek aquifer in the greatest detail. The model was calibrated to steady-state water levels measured in 23 wells in the surficial aquifer, 55 wells in the Canal Creek aquifer, and 25 wells in the lower confined aquifer. The final calibrated root mean square error between measured and simulated water levels in all 103 wells was 2.0 ft. Because complete records of historical pumpage could not be found, the model was not calibrated to stressed conditions.

The ground-water-flow model was used in conjunction with a particle tracker postprocessor to evaluate the development of contaminant plumes and the hydrologic effects of selected ground-water pumping alternatives in the Canal Creek area. The flow model and particle tracker describe advective flow and do not account for other physical, chemical, and biological processes that affect nonconservative contaminants. The flow model and particle tracker are still useful in identifying contaminant flow directions and discharge points, however, because advection is the primary transport process for mobile contaminants.

Development of contaminant plumes was simulated by use of estimates of pumpage from the 1940's to the 1960's and suspected source areas for contaminants. When water-supply wells were pumped during the 1940's to the 1960's, ground-water flow in the eastern contaminant plume was generally to the east toward the water-supply wells. When pumping stopped, the eastern plume began to move south. Ground-water flow in the western contaminant plume generally was unaffected by the pumping that took place during the 1940's to the 1960's.

A no-pumpage simulation shows that particles originating in the eastern contaminant plume move to the south toward the Gunpowder River, and particles originating in the western plume move to the west and south toward Canal Creek and the Gunpowder River. Infiltration of recharge water and dispersion could cause a decrease, with time, in contaminant concentrations along these pathlines; however, dissolution of DNAPL's in the aquifer sediments could partially counteract this dilution effect.

Remedial pumpage was simulated by use of estimates of full (2.0 Mgal/d), half (1.0 Mgal/d), and quarter (0.5 Mgal/d) capacity of existing water-supply wells. At quarter capacity, some of the particles in the eastern plume are captured by the wells. At half capacity, all of the particles in the eastern plume and some of the particles in the western plume are captured by the wells. At full capacity, all of the particles in both plumes are captured by the wells. Estimated advective traveltime for some particles is more than 60 years in the full-capacity simulation; however, transport and reaction processes affecting the nonconservative contaminants would probably increase the traveltime.

Pumpage from Harford County production wells screened in the lower confined aquifer was simulated to assess the possible effect of this pumpage on contaminant movement in the Canal Creek area. Simulations show that the capture areas for the county wells will not be affected by contamination in the Canal Creek aquifer and that pumping the wells will not affect contaminant movement.

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APPENDIXES

Appendix A1.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Lithologic logs for five well-cluster sites

[Alphanumeric codes enclosed in brackets, at selected horizons, refer to color designations as specified in the Munsell Soil Color Charts (1975)]

Sand grade scale

Grain size (in micrometers)	Term
1,410-2,000	vcU
1,000-1,410	vcL
710-1,000	cU
500- 710	cL
350- 500	mU
250- 350	mL
177- 250	fU
125- 177	fL
88- 125	vfU
62- 88	vfL

Description	Depth (ft)	Thickness (ft)
SITE 12		
Soil, grayish-brown	0.3	0.3
Sand, silty, brown [7.5YR 5/8], (vfL-fU)	2.0	1.7
Sand, brownish-yellow [10YR 6/8], (fL-mL)	4.0	2.0
Sand, pale yellow [2.5Y 7/4], poorly sorted (fL-mU)	5.5	1.5
Sand, white [10YR 8/2], mixed with reddish-brown [2.5YR 3/4], poorly sorted (fU-cL)	8.6	3.1
Sand, light-gray [2.5Y 6/0] to gray [2.5Y 4/0], poorly sorted (fL-cL), wet	9.0	0.4
Sand, gray-green, with reddish-brown streaks, poorly sorted, wet	10.0	1.0
Sand, clayey, poorly sorted	12.3	1.3
Clay, silty, olive-gray [5Y 6/2] to gray [2.5Y 5/0], plastic	14.0	1.7
Sand, pale-olive [5Y 6/3] to light-brownish-gray [2.5Y 6/2], well-sorted (mL-mU), wet	17.6	3.6
Sand, dark-gray [5Y 4/1], (fU-mU), wet; with a sharp upper contact	19.5	1.9
Clay, dark-gray [2.5Y 4/0], plastic, lignitic	24.0	4.5

Description	Depth (ft)	Thickness (ft)
SITE 28		
Sand, brown, loamy; with cobbles and roots	3.8	3.8
Sand, brown, clean, well-sorted (cL); clayey near bottom	8.0	4.2
Clay, white to pink-brown, friable	15.3	7.3
Sand, gray and brown; with irregular purple banding and purple concretions	15.6	0.3
Sand, tan to white, clean, (fU-mL), micaceous	23.8	8.2
No sample	28.8	5.0
Sand, tan, clean; becoming coarser with depth	38.8	10.0
No sample (new borehole location where land surface was at a slightly different altitude.)	63.5	24.7
Clay and sand, thinly laminated, interbedded, contains carbonaceous wood fragments; interbedded with dark-gray, micaceous, silty clay and light-gray, micaceous, fine sand	67.0	3.5
Clay, dark reddish-brown [2.5YR 3/4], gray [N6] and pale-olive [5Y 6/3] mottling, tight, massive; becoming silty with depth	80.0	13.0
Clay, silty and sandy, reddish-brown [5YR 4/3] and light-gray [10YR 7/1] interbedded	84.0	4.0
Clay, silty, dark-gray [N4]	93.0	9.0
Clay, silty, dark-gray [N4]; with thin laminae of gray [5Y 5/1] silt	94.0	1.0
Clay and sand, interbedded, micaceous, lignitic; silty to sandy, very dark gray [5Y 3/1] clay with fine to medium, gray [5Y 5/1] sand	108.0	14.0
Sand, pebbly, gray, (mL-cU), micaceous, lignitic; contains thin (0.5-2.0 in.) beds of silty to sandy, gray clay	138.0	30.0

Appendix A1.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Lithologic logs for five well-cluster sites--Continued

Sand grade scale	
Grain size (in microns)	Term
1,410-2,000	vcU
1,000-1,410	vcL
710-1,000	cU
500- 710	cL
350- 500	mU
250- 350	mL
177- 250	fU
125- 177	fL
88- 125	vfU
62- 88	vfL

Description	Depth (ft)	Thickness (ft)
SITE 36		
Soil	0.5	0.5
Clay, brown	2.5	2.0
Sand, clayey, orange-brown, well-sorted (mL); becoming increasingly sandy toward bottom	3.5	1.0
Sand, tan, poorly sorted (fU-mU); with gravel and cobbles and some red-purple nodules	12.0	8.5
Sand, gray, (mL), micaceous	17.0	5.0
Sand and clay, interbedded, lavender and orange-stained; with sand (mL) and plastic clay	22.0	5.0
Sand, tan, well-sorted (cU); with orange staining	29.0	7.0
No sample (new borehole location where land surface was at a slightly different altitude)	74.0	45.0
Clay, dark-gray, friable; with thin laminae of light-gray (fL) sand	76.0	2.0
Sand, pink-gray to brown-gray, (fL-mL), micaceous; with thin layers of dark-gray to dark brown-clay and lignite layers (0.5-4.0 in.); wet sand at bottom	85.1	9.1
Clay, dark-brown, friable, micaceous, lignitic; with lenses and thin laminae of light brown-gray (fL-fU) sand	86.8	1.7
Clay, sandy, multicolored (silver, red, and brown), hard, micaceous; with light gray to red-stained sand (mU), and large lignite fragments, some coated with pyrite	89.0	2.2
Sand, light brown-gray, (mL-mU), micaceous, lignitic, wet	94.2	5.2
Clay, brown-gray, micaceous, friable	94.7	0.5

Description	Depth (ft)	Thickness (ft)
SITE 139		
Soil, clayey, black to gray	0.8	0.8
Sand and gravel, light-gray to yellowish-brown, (cL-vcU)	9.0	8.2
Sand and gravel, red-brown [2.5YR 4/4] to yellow-brown [10YR 6/6], wet; with white to gray clay lenses towards base	14.0	5.0
Silt, light-gray [5YR 7/1], thin bands of red-brown [2.5YR 5/4]; with gravel at top	16.7	2.7
Clay, silty, light-[10YR 5/1] to dark-gray [2.5Y 4/0]	21.6	4.9
Silt, sandy, gray [10YR 5/1]; with clay lenses	24.0	2.4
Sand, silty, gray [10YR 5/1], wet; with clay lenses	28.0	4.0
Clay, silty, multicolored (gray, olive, gold, and red), dense	44.0	16.0
Clay, sandy, gray [10YR 5/1], red and gold mottling; with sand (fL-mL) becoming coarser, and increasing in moisture content with depth	59.0	15.0
Sand, clayey, light gray-brown, (mL)	60.7	1.7
Sand, multicolored, (fU-mU), wet; becoming coarser with depth; with iron concretions and sparse lenses of clayey sand	84.0	23.3

Appendix A1.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Lithologic logs for five well-cluster sites--Continued

Sand grade scale

Grain size (in microns)	Term
1,410-2,000	vcU
1,000-1,410	vcL
710-1,000	cU
500- 710	cL
350- 500	mU
250- 350	mL
177- 250	fU
125- 177	fL
88- 125	vfU
62- 88	vfL

Description	Depth (ft)	Thickness (ft)
SITE 140		
Soil, sandy, yellow-brown	0.8	0.8
Sand, yellow-brown [10YR 5/6], (mL-cU), poorly sorted; with large quartz rocks near bottom	4.0	3.2
Sand, gravelly, yellow-brown [10YR 6/8] to yellow [10YR 7/6], (mU-cU)	11.6	7.6
Sand and gravel, yellow and red, (mU-cU), moist; with some iron concretions	19.0	7.4
Sand and gravel, yellow and red-brown, (mU-vcU), wet to soupy; with iron-cemented sandstone fragments and iron concretions; sparse small, white clay lenses	29.0	10.0
Clay, multicolored (gray, red, brown), mottled, dense; with sharp upper contact	39.8	10.8
Clay, sandy, dark-gray [7.5YR N4/0], micaceous; with large lignite fragments	44.0	4.2
Clay, dark-gray; amount of large lignite fragments increases with depth	49.0	5.0
Clay, silty, dark-gray to dark red-gray; with sparse lignite fragments	63.1	14.1
Clay, sandy, gray [5YR 4/1], (fU-mL)	65.2	2.1
Clay, silty, dark-gray, lignitic	67.2	2.0
Sand, silty, dark red-gray [5YR 4/2], lignitic	69.0	1.8
Clay, silty, gray [5YR 4/1], lignitic	70.0	1.0
Sand, clayey, gray [5YR 5/1], (fU-mL)	73.9	3.9
Sand and clay, finely laminated; with brown-yellow [10YR 6/8] to white (fL-fU) sand and gray clay; some large, dark-red sandstone fragments	74.0	0.1
Clay, silty, pink-gray [7.5YR 6/2], red and yellow-brown mottling; with small lenses of (fU-mL) sand	79.0	5.0
Sand, tan, soupy; with sparse clay pockets	82.0	3.0

Appendix A2.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Cation exchange capacities and sieve analyses for aquifer-sediment samples collected at well sites

[Depth is in feet below land surface. CEC, cation exchange capacity in milliequivalents per 100 grams. **Aquifers**: S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer. Sieve numbers refer to mesh size for U.S. Standard Sieves: #10, 2,000 micrometer; #18, 1,000 micrometer; #40, 420 micrometer; #60, 250 micrometer; #120, 125 micrometer]

Site number	Depth	Aquifer	CEC	Sieve Analysis					
				Percent Retained					Percent passing
				#10	#18	#40	#60	#120	#120
CC-1	15-20	S	2.1	1.5	3.8	5	32	30	27
CC-1	20-25	S	.41	.26	.57	6.3	70	20	2.5
CC-1	45-50	CC	.42	.05	.18	0	59	38	3.2
CC-2	142-144	LC	.44	.21	1.5	3.9	26	39	30
CC-3	142-144	CC	.68	28	7.5	18	22	12	12
CC-4	79.5-83.5	CC	.75	.45	.49	3.5	38	45	12
CC-4	89-91	CC	.46	37	6.1	16	19	10	12
CC-5	14-19	S	.99	.11	.21	.36	28	65	6.8
CC-5	54-59	CC	5.3	0	.31	7.1	11	43	38
CC-5	70-75	CC	3.2	7.0	4.1	14	29	27	19
CC-7	86-88	CC	1.9	7.7	3.5	14	34	25	15
CC-8	44-49	CC	3.0	0	2.7	15	16	35	31
CC-8	74-79	CC	.55	4.5	.5	5.5	58	21	10
CC-10	9-14	S	1.5	4	.34	8.0	51	26	10
CC-13	24-29	CC	.40	30	12	29	20	6.0	1.7
CC-13	49-54	CC	.67	1.1	1.2	8.0	54	23	13
CC-14	19-24	CC	2.2	60	6.2	13	6.3	5.5	9.4
CC-16	19-24	CC	.64	.06	.22	4.8	42	44	9.4
CC-16	85-87	LC	1.8	0	2.8	8.9	9.9	38	40
CC-17	19-24	CC	1.1	.91	.47	.87	5.0	48	45
CC-17	24-29	CC	.45	25	4.3	10	24	30	6.5
CC-17	99-104	LC	.62	1.4	.56	2.4	44	42	9.5
CC-19	4-9	S	2.4	1.2	6.6	22	26	24	20
CC-19	54-59	CC	2.4	5.2	.95	2.2	26	51	14
CC-20	4-9	S	.40	0	.23	1.9	37	55	5.7
CC-22	41.5-43.5	CC	1.2	.4	.9	12	55	17	15
CC-22	65-70	CC	.62	2.5	1.1	14	53	16	14
CC-23	19-24	S	.22	.8	.32	26	51	18	3.0
CC-25	19-24	CC	.72	4.3	.97	3.4	41	39	11
CC-27	19-24	CC	2.9	14	3.6	15	20	23	24
CC-27	29-39	CC	1.4	2	3.1	9.1	31	33	22
CC-28	15.8-18.5	CC	.61	.88	1.0	.42	20	63	15
CC-29	38.7-43.7	CC	3.4	1.8	5.3	14	27	23	29
CC-29	43.7-48.7	CC	.67	.77	.31	12	54	24	8.4
CC-30	34-39	CC	.36	.07	.76	34	34	16	15
CC-31	24-29	CC	.21	.55	3.0	35	49	10	2.2
CC-32	9-14	S	.47	.89	.44	15	57	24	1.2
CC-33	9-11.5	S	1.7	0	.18	.66	13	72	15
CC-33	11.5-12.5	S	4.3	2.3	2.9	8.7	10	28	47
CC-33	49-54	S	.95	0	2	2.3	9.7	72	14
CC-34	14-19	S	2.9	12	2.4	7.4	21	38	18
CC-35	14-19	S	7.3	12	8.9	11	17	12	38
CC-37	24-29	CC	.72	1.6	1.0	13	48	20	15
CC-38	37-39	CC	.39	0	0	1.3	48	40	10
CC-39	24-27	CC	.30	0	0	1.2	54	36	8.2
CC-39	34-39	CC	.40	0	.27	4.5	64	22	7.8
CC-41	39-44	CC	.32	0	.15	12	62	18	6.3
CC-42	30-34	CC	3.5	0	12	18	12	20	38
CC-43	29-34	CC	.63	0	.17	7.2	43	38	10
CC-44	16.5-18.0	CC	1.4	13	.93	9.2	22	25	29

Appendix A3.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Physical properties of confining-unit-sediment samples collected at well sites

[Depth is in feet below land surface. CEC, cation exchange capacity in milliequivalents per 100 grams. **Geologic units:** UCU, upper confining unit; LCU, lower confining unit; MU, miscellaneous clay/silt layer. **Class:** S, sand; Si, silt; C, clay; L, loam. Liquid limit and plastic limit are expressed as percent, and plasticity index is the difference between these two limits. Plastic limit is the moisture content below which the sediment can no longer be molded. Liquid limit is the moisture content above which the sediment tends to flow similar to a liquid. Shrinkage is in square centimeters]

Site no.	Depth	Geologic unit	CEC	Silt (percent)	Sand (percent)	Clay (percent)	Class	Liquid limit	Plastic limit	Plastic-ity	Shrinkage index
CC-1	63-65	MU	4.3	32	21	47	C	32	22	10	21
CC-1	85-90	LCU	20	36	11	53	C	49	32	17	27
CC-1	90-95	LCU	8.7	51	7	42	SiC	43	29	14	20
CC-2	50-54	LCU	11	42	14	44	SiC	41	23	18	18
CC-3	124-130	UCU	10	32	34	34	CL	26	17	9	15
CC-3	148-150	MU	3.6	34	35	31	CL	20	16	4	16
CC-4	105.5-107.5	LCU	6.0	49	17	34	SiCL	27	15	12	8.3
CC-5	87-89	LCU	22	24	4	72	C	51	28	23	25
CC-5	89-93	LCU	19	24	5	71	C	47	28	19	16
CC-6	92.5-94.5	LCU	6.4	40	24	36	CL	25	18	7	16
CC-10	34-39	UCU	12	40	11	49	SiC/C	30	19	11	18
CC-13	9-14	UCU	8.4	50	12	38	SiCL	30	19	11	20
CC-17	49-59	LCU	17	36	7	57	C	49	25	24	19
CC-18	34-39	UCU	8.6	48	12	40	SiC/SiCL	30	21	9	18
CC-18	57-59	MU	5.6	31	30	39	CL	25	17	8	14
CC-18	83-85	LCU	4.4	34	3	63	C	42	25	17	14
CC-18	87-89	LCU	13	40	2	58	SiC/C	41	26	15	17
CC-18	97-99	LCU	9.4	53	7	40	SiC/SiCL	34	23	11	24
CC-21	14-19	UCU	11	38	10	52	C	35	23	12	18
CC-23	25.2-28	MU	15	35	22	43	C	32	22	10	19
CC-23	34-39	MU	14	41	18	41	SiC	30	22	8	16
CC-27	24-29	MU	5.9	33	45	22	L	23	17	6	15
CC-28	8-13.5	MU	5.0	41	29	30	CL	25	19	6	12
CC-29	19.7-23.7	UCU	7.2	35	42	23	L	23	17	6	13
CC-29	28.7-33.7	UCU	9.7	39	32	29	CL	28	21	7	17
CC-33	4-5	MU	17	53	16	31	SiCL	28	20	8	15
CC-33	22.5-22.9	MU	8.2	34	43	23	L	22	17	5	13
CC-37	13-14	UCU	12	43	27	30	CL	23	16	7	9.8
CC-37	18-19	UCU	12	43	13	44	SiC	33	22	11	16
CC-38	3-4	UCU	16	48	17	35	SiCL	34	17	17	16
CC-38	11-14	UCU	12	45	18	37	SiCL	28	20	8	11
CC-38	45-48	LCU	11	27	37	36	CL	25	16	9	14
CC-39	9-17.5	UCU	7.7	36	36	28	CL	24	17	7	17
CC-39	27-29	MU	3.7	23	49	28	SCL	22	17	5	9.8
CC-40	1-5.4	UCU	12	41	29	30	CL	27	15	12	12
CC-40	11-18	UCU	6.9	38	37	25	L	23	18	5	10
CC-40	33-34	LCU	3.8	30	33	37	CL	26	17	9	14
CC-41	0.5-4.0	UCU	21	34	21	45	C	35	18	17	10
CC-41	51-53	LCU	6.9	42	13	45	SiC	31	21	10	12
CC-42	17-19	UCU	13	38	19	43	C	34	21	13	11

Appendix A4.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Mineralogy of sediment samples collected from aquifers and confining units at well sites

[Mineralogy was analyzed quantitatively by use of X-ray diffraction and is given as percent by volume. Depths are feet below land surface. Dashes indicate mineral not present. **Abbreviations for geologic units:** S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer; UCU, upper confining unit; LCU, lower confining unit]

Geologic unit	Site no.	Depth (feet)	Quartz	Illite[1]	Kaolinite	Montmorillonite	Plagioclase	K-spar	Hematite	Goethite	Gypsum	Pyrite	Aragonite	Carbonates	Others
CC	CC-1	35-40	95	Trace	--	--	--	--	4	--	--	--	--	--	--
CC	CC-1	45-50	98	1	--	--	--	--	--	--	--	--	--	--	--
LCU	CC-1	90-95	50	12	24	3	4	3	4	--	--	--	--	--	--
CC	CC-7	84-88	90	--	--	--	--	--	7	3	--	--	--	--	--
CC	CC-7	106-108	95	2	2	--	--	--	--	--	--	--	--	--	--
UCU	CC-8	44-46	75	6	10	--	--	--	5	3	--	--	--	--	--
CC	CC-16	24-29	97	2	--	--	--	--	--	--	--	--	--	--	Trace amphibole
LC	CC-16	85-87	98	1	<1	--	--	--	--	--	--	--	--	--	--
S	CC-20	8-14	98	<1	--	--	--	--	1	--	--	--	--	--	--
UCU	CC-107	45-46	96	1	2	--	<1	--	--	--	--	--	--	--	--
CC	CC-113	24-27	85	5	6	--	<1	--	2	--	--	--	--	--	--
CC	CC-113	28-29	95	Trace	1	--	--	1	1	--	--	--	--	--	--
LCU	CC-113	63-65	25	10	40	--	3	3	15	--	--	--	--	--	--
S	CC-127	11-13	96	Trace	1	--	--	--	--	--	--	--	--	--	--

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[1] Most of the illite percentages reflect small concentrations of mica (probably muscovite). It is difficult to distinguish between the two, especially at these small concentrations, without more detailed separations and analyses (Steve Sutley, U.S. Geological Survey, Branch of Geochemistry, written commun., 1989]

Appendix A5.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--Concentrations of major and minor inorganic constituents in sediment samples collected from aquifers and confining units at well sites

[Analyzed by induction coupled argon plasma-atomic emission spectrometry (Crock and others, 1983). Concentrations given in units of percent for major constituents or parts per million for minor constituents. Depths are feet below land surface. **Abbreviations for geologic units:** S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer; UCU, upper confining unit; LCU, lower confining unit]

Site no. Depth Geologic unit	CC-1 35-40 CC	CC-1 45-50 CC	CC-1 90-95 LCU	CC-7 84-88 CC	CC-7 106-108 CC	CC-8 44-46 UCU	CC-16 24-29 CC	CC-16 85-87 LC	CC-20 8-14 S	CC-107 45-46 UCU	CC-113 24-27 CC	CC-113 28-29 CC	CC-113 63-65 LCU	CC-127 11-13 S
Major constituents														
Aluminum	0.95	0.27	16	0.70	1.0	8.5	0.67	2.0	0.74	4.0	4.2	1.6	12	1.6
Calcium	.01	.04	.05	.009	.01	.03	.01	.01	.02	.03	.03	.02	.04	.02
Iron	1.8	.25	3.2	9.2	.44	4.5	.41	.23	1.1	.74	1.1	.50	3.3	.61
Potassium	.18	.06	1.8	.17	.23	1.9	.12	.41	.16	1.0	.84	.30	1.1	.32
Magnesium	.03	.02	.21	.03	.03	.31	.02	.07	.03	.15	.12	.04	.12	.09
Sodium	.02	.02	.36	.02	.03	.10	.03	.04	.02	.06	.06	.03	.25	.04
Phosphorus	.01	<.005	.04	.03	<.005	.09	<.005	<.005	.01	.009	.009	<.005	.02	.01
Titanium	.14	.08	.55	.09	.15	.41	.15	.18	.11	.35	.32	.27	.55	.15
Minor constituents														
Manganese	13	8	130	26	16	170	33	17	13	45	22	17	71	48
Silver	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Arsenic	30	<10	<10	10	<10	<10	<10	<10	20	<10	<10	<10	10	<10
Gold	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8
Barium	62	56	600	56	77	300	110	110	58	310	190	100	180	100
Beryllium	<1	<1	4	<1	<1	5	<1	<1	<1	1	<1	<1	3	<1
Bismuth	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cerium	21	11	130	13	17	500	20	34	22	46	46	29	73	32
Cobalt	2	1	150	6	<1	28	7	4	3	31	2	<1	31	4
Chromium	81	9	130	22	14	110	26	28	71	73	59	29	100	25
Copper	18	4	51	8	3	30	6	10	18	75	6	4	33	8
Europium	<2	<2	3	<2	<2	18	<2	<2	<2	<2	<2	<2	<2	<2
Gallium	<4	<4	40	<4	<4	24	<4	5	<4	11	10	4	34	5
Holmium	<4	<4	<4	<4	<4	13	<4	<4	<4	<4	<4	<4	<4	<4
Lanthanum	9	5	62	5	8	220	9	14	9	23	28	15	37	14
Lithium	9	8	250	7	8	29	5	13	10	16	13	10	93	18
Molybdenum	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Niobium	<4	<4	18	<4	<4	10	<4	5	<4	10	8	5	18	<4
Neodymium	9	5	60	<4	7	300	7	13	9	21	22	13	37	13
Nickel	<2	<2	140	6	<2	67	3	7	3	28	3	<2	98	7
Lead	11	5	48	5	5	37	4	6	6	10	9	9	27	8
Scandium	4	<2	29	3	2	20	<2	4	6	14	8	4	23	4
Tin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Strontium	11	8	110	8	11	87	9	16	11	38	37	17	65	17
Tantalum	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
Thallium	<4	<4	20	<4	<4	10	<4	<4	<4	9	7	<4	19	<4
Uranium	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Vanadium	31	9	160	35	20	180	13	31	40	66	72	44	130	32
Yttrium	4	<2	27	2	2	380	3	7	3	13	11	5	21	8
Ytterbium	<1	<1	3	<1	<1	30	<1	<1	<1	2	2	<1	3	1
Zinc	7	3	59	27	5	48	6	36	8	13	5	5	22	16

Appendix A6.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Synoptic water-level measurements at wells

[--, data not collected. **Aquifer**: S, surficial aquifer; CC, Canal Creek aquifer; LC, lower confined aquifer; I, unidentified isolated sand lens]

Local number	Aquifer	Water level, in feet above sea level, on given date				
		08/08/88	12/02/88	04/13/89	07/19/89	10/30/89
CC-1A	S	5.61	6.50	6.77	6.74	6.28
CC-1B	CC	6.35	6.58	7.20	7.38	6.87
CC-1C	CC	6.59	6.66	7.40	7.75	7.19
CC-1D	LC	7.58	7.31	7.93	8.16	--
CC-1E	LC	7.65	7.52	8.02	8.11	8.13
CC-1F	LC	8.68	7.42	8.05	8.23	8.19
CC-2A	CC	1.62	--	2.06	2.56	1.85
CC-2B	LC	7.45	--	7.81	8.11	7.99
CC-2C	LC	5.23	--	5.46	5.73	5.72
CC-3A	CC	4.94	4.38	5.24	5.81	5.31
CC-3B	CC	4.62	4.41	5.34	5.77	5.14
CC-4A	CC	5.50	5.18	5.91	6.28	--
CC-4B	CC	5.38	5.20	5.91	6.28	5.84
CC-5A	S	10.17	11.37	11.60	11.58	10.73
CC-5B	CC	5.48	5.02	6.09	6.40	5.96
CC-5C	CC	5.50	5.85	6.13	6.44	5.97
CC-6A	CC	5.80	5.55	6.49	6.71	6.25
CC-6B	CC	5.81	5.55	6.49	6.77	6.31
CC-6C	LC	5.96	--	--	6.85	6.40
CC-7A.1	CC	4.66	4.54	6.28	6.64	6.18
CC-7A	CC	6.44	6.18	6.04	6.39	5.54
CC-7B	CC	5.46	7.33	6.05	6.39	5.91
CC-8A	I	5.45	5.15	5.99	6.33	5.87
CC-8B	CC	5.40	5.15	6.05	6.40	5.88
CC-8C	CC	5.42	5.17	6.07	6.41	5.90
CC-8D	CC	5.47	5.23	6.12	6.46	5.94
CC-8E	LC	6.05	5.64	6.44	6.67	6.48
CC-9A	S	13.81	14.23	14.70	14.65	14.23
CC-9B	CC	5.42	5.18	5.86	6.31	5.84
CC-10A	S	11.60	12.17	13.89	13.23	12.74
CC-11A	CC	3.36	2.67	3.48	4.11	3.53
CC-11B	CC	3.37	2.66	3.48	4.13	3.52
CC-12A.1	S	8.55	8.74	10.83	10.67	9.80
CC-12A	CC	4.08	3.83	4.52	5.16	4.54
CC-12B	CC	4.32	4.01	4.75	5.16	4.62
CC-13A	CC	7.15	7.17	8.15	8.29	7.71
CC-13B	CC	7.24	7.31	8.29	8.45	7.85
CC-14A	CC	5.96	6.25	6.94	6.94	6.58
CC-14B	CC	7.05	7.31	8.19	8.24	7.74
CC-15A	CC	5.93	6.00	6.75	6.91	6.38
CC-16A	CC	3.24	3.10	4.21	4.03	3.36
CC-16B	CC	2.94	2.62	3.32	3.51	2.97
CC-16C	LC	10.64	10.59	11.19	11.36	11.34
CC-16D	LC	9.67	10.63	11.23	11.38	11.39
CC-17A	CC	3.02	2.74	3.46	3.60	3.11
CC-17B	CC	3.11	2.69	3.20	3.69	3.11
CC-17C	LC	10.48	10.43	11.03	11.20	11.18
CC-18A	CC	7.95	8.07	9.14	9.26	8.65
CC-18B	CC	8.02	8.07	9.21	9.27	8.69
CC-19A	I	25.49	26.22	26.01	26.28	25.49
CC-19B	CC	7.75	7.75	8.65	9.14	8.41
CC-20A	S	6.84	7.51	7.67	7.78	7.34
CC-20B	S	7.70	8.02	9.05	8.81	8.24
CC-20C	CC	8.16	8.20	9.95	9.59	8.81
CC-20D	CC	8.18	8.30	9.24	9.60	8.83
CC-21A	CC	3.48	3.14	3.91	4.04	3.52
CC-22A	S	7.56	8.63	8.92	9.06	8.39
CC-22B	CC	8.02	8.22	9.16	9.51	8.71
CC-22C	CC	8.06	8.24	9.18	9.54	8.73
CC-23A	S	8.98	9.09	10.51	10.72	9.68

Appendix A6.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Synoptic water-level measurements at wells--Continued

Local number	Aquifer	Water level, in feet above sea level, on given date				
		08/08/88	12/02/88	04/13/89	07/19/89	10/30/89
CC-23B	CC	7.13	7.27	8.16	8.47	7.75
CC-25A	CC	5.78	5.94	6.48	6.74	6.26
CC-25B	CC	5.69	5.86	6.38	6.65	6.17
CC-26A	CC	5.91	6.16	6.75	6.99	6.67
CC-26B	CC	5.65	5.77	6.38	6.67	6.14
CC-26C	LC	9.51	9.39	10.01	10.23	10.17
CC-27A	CC	4.02	4.04	4.60	4.96	4.35
CC-27B	CC	4.79	4.86	5.48	5.81	5.14
CC-28A	CC	4.54	4.63	5.15	5.48	4.90
CC-28B	CC	4.59	4.66	5.22	5.56	4.92
CC-28C	LC	9.78	9.78	10.44	10.78	10.53
CC-29A	S	3.53	4.05	4.08	4.08	3.93
CC-29B	CC	5.43	5.39	6.02	6.36	5.91
CC-30A	CC	3.52	3.18	3.98	4.09	3.56
CC-31A	CC	9.39	9.46	10.41	10.77	10.10
CC-32A	S	1.19	.79	1.03	1.51	1.18
CC-32B	S	1.16	.58	1.29	1.85	1.18
CC-33A	S	1.09	.76	.94	1.38	1.12
CC-33B.1	S	.88	.11	1.18	1.87	.93
CC-33B	S	.97	.17	1.25	1.94	1.00
CC-34A	S	.20	.69	1.05	1.61	1.12
CC-35A	S	-3.87	-3.97	-3.40	-3.24	-3.58
CC-36A	S	8.74	9.33	10.11	10.28	9.49
CC-36B	CC	8.50	8.72	9.78	10.15	9.22
CC-36C	CC	7.98	8.16	9.14	9.51	8.67
CC-36D	CC	7.94	8.02	9.02	9.44	8.56
CC-37A	CC	14.68	14.13	16.23	16.94	15.85
CC-38A	CC	14.81	14.22	16.28	17.14	15.96
CC-39A	CC	14.65	14.09	16.13	16.98	15.80
CC-39B	CC	14.70	14.17	16.21	17.04	15.88
CC-40A	CC	14.76	13.19	16.20	17.07	15.93
CC-41A	CC	15.64	15.07	17.33	18.10	16.80
CC-42A	CC	15.83	15.25	17.52	18.31	16.99
CC-43A	CC	15.18	14.56	16.95	17.86	16.27
CC-44A	CC	10.41	10.62	11.07	11.17	10.71
CC-101A	S	6.69	7.95	7.90	8.11	7.32
CC-101B	CC	6.50	6.46	7.51	7.67	7.05
CC-101C	CC	6.27	6.23	7.02	7.29	6.81
CC-102A	CC	5.69	5.47	6.33	6.63	6.14
CC-102B	CC	7.02	6.03	7.39	6.65	6.22
CC-102C	CC	8.81	8.59	9.45	9.80	9.27
CC-104A	CC	4.26	4.87	5.82	6.16	--
CC-104B	CC	5.08	4.88	5.81	6.17	--
CC-104C	CC	5.07	4.86	5.80	6.15	--
CC-106A	CC	4.90	4.90	5.52	5.83	5.40
CC-107A	CC	8.05	8.17	9.26	9.36	8.75
CC-107B	CC	8.06	8.17	9.29	9.40	8.76
CC-108A	CC	8.19	8.31	10.41	9.51	8.90
CC-108B	CC	8.18	8.38	9.39	9.50	8.88
CC-109A	CC	7.53	7.63	8.67	8.80	8.20
CC-109B	CC	6.92	6.97	7.91	8.07	7.52
CC-110A	CC	3.95	3.71	4.53	4.74	4.11
CC-111A	CC	3.05	2.78	3.48	3.65	3.15
CC-111B	CC	3.06	2.78	3.48	3.65	3.17
CC-112A	CC	2.54	2.41	3.08	3.81	2.79

Appendix A6.--Selected hydrogeologic data in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Synoptic water-level measurements at wells--Continued

Local number	Aquifer	Water level, in feet above sea level, on given date				
		08/08/88	12/02/88	04/13/89	07/19/89	10/30/89
CC-113A	CC	5.42	5.51	6.15	6.41	5.84
CC-113B	CC	5.44	5.53	6.16	6.45	5.89
CC-114A	S	2.34	10.51	11.19	11.49	10.62
CC-114B	CC	5.77	5.89	6.47	6.82	6.27
CC-114C	CC	5.74	5.86	6.50	6.78	6.23
CC-115A	CC	6.03	6.08	6.74	7.10	6.54
CC-117A	CC	5.44	5.15	6.08	6.42	5.89
CC-117B	CC	5.45	5.17	6.09	6.43	5.90
CC-118A	CC	7.35	7.45	8.48	8.61	7.99
CC-118B	CC	7.43	7.52	8.54	8.67	8.07
CC-120A	CC	10.16	--	11.91	11.76	11.01
CC-120B	CC	10.15	--	11.89	11.74	11.00
CC-121A	CC	5.41	5.14	6.04	6.41	5.88
CC-121B	CC	5.42	5.13	6.06	6.41	5.88
CC-122A	CC	20.71	20.69	21.81	22.19	21.74
CC-123A	CC	3.79	3.75	4.41	4.87	4.31
CC-123B	CC	3.82	3.84	4.96	6.59	5.46
CC-124A	S	12.44	13.59	13.55	13.78	12.83
CC-124B	CC	7.23	7.40	8.09	8.30	7.75
CC-126A	S	12.28	12.73	15.47	14.36	13.79
CC-127A	S	15.81	16.08	19.93	19.01	17.53
CC-128A	S	16.02	16.63	19.39	18.86	17.68
CC-129A	S	15.34	15.81	18.04	17.80	16.74
CC-130A	CC	7.06	7.14	8.10	8.26	7.66
CC-130B	CC	6.98	7.03	8.00	8.15	7.56
CC-131A	S	--	6.54	8.31	8.32	7.53
CC-132A	S	7.10	6.74	8.95	9.12	8.02
CC-133A	S	9.87	9.52	10.83	11.58	10.51
CC-133B	CC	9.96	9.61	10.92	11.72	10.61
CC-134A	CC	3.66	3.65	4.31	4.77	4.17
CC-134B	CC	3.65	3.64	4.30	4.76	4.16
CC-135A	S	10.21	--	11.12	12.32	11.03
CC-136A	CC	4.62	4.06	5.87	6.19	--
CC-136B	CC	5.25	5.68	5.91	6.19	--
CC-138A	I	23.74	23.77	24.73	24.22	23.78
CC-139A	LC	12.40	12.40	12.94	13.13	13.14
CC-140A	LC	12.72	12.75	13.30	13.47	13.49
CC-W6	CC	7.33	--	8.33	8.49	7.94
CC-W7	CC	5.36	5.09	5.75	6.21	5.76

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Second sampling period (July-September 1988)

[mg/L, milligrams per liter; µg/L, micrograms per liter; deg C, degrees Celsius; µs/cm,microsiemens per centimeter at 25 degrees Celsius; R, replicate sample; B, sample from background well site in Canal Creek aquifer; G, suspected of grout contamination; Re, repeat analysis; U, sample from uncontaminated well site in surficial aquifer; --, not analyzed for]

Local identifier	Sampling date	Comments	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance, (µs/cm)	pH (standard units)	Solids, residue at 180 deg C, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
					CANAL CREEK AQUIFER					
CC-1B	08-18-88		14.0	<0.1	389	6.46	165	21	10	15
CC-1B	08-18-88	R	--	--	--	--	189	22	11	16
CC-1C	08-18-88		14.0	<.1	253	5.48	137	14	7.1	19
CC-3A	07-08-88	G	16.0	<.1	81	5.96	44	9.2	.75	4.8
CC-3B	07-08-88	B	17.0	1.1	58	5.92	42	3.0	.83	6.7
CC-4A	07-13-88	G	14.0	.2	141	6.49	63	5.4	1.7	8.0
CC-4B	07-13-88	G	19.5	.6	304	8.94	147	16	1.9	19
CC-5C	07-13-88		13.5	<.1	277	6.04	16	17	2.3	23
CC-6A	07-12-88	G	26.0	1.4	923	11.4	350	61	.20	34
CC-6B	07-11-88		23.0	.8	229	5.30	140	14	8.0	13
CC-W6	07-13-88		14.0	1.4	57	5.22	38	3.6	.96	7.6
CC-7A.1	08-15-88		15.0	<.1	431	6.25	197	14	5.5	35
CC-7A.1	08-16-88	Re	--	--	--	--	--	--	--	--
CC-7A	08-15-88		15.0	<.1	184	5.79	85	3.8	2.8	16
CC-7A	08-16-88	Re	--	--	--	--	--	--	--	--
CC-7B	08-15-88		24.0	<.1	207	5.81	96	5.7	2.5	16
CC-7B	08-15-88	R	--	--	--	--	103	6.0	2.5	16
CC-8B	08-11-88		14.0	<.1	136	5.44	65	12	1.9	13
CC-8B	08-11-88	R	--	--	--	--	52	4.3	1.8	14
CC-8C	08-11-88		14.0	<.1	202	5.05	135	13	6.3	12
CC-8D	08-11-88		21.0	<.1	127	5.67	72	4.4	1.6	11
CC-9B	08-02-88	B	26.0	1.3	158	7.14	109	12	.89	15
CC-13A	07-20-88		13.5	2.8	1,990	4.46	1,130	34	20	330
CC-13A	07-20-88	R	--	--	--	--	1,100	30	18	260
CC-13B	07-20-88		14.0	.5	66	5.37	55	2.9	.69	6.7
CC-14A	07-19-88		13.5	.2	222	4.66	--	--	--	--
CC-14B	07-19-88		18.0	.3	90	4.97	--	--	--	--
CC-15A	07-21-88		13.5	.6	394	8.27	199	39	1.2	25
CC-16A	07-25-88		16.0	.1	351	5.35	195	8.9	3.5	44
CC-16B	07-25-88		17.0	.2	815	9.07	556	48	6.8	85
CC-16B	07-25-88	R	--	--	--	--	535	54	8.3	90
CC-17A	07-25-88		16.5	.6	234	4.96	135	11	4.9	20
CC-17B	07-26-88		16.0	.6	134	5.97	72	4.6	1.3	12
CC-17B	07-26-88	R	--	--	--	--	70	12	1.3	12
CC-18A	07-18-88		16.0	1.6	2,510	4.34	1,220	46	23	390
CC-18A	07-18-88	R	--	--	--	--	1,230	47	23	310
CC-18B	07-18-88		16.0	2.2	130	5.91	89	13	1.9	9.2
CC-20C	08-19-88		15.0	.2	422	6.05	220	17	6.5	18
CC-20D	08-19-88		15.0	<.1	156	5.78	79	7.0	3.9	10
CC-21A	07-21-88		18.0	1.8	184	5.98	113	12	1.4	19
CC-22B	08-22-88		14.5	<.1	430	6.22	210	32	17	11
CC-22B	08-22-88	R	--	--	--	--	200	32	17	11
CC-22C	08-23-88		15.0	<.1	400	6.60	190	24	8.7	30
CC-23B	07-29-88		15.5	<.1	438	6.22	224	24	11	26
CC-25A	08-01-88		15.5	.6	390	6.08	217	29	8.2	26
CC-25A	08-01-88	R	--	--	--	--	217	28	8.0	25
CC-25B	08-01-88		15.5	<.1	388	6.30	229	25	9.0	33
CC-26A	07-27-88		15.5	.4	347	6.71	214	55	6.9	7.1
CC-26B	07-27-88		16.5	1.8	456	5.78	272	24	12	43
CC-26B	07-27-88	R	--	--	--	--	263	24	12	41
CC-27A	07-29-88		14.0	1.0	403	4.97	317	29	9.2	29
CC-27B	07-29-88		14.0	2.2	542	4.92	347	26	8.4	55
CC-28A	07-28-88		13.0	.4	4,630	4.14	2,610	29	28	810
CC-28A	07-28-88	R	--	--	--	--	2,660	30	29	240
CC-28B	07-28-88		14.5	1.4	1,970	4.07	1,120	18	11	410

Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (μg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Local identifier
3.3	107	92	17	23,000	3.8	0.95	0.03	1.2	CC-1B
3.4	--	85	24	24,000	3.8	.96	<.02	1.2	CC-1B
2.0	21	60	22	3,200	3.2	.12	<.02	.22	CC-1C
6.2	25	.80	6.6	810	4.3	<.10	<.02	.40	CC-3A
1.8	39	.20	3.2	3,700	4.3	<.10	.02	.20	CC-3B
12	79	5.0	3.8	11,000	4.4	.34	.05	.95	CC-4A
41	125	<.20	27	20	5.5	.14	<.02	.64	CC-4B
21	83	34	26	2,400	5.4	.70	.03	1.8	CC-5C
43	194	66	15	40	10	.44	.12	.70	CC-6A
3.3	13	46	25	90	7.9	<.10	<.02	.30	CC-6B
1.1	11	<.20	15	70	3.6	<.10	<.02	1.1	CC-W6
17	74	42	77	22,000	5.1	.36	<.02	.70	CC-7A.1
--	--	--	--	--	--	--	--	--	CC-7A.1
1.2	35	16	29	13,000	5.3	.33	<.02	.62	CC-7A
--	--	--	--	--	--	--	--	--	CC-7A
1.5	53	19	29	20,000	7.5	<.10	<.02	.47	CC-7B
1.5	--	19	24	19,000	7.4	<.10	<.02	<.20	CC-7B
3.7	10	1.5	22	980	7.2	<.10	<.02	<.20	CC-8B
3.5	--	9.5	22	960	7.2	<.10	<.02	<.20	CC-8B
2.0	3	60	17	260	5.5	<.10	<.02	<.20	CC-8C
5.2	30	9.0	17	7,700	7.4	<.10	<.02	<.20	CC-8D
11	88	8.0	6.0	20	4.2	.17	.04	.83	CC-9B
3.4	<1	28	570	20	5.3	<.10	<.02	.47	CC-13A
3.0	--	24	620	20	1.9	<.10	.06	.34	CC-13A
2.8	8	1.0	17	550	2.8	<.10	<.02	.34	CC-13B
--	--	--	--	--	--	--	--	--	CC-14A
--	--	--	--	--	--	--	--	--	CC-14B
7.5	97	48	35	30	3.6	.18	.08	.45	CC-15A
3.4	60	34	60	9,900	6.4	.16	.05	.61	CC-16A
2.8	66	20	220	10	7.1	<.10	.02	.41	CC-16B
2.9	--	22	220	30	8.3	<.10	.04	.39	CC-16B
5.4	6	40	29	110	6.1	.18	.02	.60	CC-17A
12	24	14	14	590	5.1	<.10	.01	.18	CC-17B
12	--	14	14	590	5.4	<.10	<.01	.18	CC-17B
2.8	<1	5.5	740	30	5.3	<.10	<.02	.34	CC-18A
2.9	--	5.5	740	40	5.3	<.10	<.02	.39	CC-18A
6.2	37	8.0	14	20	6.8	<.10	<.02	.46	CC-18B
2.3	61	72	53	10,000	4.3	<.10	<.02	<.20	CC-20C
2.4	20	17	19	230	4.0	<.10	<.02	<.20	CC-20D
12	52	11	23	30	5.8	<.10	.05	.31	CC-21A
1.9	134	68	34	22,000	2.7	<.10	.03	.37	CC-22B
1.9	--	75	31	22,000	2.7	.14	.04	<.20	CC-22B
6.5	116	40	41	15,000	6.6	.15	<.02	.38	CC-22C
4.3	115	68	54	24,000	4.3	.18	<.02	.63	CC-23B
3.9	78	80	38	12,000	3.2	<.10	.06	.36	CC-25A
3.7	--	78	40	11,000	3.3	<.10	.07	.50	CC-25A
5.7	99	72	50	12,000	3.1	<.10	.03	.36	CC-25B
3.2	164	23	15	30	4.1	.13	.05	.61	CC-26A
3.8	57	75	67	40	3.2	<.10	.02	.31	CC-26B
3.7	--	75	66	50	3.0	<.01	<.02	.42	CC-26B
2.6	9	120	38	170	16	<.10	.03	.45	CC-27A
2.3	7	100	91	540	1.9	<.10	<.02	<.20	CC-27B
7.9	<1	190	1,500	240	3.8	<.10	.02	<.20	CC-28A
8.4	--	170	1,600	250	6.8	<.10	.02	.20	CC-28A
4.8	<1	100	660	2,000	5.5	<.10	.02	<.20	CC-28B

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Second sampling period (July-September 1988)--Continued

Local identifier	Sampling date	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Sulfide, dissolved (mg/L as S)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Manganese, dissolved (µg/L as Mn)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Beryllium, dissolved (µg/L as Be)
					CANAL CREEK AQUIFER--Continued					
CC-1B	08-18-88	0.17	<.01	<1.0	0.15	<0.10	1,200	8	49	<1
CC-1B	08-18-88	.09	.01	--	<.10	<.10	1,200	8	53	<10
CC-1C	08-18-88	.14	<.01	<1.0	<.10	<.10	800	<3	10	<1
CC-3A	07-08-88	.10	<.01	<1.0	<.10	--	110	<3	<1	<10
CC-3B	07-08-88	.03	<.01	<1.0	<.10	--	190	<3	<1	<10
CC-4A	07-13-88	.08	<.01	<.5	.10	--	250	5	<1	<10
CC-4B	07-13-88	.07	<.01	<.5	<.10	--	20	<3	<1	<10
CC-5C	07-13-88	.96	<.01	<.5	<.10	--	250	6	<1	<10
CC-6A	07-12-88	.12	.02	<1.0	.30	--	<1	<3	<1	<1
CC-6B	07-11-88	1.3	.01	<1.0	<.10	--	1,400	<3	<1	<10
CC-W6	07-13-88	.41	<.01	<.5	<.10	--	20	3	<1	<10
CC-7A.1	08-15-88	.05	<.01	--	<.10	--	870	6	<1	<10
CC-7A.1	08-16-88	--	--	--	--	--	--	--	--	--
CC-7A	08-15-88	.13	.02	--	<.10	<.10	400	4	2	<10
CC-7A	08-16-88	--	--	--	--	--	--	--	--	--
CC-7B	08-15-88	.06	<.01	--	<.10	<.10	330	7	3	<10
CC-7B	08-15-88	.07	<.01	--	<.10	--	320	4	3	<10
CC-8B	08-11-88	.19	<.01	<1.0	<.10	<.10	160	<3	1	<10
CC-8B	08-11-88	.18	<.01	--	<.10	<.10	150	<3	2	<10
CC-8C	08-11-88	.13	.01	--	<.10	<.10	330	<3	<1	<10
CC-8D	08-11-88	.16	<.01	--	<.10	<.10	200	<3	2	<10
CC-9B	08-02-88	.11	<.01	--	.11	--	130	<3	<1	<10
CC-13A	07-20-88	.59	<.01	--	.30	--	320	<3	<1	<10
CC-13A	07-20-88	.76	<.01	--	.30	--	290	<3	<1	<10
CC-13B	07-20-88	.21	<.01	--	<.10	--	30	<3	<1	<10
CC-14A	07-19-88	--	--	--	--	--	--	--	--	--
CC-14B	07-19-88	--	--	--	--	--	--	--	--	--
CC-15A	07-21-88	.24	.05	--	.46	.14	44	<3	4	<10
CC-16A	07-25-88	.12	.04	--	.16	--	680	<3	2	<10
CC-16B	07-25-88	.26	.02	--	.28	--	4	<3	2	<10
CC-16B	07-25-88	.39	.02	--	.28	--	8	<3	7	<10
CC-17A	07-25-88	.46	.10	--	.12	--	190	<3	<1	<10
CC-17B	07-26-88	.10	.02	--	.12	--	220	<3	<1	<10
CC-17B	07-26-88	.12	.02	--	.11	--	140	<3	<1	<10
CC-18A	07-18-88	.29	<.01	--	.30	--	620	<3	<1	<10
CC-18A	07-18-88	.24	<.01	--	.20	--	630	<3	<1	<10
CC-18B	07-18-88	.35	.01	--	.10	--	30	<3	<1	<10
CC-20C	08-19-88	1.7	<.01	--	.10	--	71	<3	4	<10
CC-20D	08-19-88	.10	<.01	--	<.10	--	530	3	<1	<10
CC-21A	07-21-88	.20	.02	--	.13	--	39	<3	<1	<10
CC-22B	08-22-88	.14	.02	<1.0	.19	<.10	1,400	7	5	<10
CC-22B	08-22-88	.20	.01	--	.22	<.10	1,400	6	5	<10
CC-22C	08-23-88	.16	.02	--	.48	<.10	1,000	5	<1	<10
CC-23B	07-29-88	.26	.01	--	.16	--	260	7	26	<10
CC-25A	08-01-88	.10	<.01	--	.19	--	56	<3	14	<10
CC-25A	08-01-88	.05	<.01	--	.18	--	54	4	9	<10
CC-25B	08-01-88	.06	<.01	--	.14	--	300	<3	3	<10
CC-26A	07-27-88	.44	<.01	--	.26	--	89	<3	<1	<10
CC-26B	07-27-88	.17	<.01	--	.12	--	400	<3	<1	<10
CC-26B	07-27-88	.13	<.01	--	.11	--	390	<3	<1	<10
CC-27A	07-29-88	.25	<.01	--	.28	<.10	740	<3	<1	<10
CC-27B	07-29-88	.17	<.01	--	.46	<.10	1,200	<3	<1	<10
CC-28A	07-28-88	.13	.01	--	.90	.24	790	<3	<1	<10
CC-28A	07-28-88	.10	.01	--	.88	.30	820	<3	<1	<10
CC-28B	07-28-88	.11	.01	--	.15	.11	980	<3	<1	<10

Boron, dissolved (μg/L as B)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)	Copper, dissolved (μg/L as Cu)	Lead, dissolved (μg/L as Pb)	Mercury, dissolved (μg/L as Hg)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Zinc, dissolved (μg/L as Zn)	Local identifier
210	6	<1	<1	3	<0.5	5	<1	14	CC-1B
210	10	<1	9	2	<.5	6	<1	21	CC-1B
<100	1	<1	2	4	<.5	10	<1	22	CC-1C
10	<1	2	1	31	<.5	7	<2	70	CC-3A
10	2	2	<1	<1	<.5	5	<2	20	CC-3B
20	3	<1	<1	2	<.5	<1	<2	10	CC-4A
10	<1	<1	<1	2	<.5	1	<2	3	CC-4B
30	4	<1	7	<1	<.5	10	<2	70	CC-5C
10	<1	3	5	<1	<.5	5	<1	<10	CC-6A
10	<1	<1	5	<1	<.5	30	1	30	CC-6B
60	<1	2	3	1	<.5	7	<2	50	CC-W6
<100	5	<1	<1	8	<.5	8	<1	11	CC-7A.1
--	--	--	--	--	--	--	-	--	CC-7A.1
<100	4	<1	2	3	<.5	4	<1	37	CC-7A
--	--	--	--	--	--	--	-	--	CC-7A
<100	5	<1	<1	3	<.5	1	<1	<10	CC-7B
<100	5	<1	<1	2	<.5	2	<1	17	CC-7B
<100	<1	<1	<1	3	<.5	59	<1	170	CC-8B
<100	<1	<1	2	2	<.5	60	<1	100	CC-8B
<100	<1	<1	4	3	<.5	91	<1	130	CC-8C
<100	2	<1	2	<1	<.5	6	<1	22	CC-8D
30	<1	<1	<1	<1	<.5	1	<1	15	CC-9B
30	2	4	30	2	<.5	220	<2	290	CC-13A
10	2	4	30	2	<.5	190	<2	260	CC-13A
20	<1	<1	1	1	<.5	10	<2	30	CC-13B
--	--	--	--	--	--	--	- -	--	CC-14A
--	--	--	--	--	--	--	- -	--	CC-14B
30	<1	2	3	2	.9	3	1	58	CC-15A
120	3	1	<1	2	.8	12	<1	48	CC-16A
40	<1	<1	2	<1	.9	3	<1	18	CC-16B
40	<1	2	1	3	.9	6	<1	140	CC-16B
90	<1	2	18	1	.8	48	<1	70	CC-17A
30	1	<1	10	<1	.8	16	<1	38	CC-17B
120	<1	2	9	1	.8	16	<1	35	CC-17B
10	3	4	70	5	<.5	190	<2	310	CC-18A
20	3	4	70	12	<.5	190	<2	370	CC-18A
20	<1	<1	3	<1	<.5	10	<2	20	CC-18B
<100	3	1	1	3	<.5	<1	2	14	CC-20C
<100	1	1	1	1	<.5	6	<1	22	CC-20D
120	<1	2	2	<1	.8	23	<1	24	CC-21A
110	6	<1	<1	<1	<.5	5	<1	12	CC-22B
110	5	<1	<1	<1	<.5	4	<1	<10	CC-22B
100	4	<1	<1	2	<.5	<1	<1	55	CC-22C
130	10	1	16	<1	<.5	<1	<1	26	CC-23B
110	3	<1	2	2	<.5	<1	<1	19	CC-25A
--	3	<1	<1	<1	<.5	<1	<1	<10	CC-25A
90	3	<1	<1	<1	<.5	<1	<1	33	CC-25B
630	<1	<1	4	1	<.5	4	<1	32	CC-26A
210	3	<1	<2	<1	<.5	9	<1	860	CC-26B
210	3	<1	2	<1	<.5	9	<1	850	CC-26B
180	<1	2	15	3	<.5	51	<1	110	CC-27A
20	<1	1	12	<1	<.5	34	<1	55	CC-27B
80	6	3	180	65	<.5	69	<1	870	CC-28A
90	6	2	190	67	<.5	72	<1	880	CC-28A
130	6	2	22	2	<.5	38	<1	1,400	CC-28B

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Second sampling period (July-September 1988)--Continued

Local ident-ifier	Sampling date	Comments	Temper-ature, water (deg C)	Oxygen, dis-solved (mg/L)	Spe-cific con-duct-ance, (µs/cm)	pH (stand-ard units)	Solids, residue at 180 deg C, dis-solved (mg/L)	Calcium dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)
CANAL CREEK AQUIFER--Continued										
CC-29B	08-01-88		14.5	0.10	160	6.01	132	8.7	0.33	23
CC-30A	07-21-88		16.5	1.2	134	5.11	79	7.6	2.9	11
CC-36B	08-22-88		14.0	<.10	513	6.30	180	21	16	28
CC-36C	08-22-88		15.0	<.1	436	6.21	180	34	15	8.5
CC-36D	08-23-88		14.5	<.10	70	6.28	53	6.8	1.2	5.5
CC-36D	08-23-88	R	--	--	--	--	54	6.8	1.2	5.5
CC-39A	09-08-88		14.5	1.8	390	5.63	--	--	--	--
CC-39B	09-08-88		14.0	.40	100	5.25	--	--	--	--
CC-42A	09-08-88		13.5	4.7	341	4.84	--	--	--	--
CC-101B	08-17-88		15.0	.5	511	6.80	298	68	10	11
CC-101C	08-17-88		25.0	<.10	239	5.87	124	25	5.4	11
CC-102A	08-16-88		14.0	<.10	--	--	133	7.9	5.0	12
CC-102A	08-17-88	Re	14.0	<.10	201	5.72	145	23	5.8	11
CC-102B	08-16-88		14.0	.20	221	4.92	226	20	2.7	46
CC-102C	08-16-88		23.0	.4	216	5.29	130	14	6.8	12
CC-104A	08-12-88		13.5	<.10	86	5.40	40	2.9	.86	7.2
CC-104B	08-12-88		15.0	<.10	73	5.68	32	7.5	.84	5.1
CC-104C	08-12-88		20.0	.40	112	6.25	--	--	--	--
CC-106A	07-13-88		19.5	<.10	636	11.2	--	--	--	--
CC-107A	07-15-88	G	15.0	.20	1,130	10.3	648	9.8	.73	210
CC-107B	07-15-88		14.0	.80	3,660	5.11	2,090	70	32	570
CC-108A	07-15-88		15.5	1.8	395	6.28	269	23	13	32
CC-108B	07-15-88	G	15.5	1.4	436	6.50	267	16	5.4	38
CC-109A	07-19-88		16.5	1.9	439	5.68	278	22	8.0	44
CC-109B	07-20-88	G	16.0	<.10	621	11.2	255	23	.69	45
CC-110A	07-21-88	G	14.5	<.10	412	10.8	239	17	.17	38
CC-111A	07-26-88		16.0	2.1	126	5.27	81	7.4	1.8	12
CC-111B	07-26-88		16.0	.30	108	4.87	67	4.6	2.3	9.9
CC-112A	07-26-88		16.0	<.10	56	5.12	38	1.8	.93	6.2
CC-113A	07-28-88		16.0	.20	738	5.41	442	23	9.5	98
CC-113B	07-28-88		16.5	1.8	351	5.62	217	12	6.2	35
CC-114B	07-27-88		16.0	1.9	439	6.25	245	16	6.3	35
CC-114C	07-27-88		16.5	1.8	395	4.85	250	17	12	32
CC-115A	07-26-88		18.5	<.10	394	5.60	238	30	8.1	18
CC-117A	08-10-88		14.0	<.10	185	5.14	106	13	6.8	9.1
CC-117B	08-11-88		21.5	<.10	125	6.41	48	8.7	2.7	3.4
CC-118A	07-18-88		16.0	4.2	2,640	5.52	1,410	36	21	450
CC-118B	07-18-88		16.0	1.0	1,030	5.21	550	32	16	100
CC-120A	07-12-88		17.5	.70	310	5.32	200	13	9.9	27
CC-120B	07-12-88	G	18.0	.60	351	9.73	230	22	2.4	32
CC-121A	07-11-88	B	13.0	1.0	151	5.51	90	10	3.4	11
CC-121B	07-11-88	B	18.5	.60	160	6.25	100	19	2.2	7.0
CC-122A	08-03-88	B	14.0	.60	311	6.16	206	7.5	4.8	41
CC-123A	07-14-88	B	17.0	--	99	5.50	84	1.7	.66	12
CC-123A	07-14-88	B,R	--	--	--	--	62	26	.72	13
CC-123B	07-14-88	B	22.5	1.2	160	5.69	115	13	.96	18
CC-124B	07-13-88	G	15.0	.20	447	6.60	268	26	8.7	20
CC-130A	07-20-88		16.0	<.10	307	5.74	197	9.5	3.5	40
CC-130B	07-21-88		15.0	1.5	2,970	9.12	1,620	41	12	550
CC-133B	08-23-88		17.0	4.5	512	5.05	274	17	12	51
CC-134A	07-14-88	B	15.0	4.2	68	5.07	45	4.6	1.3	6.0
CC-134B	07-14-88	B	15.0	.90	71	5.58	39	3.6	.96	4.2
CC-136A	08-10-88	B	14.5	<.10	87	5.78	32	2.4	.81	7.2
CC-136A	08-10-88	B,R	--	--	--	--	34	2.3	.83	7.3
CC-136B	08-10-88	B	19.0	.40	97	6.15	48	7.8	1.5	2.7

Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Local identifier
8.6	49	6.0	33	410	0.87	0.14	<0.01	0.52	CC-29B
2.0	11	20	13	1,600	5.1	<.10	.02	.34	CC-30A
2.3	250	38	41	51,000	2.4	.24	.03	.52	CC-36B
4.6	219	31	17	36,000	2.9	.46	.10	.85	CC-36C
5.1	42	14	1.8	5,400	3.9	<.10	.02	.45	CC-36D
5.0	--	14	2.4	5,400	3.9	<.10	<.02	.39	CC-36D
--	--	--	--	--	--	--	--	--	CC-39A
--	--	--	--	--	--	--	--	--	CC-39B
--	--	--	--	--	--	--	--	--	CC-42A
3.3	216	55	19	290	14	1.9	.02	2.1	CC-101B
4.3	105	12	21	2,900	6.8	.14	<.02	<.20	CC-101C
9.0	3	62	6.0	180	22	<.10	<.02	.25	CC-102A
8.8	12	65	6.6	80	24	<.10	<.02	<.20	CC-102A
37	6	62	16	30	7.4	.20	.20	.40	CC-102B
2.9	14	50	19	550	5.1	<.10	<.02	<.20	CC-102C
3.2	10	11	10	5,700	5.5	<.10	<.02	<.20	CC-104A
2.1	22	5.0	7.8	100	7.7	<.10	<.02	<.20	CC-104B
--	53	--	--	--	--	--	--	--	CC-104C
--	--	--	--	--	--	--	--	--	CC-106A
160	326	8.5	250	10	3.1	.67	.04	.67	CC-107A
14	21	4.0	1,300	460	5.2	<.10	.02	.30	CC-107B
22	98	85	25	70	6.4	<.10	.02	.37	CC-108A
52	113	55	20	50	5.5	.17	.17	.58	CC-108B
10	27	6.0	120	20	5.4	<.10	<.02	.18	CC-109A
50	169	5.5	54	20	4.3	.70	.03	2.1	CC-109B
52	220	19	14	20	.62	--	.16	--	CC-110A
2.3	14	7.0	23	<10	5.1	<.10	<.01	.33	CC-111A
1.4	4	11	17	110	5.3	<.10	<.01	.23	CC-111B
.89	6	<.20	12	1,400	5.0	<.10	.01	.18	CC-112A
2.4	16	160	130	30	4.6	<.10	<.01	.27	CC-113A
15	35	25	63	60	5.6	<.10	.02	<.20	CC-113B
27	70	62	52	250	.48	.13	.04	.36	CC-114B
3.8	6	60	69	30	5.8	<.10	.02	.13	CC-114C
17	30	100	50	4,000	5.6	<.10	.02	.18	CC-115A
1.8	8	60	11	120	6.4	<.10	<.02	<.20	CC-117A
1.7	64	20	3.6	14,000	5.1	<.10	<.02	<.20	CC-117B
5.9	35	22	870	30	4.6	<.10	.02	.57	CC-118A
12	12	<.20	290	40	5.5	<.10	<.02	.40	CC-118B
5.0	12	95	34	590	7.0	<.10	<.02	.30	CC-120A
54	155	34	12	20	5.0	<.10	.16	.20	CC-120B
3.0	23	26	13	50	6.8	<.10	<.02	.50	CC-121A
1.3	56	11	11	3,300	6.7	<.10	.03	.40	CC-121B
2.7	59	48	36	4,700	6.0	<.10	.06	.58	CC-122A
.85	20	7.5	18	3,800	.80	.20	.02	.37	CC-123A
.96	--	5.0	15	4,100	6.6	.18	<.02	.66	CC-123A
2.4	39	14	15	500	8.9	<.10	.03	.12	CC-123B
53	176	80	11	9,100	8.3	.24	<.02	1.0	CC-124B
24	58	30	57	420	6.1	<.10	<.02	.27	CC-130A
66	124	18	620	20	1.6	.15	.07	.55	CC-130B
4.8	5	40	110	40	3.8	<.10	.04	.66	CC-133B
1.3	8	3.0	8.2	220	8.3	<.10	<.02	.49	CC-134A
1.8	21	1.0	5.0	70	6.2	<.10	.02	.42	CC-134B
1.1	29	12	7.2	7,500	5.2	<.10	<.02	<.20	CC-136A
1.1	--	18	6.6	7,600	5.2	<.10	.02	<.20	CC-136A
1.9	52	17	3.6	8,100	6.2	<.10	.03	<.20	CC-136B

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Second sampling period (July-September 1988)--Continued

Local identifier	Date	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Sulfide, dissolved (mg/L as S)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Manganese, dissolved (µg/L as Mn)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Beryllium, dissolved (µg/L as Be)
					CANAL CREEK AQUIFER--Continued					
CC-29B	08-01-88	<0.030	<0.010	--	0.12	0.19	38	<3	<1	<10
CC-30A	07-21-88	.450	<.010	--	<.10	--	150	<3	<1	<10
CC-36B	08-22-88	.140	<.010	--	.22	<.10	1,700	12	44	<10
CC-36C	08-22-88	.150	<.010	<1.0	.18	<.10	980	9	9	<10
CC-36D	08-23-88	.140	<.010	--	<.10	<.10	260	<3	<1	<10
CC-36D	08-23-88	.120	<.010	--	<.10	--	260	<3	<1	<10
CC-39A	09-08-88	--	--	--	--	--	--	--	--	--
CC-39B	09-08-88	--	--	--	--	--	--	--	--	--
CC-42A	09-08-88	--	--	--	--	--	--	--	--	--
CC-101B	08-17-88	.040	.040	--	.11	<.10	820	<3	7	<10
CC-101C	08-17-88	.040	<.010	--	.30	<.10	620	<3	4	<10
CC-102A	08-16-88	.030	<.010	--	.17	--	620	<3	<1	<10
CC-102A	08-17-88	.040	<.010	--	.16	--	640	3	<1	<10
CC-102B	08-16-88	.050	<.010	--	.24	<.10	170	<3	<1	<10
CC-102C	08-16-88	.260	<.010	--	<.10	<.10	270	<3	<1	<10
CC-104A	08-12-88	.110	<.010	--	<.10	<.10	200	<3	<1	<10
CC-104B	08-12-88	.080	<.010	--	<.10	.10	140	<3	<1	<10
CC-104C	08-12-88	--	--	--	--	--	--	--	--	--
CC-106A	07-13-88	--	--	--	--	--	--	--	--	--
CC-107A	07-15-88	.050	.020	<.5	.30	--	<1	<3	<1	<10
CC-107B	07-15-88	.230	<.010	<.5	<.10	--	1,300	<3	<1	<10
CC-108A	07-15-88	.730	<.010	<.5	<.10	--	2,000	<3	<1	<10
CC-108B	07-15-88	.640	.020	<.5	.20	--	660	<3	<1	<10
CC-109A	07-19-88	.260	<.010	--	<.10	--	260	<3	<1	<10
CC-109B	07-20-88	.090	.010	--	.20	--	2	<3	<1	<10
CC-110A	07-21-88	--	--	--	.19	--	3	<3	2	<10
CC-111A	07-26-88	.840	.020	--	<.10	--	36	<3	<1	<10
CC-111B	07-26-88	.270	<.010	--	<.10	--	71	<3	<1	<10
CC-112A	07-26-88	.040	<.010	--	<.10	--	97	<3	<1	<10
CC-113A	07-28-88	.080	<.010	--	.11	--	750	<3	<1	<10
CC-113B	07-28-88	.140	<.010	--	<.10	--	220	<3	<1	<10
CC-114B	07-27-88	1.10	<.010	--	.11	--	330	<3	<1	<10
CC-114C	07-27-88	1.80	<.010	--	<.10	--	480	<3	<1	<10
CC-115A	07-26-88	.030	<.010	--	.10	--	250	<3	<1	<10
CC-117A	08-10-88	.250	<.010	--	<.10	--	450	<3	<1	<10
CC-117B	08-11-88	.100	<.010	--	.22	--	650	<3	<1	<10
CC-118A	07-18-88	.730	<.010	--	.20	--	280	<3	<1	<10
CC-118B	07-18-88	.330	<.010	--	.20	--	580	<3	<1	<10
CC-120A	07-12-88	.360	.020	<1.0	.30	--	2,100	<3	<1	2
CC-120B	07-12-88	.550	.030	<1.0	.20	--	11	<3	2	<1
CC-121A	07-11-88	.240	<.010	<1.0	<.10	--	1,200	<3	<1	<10
CC-121B	07-11-88	.210	.010	<1.0	.10	--	440	<3	<1	<10
CC-122A	08-03-88	.190	.010	--	.15	--	2,400	<3	<1	<10
CC-123A	07-14-88	.050	.010	<.5	<.10	--	170	<3	<1	<10
CC-123A	07-14-88	.270	<.010	<.5	<.10	--	180	4	<1	<10
CC-123B	07-14-88	.320	<.010	--	<.10	--	240	<3	<1	<10
CC-124B	07-13-88	.160	<.010	<.5	<.10	--	950	<3	<1	<10
CC-130A	07-20-88	.180	.010	--	.10	--	60	<3	<1	<10
CC-130B	07-21-88	.290	<.010	--	.34	--	200	<3	<1	<10
CC-133B	08-23-88	3.10	<.010	--	<.10	<.10	350	<3	<1	<10
CC-134A	07-14-88	.850	<.010	--	<.10	--	190	<3	<1	<10
CC-134B	07-14-88	.420	<.010	<.5	<.10	--	20	3	<1	<10
CC-136A	08-10-88	.070	<.010	--	<.10	<.10	150	<3	<1	<10
CC-136A	08-10-88	.070	<.010	--	<.10	--	160	<3	<1	<10
CC-136B	08-10-88	.070	<.010	--	<.10	--	200	<3	<1	<10

Boron, dissolved (μg/L as B)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)	Copper, dissolved (μg/L as Cu)	Lead, dissolved (μg/L as Pb)	Mercury, dissolved (μg/L as Hg)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Zinc, dissolved (μg/L as Zn)	Local identifier
20	<1	2	<1	<1	<0.5	2	<1	<10	CC-29B
50	1	3	65	2	.8	57	<1	110	CC-30A
640	13	<1	<1	4	<.5	<1	<1	140	CC-36B
180	8	<1	<1	<1	<.5	<1	<1	16	CC-36C
<100	2	<1	<1	<1	<.5	3	<1	240	CC-36D
<100	2	<1	<1	<1	<.5	2	<1	240	CC-36D
--	--	--	--	--	--	--	--	--	CC-39A
--	--	--	--	--	--	--	--	--	CC-39B
--	--	--	--	--	--	--	--	--	CC-42A
<100	<1	<1	<1	2	<.5	6	<1	<10	CC-101B
<100	<1	<1	<1	3	<.5	8	<1	17	CC-101C
<100	2	2	2	4	<.5	250	<1	420	CC-102A
<100	<1	<1	<1	11	<.5	250	<1	580	CC-102A
<100	<1	7	9	8	<.5	34	<1	230	CC-102B
<100	<1	<1	<1	3	<.5	25	<1	27	CC-102C
<100	1	<1	<1	2	<.5	12	<1	31	CC-104A
<100	<1	<1	<1	3	<.5	19	<1	20	CC-104B
--	--	--	--	--	--	--	--	--	CC-104C
--	--	--	--	--	--	--	--	--	CC-106A
30	<1	3	1	<1	<.5	1	<2	<10	CC-107A
40	4	<1	40	<1	<.5	230	<2	360	CC-107B
300	3	3	2	<1	<.5	180	2	90	CC-108A
210	<1	6	3	2	<.5	50	5	80	CC-108B
40	2	3	4	<1	<.5	110	<2	190	CC-109A
20	<1	1	2	1	<.5	20	<2	10	CC-109B
20	<1	5	3	1	.8	5	<1	48	CC-110A
40	<1	5	16	<1	.9	26	<1	42	CC-111A
40	<1	2	8	1	.8	40	<1	55	CC-111B
20	<1	<1	3	2	.8	11	<1	30	CC-112A
20	<1	5	4	2	<.5	15	<1	30	CC-113A
70	<1	<1	<1	<1	<.5	25	<1	19	CC-113B
80	16	2	2	<1	.8	18	<1	3,100	CC-114B
60	4	1	5	2	.5	37	<1	670	CC-114C
30	1	<1	2	<1	.5	78	<1	72	CC-115A
<100	<1	<1	5	1	<.5	37	<1	67	CC-117A
<100	2	<1	<1	1	<.5	1	<1	23	CC-117B
20	2	5	9	<1	<.5	120	<2	180	CC-118A
20	<1	<1	10	<1	<.5	180	<2	240	CC-118B
160	<1	<1	6	2	<.5	130	1	140	CC-120A
80	<1	<1	<1	<1	<.5	1	<1	<10	CC-120B
<50	<1	<1	<1	1	<.5	52	<1	70	CC-121A
20	<1	<1	<1	<1	<.5	18	<1	10	CC-121B
80	1	<1	<1	<1	<.5	7	<1	12	CC-122A
10	<1	2	1	<1	<.5	4	<2	30	CC-123A
30	1	<1	1	2	<.5	4	<2	40	CC-123A
10	<1	<1	<1	<1	<.5	20	<2	30	CC-123B
20	2	<1	<1	<1	<.5	<1	<2	20	CC-124B
60	<1	2	1	2	<.5	70	<2	70	CC-130A
10	<1	2	3	<1	.5	19	<1	18	CC-130B
<100	<1	2	7	<1	<.5	18	2	47	CC-133B
20	<1	1	2	2	<.5	20	<2	60	CC-134A
60	<1	2	3	<1	<.5	4	<2	50	CC-134B
<100	1	<1	<1	<1	<.5	1	<1	11	CC-136A
<100	1	<1	<1	<1	<.5	1	<1	<10	CC-136A
<100	1	<1	<1	<1	<.5	3	<1	2,400	CC-136B

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland, Second sampling period (July-September 1988)--Continued

Local identifier	Sampling date	Comments	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance (µs/cm)	pH (standard units)	Solids, residue at 180 deg C, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
SURFICIAL AQUIFER										
CC-1A	08-18-88		14.0	<0.10	255	6.48	86	9.8	5.4	13
CC-9A	08-02-88		19.0	1.6	313	5.33	237	5.1	6.2	26
CC-10A	08-04-88		18.0	1.0	237	5.88	--	--	--	--
CC-12A.1	08-09-88		15.0	<.10	274	6.46	112	17	6.5	6.3
CC-20A	08-19-88		16.0	4.1	314	6.18	180	25	11	17
CC-20B	08-19-88		14.5	3.6	349	5.96	200	24	12	18
CC-22A	08-22-88		14.5	<.1	299	6.02	170	34	10	7.8
CC-29A	08-02-88		16.0	4.8	4,950	12.7	1,470	590	.02	63
CC-32A	09-07-88		15.5	2.4	879	5.35	514	11	11	200
CC-32B	09-07-88		14.0	<.10	1,500	5.08	915	25	27	270
CC-33A	09-07-88		15.0	2.0	391	5.37	292	5.6	7.6	55
CC-33B.1	09-07-88		14.0	<.10	978	4.37	519	13	15	260
CC-33B	09-07-88		14.0	<.10	2,160	4.14	1,190	23	46	380
CC-33B	09-07-88	R	--	--	--	--	--	--	--	--
CC-34A	09-07-88		15.0	3.1	4,480	6.16	2,770	91	72	850
CC-101A	08-17-88	U	20.0	.40	318	6.05	123	23	5.6	4.9
CC-114A	07-27-88		17.5	6.9	359	6.37	227	44	8.2	17
CC-124A	07-12-88		14.0	4.7	262	5.77	170	18	6.4	25
CC-126A	08-04-88	U	15.0	1.2	108	4.72	83	3.0	5.8	6.0
CC-127A	08-04-88	U	17.5	7.4	58	4.68	52	1.8	2.9	1.4
CC-128A	08-04-88		16.0	7.3	64	5.62	49	2.6	1.8	4.0
CC-129A	08-04-88		14.5	.20	102	5.24	73	5.1	3.8	6.7
CC-129A	08-04-88	R	--	--	--	--	80	7.6	3.8	6.5
CC-131A	08-09-88		15.0	.20	148	5.58	77	7.3	4.6	6.1
CC-132A	08-09-88	R	13.0	.20	170	5.27	114	.001	4.8	5.0
CC-133A	08-23-88		17.0	6.7	280	6.18	145	18	8.2	21
CC-135A	08-09-88		13.0	.30	94	5.89	52	6.4	1.8	9.5
LOWER CONFINED AQUIFER										
CC-6C	07-11-88		14.0	<0.10	83	6.03	50	9.6	0.83	3.1
CC-17C	07-25-88		22.0	--	41	5.27	--	--	--	--
CC-28C	07-28-88		19.0	1.8	53	5.58	42	4.0	.66	2.4
CC-139A	08-03-88		19.0	.50	50	5.05	38	1.9	.89	2.9
CC-140A	08-03-88		20.5	.40	76	5.12	56	1.2	.55	10

Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Local identifier
4.4	82	28	23	20,000	5.2	0.52	<0.02	0.79	CC-1A
.93	16	44	56	21,000	19	.25	.05	.84	CC-9A
--	--	--	--	--	--	--	--	--	CC-10A
10	107	88	8.4	23,000	3.0	.11	<.02	<.20	CC-12A.1
4.5	73	48	28	50	2.9	<.10	<.02	<.20	CC-20A
4.4	48	50	41	40	--	<.10	<.02	<.20	CC-20B
3.2	95	38	19	50	1.6	<.10	<.02	<.20	CC-22A
9.8	1,410	<.20	200	20	.42	5.7	.12	4.9	CC-29A
.85	18	75	200	110	18	<.10	<.02	.20	CC-32A
3.6	8	50	450	190	17	<.10	<.02	<.20	CC-32B
2.1	20	55	60	390	21	<.10	<.02	<.20	CC-33A
2.5	<1	15	280	14,000	11	<.10	<.02	<.20	CC-33B.1
4.1	<1	75	630	6,300	14	<.10	<.02	<.20	CC-33B
--	--	--	--	--	--	--	--	--	CC-33B
32	83	210	1,400	90	8.3	<.10	<.02	<.20	CC-34A
1.1	98	50	4.8	25,000	4.9	.15	<.02	.45	CC-101A
3.8	80	87	18	20	4.9	<.10	.03	.26	CC-114A
2.8	30	46	33	40	2.2	<.10	.04	.40	CC-124A
.98	<1	20	17	460	5.9	<.10	<.03	.43	CC-126A
1.3	<1	12	2.4	40	4.3	<.10	<.03	.51	CC-127A
1.8	3	10	4.8	50	3.8	<.10	<.03	.47	CC-128A
1.8	5	24	7.1	2,700	5.2	<.10	<.03	.56	CC-129A
1.8	--	28	7.1	2,800	5.3	<.10	<.03	.58	CC-129A
1.7	143	28	16	7,300	7.0	<.10	<.02	.24	CC-131A
3.5	7	17	30	60	6.3	<.10	<.02	<.20	CC-132A
2.2	33	39	37	40	2.2	<.10	<.02	.59	CC-133A
3.1	14	20	5.4	920	2.6	<.10	<.02	.26	CC-135A
2.9	14	4.0	2.1	590	4.8	<0.10	<0.02	0.20	CC-6C
--	--	--	--	--	--	--	--	--	CC-17C
.96	15	24	4.4	4,300	4.6	<.10	.02	.28	CC-28C
1.2	3	4.0	4.8	330	4.4	<.10	<.03	.44	CC-139A
1.2	5	8.0	12	520	5.2	<.10	<.03	.50	CC-140A

Appendix B1.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Second sampling period (July-September 1988)--Continued

Local identifier	Sampling date	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Sulfide, dissolved (mg/L as S)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Manganese, dissolved (µg/L as Mn)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Beryllium, dissolved (µg/L as Be)
SURFICIAL AQUIFER--Continued										
CC-1A	08-18-88	0.23	<0.01	--	0.18	<0.10	340	6	33	<10
CC-9A	08-02-88	.09	.02	--	<.10	--	490	8	<1	<10
CC-10A	08-04-88	--	--	--	--	--	--	--	--	--
CC-12A.1	08-09-88	.08	.01	<1.0	.12	--	700	6	24	<10
CC-20A	08-19-88	2.7	<.01	--	.14	.49	3	<3	<1	<10
CC-20B	08-19-88	2.6	<.01	--	.11	.30	12	<3	<1	<10
CC-22A	08-22-88	.85	.01	<1.0	<.10	.29	18	<3	<1	<10
CC-29A	08-02-88	.12	.02	--	.26	--	<1	<3	2	<10
CC-32A	09-07-88	.10	<.01	--	.15	1.2	60	<3	<1	<10
CC-32B	09-07-88	.05	.01	--	.17	1.4	320	<3	<1	<10
CC-33A	09-07-88	.06	.01	--	<.10	.37	180	<3	<1	<10
CC-33B.1	09-07-88	.08	<.01	--	<.10	<.10	1,400	<3	<1	<10
CC-33B	09-07-88	<.05	<.01	--	.23	1.1	3,100	<3	<1	<10
CC-33B	09-07-88	--	--	--	--	--	--	--	--	--
CC-34A	09-07-88	.16	.02	--	.14	.81	66	<3	<1	<10
CC-101A	08-17-88	.13	<.01	--	.15	<.10	680	7	3	<10
CC-114A	07-27-88	.56	<.01	--	.22	--	8	<3	<1	<10
CC-124A	07-12-88	1.2	<.01	<1.0	<.10	--	7	<3	<1	<1
CC-126A	08-04-88	.15	<.01	--	.14	--	90	<3	<1	<10
CC-127A	08-04-88	.11	<.01	--	<.10	--	30	<3	<1	<10
CC-128A	08-04-88	.12	<.01	--	.11	--	90	<3	<1	<10
CC-129A	08-04-88	.06	<.01	--	<.10	--	40	<3	<1	<10
CC-129A	08-04-88	.08	<.01	--	<.10	--	40	<3	<1	<10
CC-131A	08-09-88	.09	<.01	<1.0	<.10	--	120	<3	<1	<10
CC-132A	08-09-88	1.0	<.01	<1.0	<.10	--	14	<3	<1	<10
CC-133A	08-23-88	2.2	.01	--	<.10	.24	6	<3	<1	<10
CC-135A	08-09-88	.16	<.01	<1.0	<.10	--	160	<3	<1	<10
LOWER CONFINED AQUIFER--Continued										
CC-6C	07-11-88	.21	<0.01	<1.0	<0.10	--	40	<3	<1	<10
CC-17C	07-25-88	--	--	--	--	--	--	--	--	--
CC-28C	07-28-88	.04	<.01	--	.10	.14	120	<3	<1	<10
CC-139A	08-03-88	.10	<.01	--	<.10	--	80	<3	<1	<10
CC-140A	08-03-88	.36	<.01	--	<.10	--	40	<3	<1	<10

Boron, dis- solved (μg/L as B)	Cadmium, dis- solved (μg/L as Cd)	Chro- mium, dis- solved (μg/L as Cr)	Copper, dis- solved (μg/L as Cu)	Lead, dis- solved (μg/L as Pb)	Mercury, dis- solved (μg/L as Hg)	Nickel, dis- solved (μg/L as Ni)	Sele- nium, dis- solved (μg/L as Se)	Zinc, dis- solved (μg/L as Zn)	Local ident- ifier
<100	5	<1	<1	4	<0.5	3	<1	27	CC-1A
40	5	<1	<1	<1	<.5	<1	<1	13	CC-9A
--	--	--	--	--	--	--	--	--	CC-10A
<100	4	<1	<1	<1	<.5	4	<1	20	CC-12A.1
<100	<1	2	1	<1	<.5	1	2	<10	CC-20A
<100	<1	1	<1	<1	<.5	6	2	<10	CC-20B
<100	<1	<1	<1	<1	<.5	2	<1	85	CC-22A
20	<1	<1	9	<1	<.5	36	<1	<10	CC-29A
50	3	1	10	<1	<.5	15	<1	32	CC-32A
70	<1	2	3	2	<.5	40	<1	73	CC-32B
<50	<1	<1	1	<1	<.5	11	<1	19	CC-33A
<50	4	<1	10	8	<.5	180	<1	370	CC-33B.1
50	3	<1	10	6	<.5	180	<1	490	CC-33B
--	--	--	--	--	--	--	--	--	CC-33B
370	<1	<1	2	<1	<.5	16	<1	510	CC-34A
<100	6	<1	<1	4	<.5	<1	<1	60	CC-101A
240	<1	2	2	1	.8	2	3	50	CC-114A
20	<1	<1	<1	1	<.5	2	<1	40	CC-124A
50	<1	<1	4	1	<.5	15	<1	71	CC-126A
30	<1	<1	1	<1	<.5	8	<1	46	CC-127A
40	<1	<1	<1	<1	<.5	6	<1	120	CC-128A
40	<1	<1	<1	<1	<.5	42	<1	120	CC-129A
50	<1	<1	<1	2	<.5	42	<1	150	CC-129A
110	1	<1	<1	<1	<.5	13	<1	14	CC-131A
<100	1	<1	<1	3	<.5	14	<1	46	CC-132A
<100	<1	2	<1	<1	<.5	2	<1	16	CC-133A
<100	<1	<1	<1	<1	<.5	2	<1	21	CC-135A
<10	<1	<1	<1	<1	<0.5	4	<1	<10	CC-6C
--	--	--	--	--	.8	--	--	--	CC-17C
20	1	<1	<1	<1	<.5	11	<1	38	CC-28C
30	6	<1	17	<1	<.5	27	<1	73	CC-139A
50	<1	<1	1	<1	<.5	17	<1	28	CC-140A

Appendix B2.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Second sampling period (July-September 1988)

[µg/L, micrograms per liter; R, replicate sample; B, sample from background well site in Canal Creek aquifer; G, suspected of grout contamination; Re, repeat analysis; U, sample from uncontaminated well site in surficial aquifer; --, not analyzed for; *, below method blank concentration; J, estimated concentration, peak present but below reported detection limit]

Local ident-ifier	Sampling date	Analysis date	Comments	Methane (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	Benzene (µg/L)	Chloro-benzene (µg/L)	Carbon tetra-chlo-ride (µg/L)	Chloro-form (µg/L)	Methylene chloride (µg/L)
CANAL CREEK AQUIFER											
CC-1B	08-18-88	08-29-88		3,900	<5.0	<5.0	1.0J	<5.0	<5.0	<5.0	18
CC-1B	08-18-88	08-30-88	R	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0
CC-1C	08-18-88	08-29-88		1,100	<5.0	<5.0	2.0J	<5.0	<5.0	<5.0	10*
CC-3A	07-08-88	07-20-88	G	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.0*J
CC-3B	07-08-88	07-20-88	B	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	12
CC-4A	07-13-88	07-20-88	G	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	11
CC-4B	07-13-88	07-23-88	G	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-5C	07-13-88	07-23-88		--	<5.0	1.0*J	3.0J	14	<5.0	2.0J	2.0*J
CC-6A	07-12-88	07-18-88	G	--	<5.0	<5.0	<5.0	<5.0	<5.0	1.0J	9.0*
CC-6B	07-11-88	07-20-88		--	<5.0	<5.0	<5.0	<5.0	19	7.0	7.0*
CC-W6	07-13-88	07-23-88		--	<5.0	1.0*J	<5.0	<5.0	16	5.0	2.0*
CC-7A.1	08-15-88	08-27-88		29	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	12
CC-7A.1	08-16-88	08-27-88	Re	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0*
CC-7A	08-15-88	08-27-88		2,200	<5.0	<5.0	2.0J	4.0J	<5.0	<5.0	6.0*
CC-7A	08-16-88	08-27-88	Re	--	<5.0	<5.0	2.0J	3.0J	<5.0	2.0J	12
CC-7B	08-15-88	08-27-88		4,900	<5.0	<5.0	3.0J	4.0J	2.0J	6.0	23
CC-7B	08-15-88	08-27-88	R	--	<5.0	<5.0	2.0J	3.0J	1.0J	6.0	6.0*
CC-8B	08-11-88	08-22-88		1,500	<5.0	<5.0	2.0J	2.0J	18	13	10*
CC-8B	08-11-88	08-23-88	R	--	<5.0	<5.0	3.0J	2.0J	21	14	11*
CC-8C	08-11-88	08-23-88		1,200	<5.0	<5.0	<5.0	<5.0	5.0	15	19
CC-8D	08-11-88	08-23-88		2,500	<5.0	<5.0	2.0J	1.0J	3.0J	13	6.0*
CC-9B	08-02-88	08-13-88	B	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*
CC-13A	07-20-88	08-02-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	3.0J	8.0
CC-13A	07-20-88	08-02-88	R	--	<5.0	<5.0	<5.0	<5.0	<5.0	3.0J	10
CC-13B	07-20-88	08-02-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	1.0J	5.0*
CC-14A	07-19-88	08-02-88		--	<5.0	<5.0	<5.0	11	<5.0	4.0J	11
CC-14B	07-19-88	08-02-88		--	<5.0	<5.0	6.0	<5.0	<5.0	<5.0	8.0
CC-15A	07-21-88	08-04-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	12
CC-16A	07-25-88	08-05-88		--	2.0J	2.0J	40	11	<5.0	37	1 20
CC-16B	07-25-88	08-05-88		--	<5.0	<5.0	<5.0	1.0J	14	4.0J	6.0*
CC-16B	07-25-88	08-05-88	R	--	<5.0	<5.0	<5.0	1.0J	15	4.0J	11
CC-17A	07-25-88	08-06-88		--	<5.0	<5.0	<5.0	<5.0	190	33	9.0
CC-17B	07-26-88	08-07-88		--	<5.0	<5.0	<5.0	<5.0	70	14	4.0*J
CC-17B	07-26-88	08-07-88	R	--	<5.0	<5.0	<5.0	<5.0	64	13	15
CC-18A	07-18-88	08-01-88		--	<5.0	<5.0	<5.0	<5.0	4.0J	<5.0	11
CC-18A	07-18-88	0--	R	--	--	--	--	--	--	--	--
CC-18B	07-18-88	08-01-88		--	<5.0	<5.0	<5.0	<5.0	30	6.0	8.0
CC-20C	08-19-88	08-31-88		<1.3	<5.0	<5.0	<5.0	<5.0	<5.0	7.0	3.0*J
CC-20D	08-19-88	08-30-88		<1.3	1.0J	<5.0	<5.0	<5.0	1.0J	7.0	7.0*J
CC-21A	07-21-88	08-04-88		--	<5.0	<5.0	<5.0	<5.0	200	12	20
CC-22B	08-22-88	09-03-88		150	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.0*J
CC-22B	08-22-88	09-01-88	R	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	2.0*J
CC-22C	08-23-88	09-06-88		120	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.0*J
CC-23B	07-29-88	08-12-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	7.0*
CC-25A	08-01-88	08-13-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-25A	08-01-88	08-13-88	R	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*
CC-25B	08-01-88	08-13-88		--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*
CC-26A	07-27-88	08-10-88		--	<5.0	<5.0	<5.0	<5.0	200	72	5.0*
CC-26B	07-27-88	08-09-88		--	<5.0	<5.0	46	4.0J	280	180	16
CC-26B	07-27-88	08-10-88	R	--	<5.0	<5.0	46	5.0	190	150	5.0*
CC-27A	07-29-88	08-12-88		--	<5.0	<5.0	<5.0	<5.0	2.0J	2.0J	12
CC-27B	07-29-88	08-12-88		--	<5.0	<5.0	<5.0	<5.0	59	110	4.0*J
CC-28A	07-28-88	08-11-88		--	<5.0	<5.0	<5.0	1.0J	600	360	6.0*
CC-28A	07-28-88	08-11-88	R	--	<5.0	<5.0	<5.0	1.0J	540	380	7.0*
CC-28B	07-28-88	08-11-88		--	<5.0	<5.0	10	<5.0	360	260	8.0*

1,1,2,2-Tetrachloroethane (μg/L)	1,1,2-Trichloroethane (μg/L)	1,2-Dichloroethane (μg/L)	1,1-Dichloroethane (μg/L)	Tetrachloroethylene (μg/L)	Trichloroethylene (μg/L)	1,1-Dichloroethylene (μg/L)	1,2-trans-Dichloroethylene (μg/L)	Vinyl chloride (μg/L)	Total organic halogen, calculated (μg/L)	Local identifier
4.0J	<5.0	<10	<5.0	<5.0	340	5.0	1,100	130	1,200	CC-1B
3.0J	<5.0	3.0J	<5.0	<5.0	250	4.0J	870	110	910	CC-1B
11	2.0J	5.0	<5.0	1.0J	390	1.0J	950	21	1,000	CC-1C
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-3A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-3B
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-4
<10	<5.0	<10	<5.0	<5.0	17	<5.0	33	25	52	CC-4B
19	2.0J	4.0J	<5.0	11	480	1.0J	120	120	580	CC-5C
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-6A
25	<5.0	<10	<5.0	<5.0	8.0	<5.0	<5.0	<10	51	CC-6B
46	<5.0	<10	<5.0	<5.0	9.0	<5.0	<5.0	<10	65	CC-W6
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-7A.1
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-7A.1
13	2.0J	2.0J	<5.0	3.0J	32	<5.0	150	4.0J	150	CC-7A
12	2.0J	2.0J	<5.0	<5.0	28	<5.0	130	3.0J	130	CC-7A
630	12	6.0J	<5.0	<5.0	210	1.0J	400	39	1,000	CC-7B
620	12	6.0J	<5.0	<5.0	190	1.0J	380	39	1,000	CC-7B
640	8.0	3.0J	<5.0	<5.0	160	<5.0	170	23	840	CC-8B
540	9.0	<10	<5.0	<5.0	190	<5.0	180	13	790	CC-8B
230	7.0	7.0J	<5.0	<5.0	130	<5.0	81	15	390	CC-8C
310	6.0	5.0J	<5.0	<5.0	130	<5.0	260	15	580	CC-8D
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-9B
400	5.0	<10	<5.0	2.0J	47	<5.0	2.0J	<10	380	CC-13A
390	5.0	<10	<5.0	2.0J	48	<5.0	2.0J	<10	370	CC-13A
79	<5.0	<10	<5.0	<5.0	8.0	<5.0	<5.0	<10	73	CC-13B
24	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	27	CC-14A
10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	8	CC-14B
2.0J	<5.0	<10	<5.0	<5.0	4.0J	<5.0	<5.0	<10	<5	CC-15A
6.0J	<5.0	260	<5.0	200	660	9.0	1,000	210	1,800	CC-16A
1.0J	4.0J	3.0J	<5.0	3.0J	140	<5.0	15	<10	140	CC-16B
53	4.0J	3.0J	<5.0	6.0	110	<5.0	15	<10	170	CC-16B
340	4.0J	8.0J	<5.0	<5.0	160	<5.0	8.0	<10	630	CC-17A
360	8.0	7.0J	<5.0	<5.0	67	<5.0	15	<10	450	CC-17B
360	9.0	7.0J	<5.0	<5.0	66	<5.0	14	<10	450	CC-17B
200	3.0J	<10	<5.0	4.0J	45	<5.0	<5.0	<10	210	CC-18A
--	--	--	--	--	--	--	--	--	--	CC-18A
270	3.0J	<10	<5.0	3.0J	40	<5.0	<5.0	<10	300	CC-18B
9.0J	<5.0	<10	<5.0	<5.0	8.0	<5.0	4.0J	<10	12	CC-20C
12	<5.0	<10	<5.0	<5.0	4.0J	<5.0	18	<10	29	CC-20D
140	1.0J	<10	<5.0	<5.0	36	<5.0	<5.0	<10	350	CC-21A
<10	<5.0	<10	<5.0	<5.0	3.0J	<5.0	200	10	150	CC-22B
<10	<5.0	<10	<5.0	<5.0	3.0J	<5.0	170	9.0J	120	CC-22B
<10	<5.0	<10	<5.0	<5.0	4.0J	<5.0	38	4.0J	28	CC-22C
2.0J	<5.0	<10	<5.0	<5.0	14	<5.0	120	12	110	CC-23B
19	2.0J	<10	<5.0	20	220	<5.0	30	<10	230	CC-25A
17	2.0J	<10	<5.0	18	180	<5.0	26	<10	190	CC-25A
<10	<5.0	<10	<5.0	<5.0	12	<5.0	54	<10	50	CC-25B
<10	<5.0	<10	<5.0	3.0J	<5.0	<5.0	<5.0	<10	250	CC-26A
140	2.0J	4.0J	3.0J	110	130	2.0J	7.0	<10	750	CC-26B
140	2.0J	4.0J	3.0J	120	130	2.0J	7.0	<10	650	CC-26B
5,800	31	<10	<5.0	<5.0	760	<5.0	80	<10	5,600	CC-27A
120	<5.0	1.0J	<5.0	<5.0	32	<5.0	1.0J	<10	280	CC-27B
89	2.0J	4.0J	<5.0	<5.0	81	<5.0	3.0J	<10	1,000	CC-28A
96	2.0J	4.0J	<5.0	27	83	<5.0	4.0J	<10	1,000	CC-28A
38	<5.0	2.0J	<5.0	44	42	<5.0	4.0J	<10	670	CC-28B

Appendix B2.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Second sampling period (July-September 1988)--Continued

CANAL CREEK AQUIFER--Continued

Local identifier	Sampling date	Analysis date	Methane (μg/L)	Toluene (μg/L)	Ethylbenzene (μg/L)	Benzene (μg/L)	Chlorobenzene (μg/L)	Carbon tetrachloride (μg/L)	Chloroform (μg/L)	Methylene chloride (μg/L)
CC-29B	08-01-88	08-13-88	--	<5.0	<5.0	<5.0	11	<5.0	<5.0	15
CC-30A	07-21-88	08-04-88	--	<5.0	<5.0	<5.0	<5.0	320	34	7.0*
CC-36B	08-22-88	09-03-88	230	<5.0	3.0J	2.0J	<5.0	<5.0	<5.0	3.0*J
CC-36C	08-22-88	09-03-88	160	<5.0	1.0J	1.0J	<5.0	<5.0	<5.0	6.0
CC-36D	08-23-88	09-03-88	<1.3	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.0*J
CC-36D	08-23-88	09-05-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-39A	09-08-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	14
CC-39B	09-08-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	2.0J	9.0
CC-42A	09-08-88	10-13-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	10
CC-101B	08-17-88	08-28-88	410	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	11
CC-101C	08-17-88	08-28-88	1,100	<5.0	<5.0	4.0J	<5.0	<5.0	3.0J	<5.0
CC-102A	08-16-88	08-28-88	10	--	--	--	--	--	--	--
CC-102A	08-17-88	08-28-88	10	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.0*
CC-102B	08-16-88	08-28-88	3,300	<5.0	<5.0	1.0J	<5.0	1.0J	2.0J	22
CC-102C	08-16-88	08-28-88	1,800	<5.0	<5.0	<5.0	<5.0	<5.0	2.0J	12
CC-104A	08-12-88	08-25-88	12	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*
CC-104B	08-12-88	08-25-88	210	<5.0	<5.0	<5.0	<5.0	12	6.0	12*
CC-104C	08-12-88	08-25-88	170	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	22
CC-106A	07-13-88	08-22-88	--	4.0J	2.0J	<5.0	<5.0	<5.0	<5.0	20
CC-107A	07-15-88	07-24-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	4.0J	9.0
CC-107B	07-15-88	07-24-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	2.0J	3.0*
CC-108A	07-15-88	07-24-88	--	<5.0	<5.0	<5.0	<5.0	3,100	110	8.0
CC-108B	07-15-88	07-24-88	--	<5.0	<5.0	<5.0	<5.0	1,900	75	10
CC-109A	07-19-88	08-02-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	2.0J	5.0*
CC-109B	07-20-88	08-02-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	1.0J	11
CC-110A	07-21-88	08-04-88	--	<5.0	<5.0	<5.0	<5.0	160	40	14
CC-111A	07-26-88	08-08-88	--	<5.0	<5.0	<5.0	<5.0	310	35	20
CC-111B	07-26-88	08-08-88	--	<25	<25	<25	<25	450	48	62
CC-112A	07-26-88	08-08-88	--	2.0J	<5.0	110	<5.0	62	42	6.0*
CC-113A	07-28-88	08-10-88	--	<5.0	<5.0	<5.0	<5.0	370	650	10
CC-113B	07-28-88	08-11-88	--	<5.0	<5.0	<5.0	<5.0	7.0	39	10
CC-114B	07-27-88	08-09-88	--	1.0J	<5.0	3.0J	<5.0	10	130	5.0*
CC-114C	07-27-88	08-09-88	--	<5.0	<5.0	<5.0	<5.0	8.0	75	10
CC-115A	07-26-88	08-08-88	--	<5.0	<5.0	<5.0	<5.0	44	45	21
CC-117A	08-10-88	08-16-88	--	<5.0	<5.0	3.0J	<5.0	75	<5.0	42
CC-117B	08-11-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	31
CC-118A	07-18-88	08-01-88	--	<5.0	<5.0	<5.0	<5.0	3.0J	3.0J	8.0
CC-118B	07-18-88	08-01-88	--	<5.0	<5.0	<5.0	<5.0	2.0J	2.0J	3.0*J
CC-120A	07-12-88	07-20-88	--	3.0J	<5.0	45	100	2,200	170	4.0*J
CC-120B	07-12-88	07-20-88	--	<5.0	<5.0	3.0J	12	130	32	6.0
CC-121A	07-11-88	07-18-88	--	<5.0	<5.0	<5.0	<5.0	3.0J	<5.0	12*
CC-121B	07-11-88	07-18-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*
CC-122A	08-03-88	08-14-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	16
CC-123A	07-14-88	07-23-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	7.0*
CC-123A	07-14-88	07-24-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-123B	07-14-88	07-23-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	2.0*J
CC-124B	07-13-88	07-23-88	--	<5.0	3.0*J	<5.0	<5.0	<5.0	1.0J	3.0*J
CC-130A	07-20-88	08-04-88	--	<5.0	1.0J	<5.0	<5.0	<5.0	<5.0	11
CC-130B	07-21-88	08-04-88	--	<5.0	<5.0	<5.0	<5.0	3.0J	2.0J	7.0*
CC-133B	08-23-88	09-05-88	<1.3	<5.0	<5.0	<5.0	<5.0	2.0J	52	3.0
CC-134A	07-14-88	07-23-88	--	<5.0	<5.0	<5.0	<5.0	4.0J	1.0J	<5.0*
CC-134B	07-14-88	07-23-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.0*J
CC-136A	08-10-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	22
CC-136A	08-10-88	08-16-88	--	--	--	--	--	--	--	--
CC-136B	08-10-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	35

1,1,2,2-Tetra-chloro-ethane (μg/L)	1,1,2-Tri-chloro-ethane (μg/L)	1,2-Di-chloro-ethane (μg/L)	1,1-Di-chloro-ethane (μg/L)	Tetra-chloro-ethyl-ene (μg/L)	Tri-chloro-ethyl-ene (μg/L)	1,1-Di-chloro-ethyl-ene (μg/L)	1,2-trans-Di-chloro-ethylene (μg/L)	Vinyl chlo-ride (μg/L)	Total organic halogen, calcu-lated (μg/L)	Local ient-ifer
3.0J	<5.0	2.0J	<5.0	<5.0	18	1.0J	42	14	58	CC-29B
690	<5.0	11	<5.0	<5.0	90	<5.0	3.0	<10	990	CC-30A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-36B
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-36C
<10	<5.0	<10	3.0J	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-36D
<10	<5.0	<10	3.0J	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-36D
580	14	<10	<5.0	<5.0	330	3.0	32	<10	800	CC-39A
12	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	14	CC-39B
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-42A
<10	<5.0	8.0J	<5.0	<5.0	450	3.0J	59	20	420	CC-101B
250	<5.0	<10	<5.0	<5.0	120	<5.0	62	4.OJ	350	CC-101C
--	--	--	--	--	--	--	--	--	--	CC-102A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-102A
110	1.0J	<10	<5.0	<5.0	21	<5.0	40	22	160	CC-102B
220	11	5.0J	<5.0	<5.0	83	<5.0	56	30	320	CC-102C
2.0J	<5.0	<10	2.0J	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-104A
100	2.0J	1.0J	<5.0	<5.0	28	<5.0	18	<10	140	CC-104B
28	<5.0	<10	4.0J	<5.0	6.0	<5.0	7.0	<10	42	CC-104C
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	8	CC-106A
<10	<5.0	<10	<5.0	<5.0	140	1.0J	1.0J	<10	110	CC-107A
250	<5.0	<10	<5.0	3.0J	15	<5.0	<5.0	<10	220	CC-107B
1,100	9.0	140	<5.0	12	410	<5.0	2.0J	<10	4,300	CC-108A
630	5.0	72	<5.0	12	320	2.0J	2.0J	<10	2,700	CC-108B
160	<5.0	<10	<5.0	<5.0	16	<5.0	<5.0	<10	150	CC-109A
<10	<5.0	<10	<5.0	<5.0	38	<5.0	<5.0	<10	31	CC-109B
<10	2.0J	15	<5.0	3.0J	200	<5.0	1.0J	<10	360	CC-110A
450	4.0J	14	<5.0	<5.0	60	<5.0	<5.0	<10	760	CC-111A
630	<25	<50	<25	7.0	82	<25	<25	<50	1,100	CC-111B
30	<5.0	43	<5.0	<5.0	3.0J	<5.0	<5.0	<10	150	CC-112A
180	2.0J	7.0J	<5.0	19	160	<5.0	2.0J	<10	1,200	CC-113A
12	1.0J	<10	<5.0	15	170	<5.0	12	<10	210	CC-113B
46	<5.0	8.0J	<5.0	<5.0	62	<5.0	9.0	<10	210	CC-114B
31	<5.0	9.0J	<5.0	<5.0	40	<5.0	2.0J	<10	130	CC-114C
38	<5.0	2.0J	<5.0	<5.0	19	<5.0	<5.0	<10	140	CC-115A
87	2.0J	<10	<5.0	<5.0	38	<5.0	8.0	<10	200	CC-117A
13	1.0J	1.0J	2.0J	<5.0	3.0J	<5.0	9.0	<10	34	CC-117B
530	7.0	<10	<5.0	8.0	53	<5.0	1.0J	<10	500	CC-118A
200	3.0J	<10	<5.0	4.0J	35	<5.0	<5.0	<10	200	CC-118B
3,800	20	<10	<5.0	73	670	<5.0	6.0	4.OJ	6,000	CC-120A
<10	7.0	<10	<5.0	14	680	<5.0	1.0J	<10	720	CC-120B
2.0J	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-121A
1.0J	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-121B
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	7	CC-122A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-123A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-123A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-123B
24	<5.0	<10	<5.0	<5.0	14	<5.0	<5.0	<10	31	CC-124B
33	<5.0	<10	<5.0	<5.0	8.0	<5.0	<5.0	<10	40	CC-130A
240	4.0J	<10	<5.0	<5.0	110	<5.0	12	<10	300	CC-130B
34	<5.0	<10	<5.0	<5.0	9.0	<5.0	<5.0	<10	82	CC-133B
7.0J	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-134A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-134B
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	8	CC-136A
--	--	--	--	--	--	--	--	--	--	CC-136A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	19	CC-136B

Appendix B2.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Second sampling period (July-September 1988)--Continued

Local identifier	Sampling date	Analysis date	Methane (μg/L)	Toluene (μg/L)	Ethylbenzene (μg/L)	Benzene (μg/L)	Chlorobenzene (μg/L)	Carbon tetrachloride (μg/L)	Chloroform (μg/L)	Methylene chloride (μg/L)
SURFICIAL AQUIFER										
CC-1A	08-18-88	08-29-88	30	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0*
CC-9A	08-02-88	08-13-88	--	<5.0	<5.0	<5.0	19	<5.0	<5.0	5.0*
CC-10A	08-04-88	08-15-88	--	<5.0	<5.0	<5.0	<5.0	2.0	<5.0	11*
CC-12A.1	08-09-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	11*
CC-20A	08-19-88	08-31-88	<1.3	<5.0	<5.0	<5.0	<5.0	<5.0	3.0	3.0*J
CC-20B	08-19-88	08-31-88	<1.3	<5.0	<5.0	<5.0	<5.0	4.0	6.0	3.0*J
CC-22A	08-22-88	09-01-88	<1.3	<5.0	<5.0	<5.0	<5.0	10	5.0	2.0*J
CC-29A	08-02-88	08-13-88	--	<5.0	<5.0	2.0	21	<5.0	8.0	15
CC-32A	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	32	4.0*J
CC-32B	09-07-88	09-30-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	9.0
CC-33A	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	7.0	14
CC-33B.1	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	2.0	10
CC-33B	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	2.0	<5.0	14	9.0
CC-33B	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	1.0	<5.0	14	7.0
CC-34A	09-07-88	09-21-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	8.0	9.0
CC-101A	08-17-88	08-28-88	37	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	22
CC-114A	07-27-88	08-09-88	--	<5.0	<5.0	<5.0	<5.0	230	15	16
CC-124A	07-12-88	07-20-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	48
CC-126A	08-04-88	08-15-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	2.0	19
CC-127A	08-04-88	08-15-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	12
CC-128A	08-04-88	08-15-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	31
CC-129A	08-04-88	08-15-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	19
CC-129A	08-04-88	08-15-88	--	--	--	--	--	--	--	--
CC-131A	08-09-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	21
CC-132A	08-09-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	18
CC-133A	08-23-88	09-05-88	<1.3	<5.0	<5.0	<5.0	<5.0	1.0	<5.0	5.0
CC-135A	08-09-88	08-16-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	31
LOWER CONFINED AQUIFER										
CC-6C	07-11-88	07-18-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	7.0*
CC-17C	07-25-88	--	--	--	--	--	--	--	--	--
CC-28C	07-28-88	08-13-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	14
C-139A	08-03-88	08-13-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	4.8*
C-140A	08-03-88	08-13-88	--	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	8.0*

1,1,2,2-Tetra-chloro-ethane (µg/L)	1,1,2-Tri-chloro-ethane (µg/L)	1,2-Di-chloro-ethane (µg/L)	1,1-Di-chloro-ethane (µg/L)	Tetra-chloro-ethyl-ene (µg/L)	Tri-chloro-ethyl-ene (µg/L)	1,1-Di-chloro-ethyl-ene (µg/L)	1,2-trans-Di-chloro-ethylene (µg/L)	Vinyl chlo-ride (µg/L)	Total organic halogen, calcu-lated (µg/L)	Local ient-ifer
57	3.0J	<10	<5.0	<5.0	58	<5.0	19	2.0J	110	CC-1A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	2.0J	<10	6	CC-9A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	11	CC-10A
<10	<5.0	<10	2.0J	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-12A.1
2.0J	<5.0	<10	<5.0	<5.0	28	<5.0	<5.0	<10	23	CC-20A
7.0J	<5.0	<10	<5.0	<5.0	120	<5.0	1.0J	<10	<5	CC-20B
2.0J	<5.0	<10	<5.0	4.0J	12	<5.0	8.0	<10	29	CC-22A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	2.0J	9.0J	20	CC-29A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	28	CC-32A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-32B
--	6.0	<10	<5.0	28	--	<5.0	3.0J	<10	--	CC-33A
38	<5.0	<10	<5.0	<5.0	8.0	<5.0	<5.0	<10	43	C-33B.1
7,200	71	<10	<5.0	59	700	<5.0	250	<10	6,900	CC-33B
7,000	67	<10	<5.0	59	670	<5.0	610	<10	7,000	CC-33B
130	2.0	<10	<5.0	8.0	160	<5.0	<5.0	<10	250	CC-34A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	9	CC-101A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	230	CC-114A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	32	CC-124A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	7	CC-126A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-127A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	17	CC-128A
<10	<5.0	20	<5.0	<5.0	<5.0	<5.0	7.0	<10	26	CC-129A
--	--	--	--	--	--	--	--	--	--	CC-129A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	8	CC-131A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-132A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-133A
<10	<5.0	<10	<5.0	<5.0	47	<5.0	8.0	<10	60	CC-135A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-6C
--	--	--	--	--	--	--	--	--	--	CC-17C
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	CC-28C
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	C-139A
<10	<5.0	<10	<5.0	<5.0	<5.0	<5.0	<5.0	<10	<5	C-140A

Appendix B3.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Third sampling period (April-May 1989)

[mg/L, milligrams per liter; µg/L, micrograms per liter; deg C, degrees Celsius; µs/cm, microsiemens per centimeter at 25 degrees Celsius; R, replicate sample; B, sample from background well site in Canal Creek aquifer; G, suspected of grout; contamination; U, sample from uncontaminated well site in surficial aquifer; H, halocarbon analysis for volatile organics N, sample analyzed by U.S. Geological Survey National Water Quality Laboratory; --, not analyzed for]

Local identifier	Sampling date	Comments	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance (µs/cm)	pH (standard units)	Solids, residue at 180 deg C, dissolved (mg/L)	Tritium, total (pci/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium dissolved (mg/L as Na
CANAL CREEK AQUIFER											
CC-1B	05-22-89	H	15.0	<0.1	367	5.98	228	--	28	13	14
CC-1B	05-22-89	R,H	--	--	--	--	220	--	26	11	11
CC-1B	05-22-89	R,N	15.0	<.1	367	5.98	--	70	22	11	16
CC-1C	05-22-89	H	15.0	<.1	252	5.75	175	45	16	7.9	16
CC-7A	05-24-89	H	15.0	<.1	182	5.42	93	<5.7	4.4	2.3	13
CC-7B	05-24-89	H	15.0	<.1	188	5.66	96	--	2.8	2.2	13
CC-7B	05-24-89	R,N	15.0	.1	188	5.66	--	12	--	--	--
CC-8B	05-25-89	H	15.0	.3	124	4.89	79	--	4.8	1.5	9.
CC-8B	05-25-89	R,H	--	--	--	--	79	--	5.4	1.6	1.
CC-8B	05-25-89	R,N	15.0	.3	124	4.89	--	<5.7	4.1	1.9	14
CC-8C	05-25-89	H	15.0	.4	209	4.82	148	10	14	6.4	8.
CC-8D	05-25-89	H	15.0	<.1	103	5.33	58	<5.7	4.3	1.3	7.
CC-11A	05-30-89	N,B	15.0	.4	42	5.32	--	<5.7	1.8	.45	3.
CC-11B	05-31-89	N,B	15.5	.1	52	5.75	--	<5.7	3.3	.81	3.
CC-13A	05-04-89	H	13.0	2.9	1,950	4.37	1,180	--	3.0	16	270
CC-13B	05-04-89	H	15.0	.7	82	5.10	62	--	2.5	1.0	5.
CC-16A	05-03-89		14.0	.2	329	5.57	177	--	6.5	3.9	36
CC-16B	05-03-89		15.5	.8	1,030	7.62	635	--	64	8.2	77
CC-17A	05-03-89	H	14.5	1.0	266	4.89	173	--	12	4.2	17
CC-17B	05-03-89	H	16.0	1.0	144	5.92	85	--	5.0	1.3	8.
CC-18A	05-08-89	H	13.5	1.2	2,030	4.32	1,200	--	44	22	250
CC-18B	05-08-89	H	14.0	2.2	128	5.65	89	--	12	1.6	<49
CC-20C	05-18-89	N	20.0	.5	406	6.14	--	93	23	9.7	27
CC-20D	05-19-89	H	16.0	<.1	138	5.76	75	18	6.8	2.8	8.
CC-21A	05-04-89	H	18.0	2.1	165	5.57	82	--	7.7	1.7	14
CC-21A	05-04-89	R,H	--	--	--	--	96	--	7.4	1.8	13
CC-22B	05-17-89	H	15.0	.6	477	6.68	296	--	41	17	8.
CC-23B	05-15-89	H	15.0	.2	442	6.44	252	--	26	12	<49
CC-25A	05-17-89	H	14.0	.6	416	6.20	267	--	34	12	<49
CC-25A	05-17-89	R,H	--	--	--	--	268	--	34	<8.6	<49
CC-26A	04-27-89		14.0	.2	339	6.21	209	--	19	>5.1	>6.
CC-26B	04-27-89		15.0	1.1	474	5.80	306	--	22	>5.1	>6.
CC-27A	05-01-89		13.0	1.7	406	4.56	265	--	64	7.4	28
CC-27B	05-01-89		13.0	2.6	532	5.30	321	--	29	7.0	48
CC-28A	04-28-89		12.5	1.3	4,820	4.50	2,770	--	3.0	3.0	630
CC-28B	04-28-89		13.5	1.4	1,780	4.51	1,010	--	15	8.7	220
CC-30A	05-03-89	H	15.5	1.5	142	5.08	80	--	5.6	3.4	8.
CC-36B	05-17-89	H	15.0	.5	477	6.68	283	--	17	12	<49
CC-36C	05-17-89	H	15.0	.5	427	6.62	268	--	36	14	<49
CC-102B	05-22-89	H	15.0	.7	232	5.00	167	31	11	4.0	17
CC-102C	05-24-89	H	14.5	.9	220	5.17	139	19	14	6.8	8.
CC-104B	05-25-89	H	16.5	.5	58	5.31	38	<5.7	6.2	.67	3.
CC-104C	05-26-89	H	15.0	<.1	55	5.87	71	<5.7	2.0	.58	4.
CC-107A	05-09-89	G,H	14.0	.4	985	7.31	547	--	21	<8.6	97
CC-107B	05-09-89	H	14.0	1.4	3,500	5.73	1,640	--	5.0	2.0	340
CC-108A	05-09-89		15.0	1.0	448	6.29	265	--	19	11	49
CC-108B	05-09-89	G	15.5	.7	265	6.31	181	--	15	4.3	<49
CC-109A	05-08-89	H	15.0	2.4	508	5.35	324	--	17	<8.6	<49
CC-110A	05-01-89	G,H	14.0	.2	639	11.2	243	--	37	.21	18
CC-111A	05-01-89		15.5	1.0	141	5.70	96	--	8.2	1.9	9.

Potassium, dissolved (mg/L as K)	Bicarbonate, (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (μg/L as Fe)	Silica, dissolved (mg/L SiO_2)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Local identifier
--	96	68	24	32,000	3.0	<0.031	<0.071	0.06	CC-1B
--	--	65	23	29,000	3.0	<.031	<.071	.06	CC-1B
3.0	96	65	18	28,000	7.1	--	.10	.08	CC-1B
--	32	62	24	3,200	2.9	<.031	<.071	.07	CC-1C
--	36	14	33	18,000	4.2	<.031	<.071	.09	CC-7A
--	37	15	38	16,000	5.6	<.031	<.071	.08	CC-7B
--	37	--	--	--	--	--	--	--	CC-7B
--	6	16	2.0	1,100	6.2	.16	<.071	.08	CC-8B
--	--	15	23	1,300	6.2	.12	<.071	.08	CC-8B
2.7	6	16	19	820	13	--	<.10	.08	CC-8B
--	6	62	19	130	4.7	<.031	<.071	.10	CC-8C
--	15	13	18	7,900	5.4	<.031	<.071	.06	CC-8D
.90	7	4.0	4.2	1,800	9.8	--	<.10	.05	CC-11A
1.1	15	4.0	5.5	3,800	10	--	<.10	.10	CC-11B
--	<1	31	700	<26	5.1	.73	<.071	.19	CC-13A
--	7	2.2	2.0	500	4.8	.13	<.071	<.05	CC-13B
--	62	27	54	11,000	5.3	<.031	<.071	1.0	CC-16A
--	111	2.0	190	460	6.5	.18	<.071	.20	CC-16B
--	6	54	29	<26	5.7	1.6	.12	.10	CC-17A
--	24	19	17	170	4.8	.055	<.071	.09	CC-17B
--	<1	9.1	720	<24	5.4	<.031	<.071	.38	CC-18A
--	26	15	14	<24	5.3	>.22	<.071	.12	CC-18B
3.0	62	56	51	13,000	7.8	--	.10	.12	CC-20C
--	27	14	19	>5,000	4.2	.084	<.071	.07	CC-20D
--	26	18	24	28	5.4	.18	<.071	.90	CC-21A
--	--	16	24	49	5.4	.18	<.071	.09	CC-21A
--	151	64	<33	34,000	2.4	<.031	<.071	<.05	CC-22B
--	112	52	42	24,000	3.8	<.031	<.071	.06	CC-23B
--	96	68	42	14,000	3.4	<.031	<.071	.10	CC-25A
--	--	72	39	14,000	3.5	<.031	<.071	.09	CC-25A
--	61	39	56	62	5.2	.87	.13	<.05	CC-26A
--	60	6.0	82	68	2.9	1.4	<.071	.08	CC-26B
--	1	120	41	220	16	1.3	.25	<.05	CC-27A
--	12	100	8.0	270	8.1	.91	.42	<.05	CC-27B
--	<1	170	1,900	110	7.2	1.8	<.071	.62	CC-28A
--	<1	100	610	400	4.5	1.9	<.071	.12	CC-28B
--	6	27	2.0	340	5.2	.55	.11	.11	CC-30A
--	241	.26	35	>50,000	2.1	.034	<.071	.10	CC-36B
--	286	.27	18	49,000	2.7	<.031	<.071	.06	CC-36C
--	12	67	21	1,200	8.8	.044	.13	.11	CC-102B
--	10	61	19	460	3.8	<.031	<.071	.07	CC-102C
--	9	6.5	6.6	200	5.4	.051	<.071	<.05	CC-104B
--	24	2.4	3.8	4,100	4.9	<.031	<.071	<.05	CC-104C
--	100	12	>240	<24	4.5	<.031	<.071	.13	CC-107A
--	47	5.2	980	<24	4.8	.17	<.071	.40	CC-107B
--	77	81	31	220	6.6	.66	<.071	.20	CC-108A
--	56	55	23	<24	5.8	.47	<.071	.16	CC-108B
--	18	7.8	140	<24	5.5	.21	<.071	.16	CC-109A
--	180	18	14	<26	5.6	.14	.30	.07	CC-110A
--	23	13	23	<26	5.0	1.1	<.071	.12	CC-111A

Appendix B3.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Third sampling period (April-May 1989)--Continued

Local identifier	Sampling date	Manganese, dissolved (μg/L as Mn)	Aluminum, dissolved (μg/L as Al)	Antimony, dissolved (μg/L as Sb)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Boron, dissolved (μg/L as B)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)
CANAL CREEK AQUIFER--Continued									
CC-1B	05-22-89	1,000	<180	<67	32	16	<260	<3	<49
CC-1B	05-22-89	1,300	<180	<67	31	17	310	<3	<49
CC-1B	05-22-89	1,000	<10	3	45	14	190	<1	<5
CC-1C	05-22-89	830	<180	<67	6	29	<260	<3	<49
CC-7A	05-24-89	390	<180	<67	<3	16	<260	<3	<49
CC-7B	05-24-89	280	210	<67	<3	22	<260	3	<49
CC-7B	05-24-89	--	--	--	--	--	--	--	--
CC-8B	05-25-89	140	<180	<67	<3	20	<260	<3	<50
CC-8B	05-25-89	140	<180	<67	<3	21	<260	<3	<49
CC-8B	05-25-89	150	40	<1	1	18	<10	<1	<5
CC-8C	05-25-89	380	190	<67	<3	43	<260	<3	<50
CC-8D	05-25-89	190	<180	<67	<3	15	<260	<3	<49
CC-11A	05-30-89	77	<10	<1	1	6	<10	<1	<5
CC-11B	05-31-89	110	<10	<1	<1	8	<10	<1	<5
CC-13A	05-04-89	320	670	<72	<3	210	<270	<3	<50
CC-13B	05-04-89	40	<160	<72	<3	18	<270	<3	<50
CC-16A	05-03-89	720	<160	<72	3	29	<270	<3	<50
CC-16B	05-03-89	<1	<160	<72	4	81	<270	<3	<50
CC-17A	05-03-89	180	<160	<72	<3	52	<270	<3	<50
CC-17B	05-03-89	170	<160	<72	<3	24	<270	<3	<50
CC-18A	05-08-89	600	570	<67	<3	190	<260	<3	<49
CC-18B	05-08-89	41	<180	<67	<3	12	<260	<3	<49
CC-20C	05-18-89	100	<10	<1	7	32	90	2	<5
CC-20D	05-19-89	530	<180	<67	<3	2	<260	<3	<49
CC-21A	05-04-89	40	<160	<72	<3	19	<270	<3	<50
CC-21A	05-04-89	43	<160	<72	<3	19	<270	<3	<50
CC-22B	05-17-89	1,700	<180	<67	3	39	<270	<3	<49
CC-23B	05-15-89	320	<180	<67	18	42	<270	<3	<49
CC-25A	05-17-89	81	<180	<67	9	31	<270	<3	<49
CC-25A	05-17-89	79	<180	<67	10	33	<260	<3	<49
CC-26A	04-27-89	100	<160	<72	<1	35	2,800	<3	<50
CC-26B	04-27-89	400	<160	<72	<1	41	320	<3	<50
CC-27A	05-01-89	490	2,400	<72	<3	44	<270	<3	<50
CC-27B	05-01-89	1,100	2,100	<72	<3	45	<270	<3	<50
CC-28A	04-28-89	740	14,000	<72	8	39	<270	5	<50
CC-28B	04-28-89	800	2,700	<72	<1	34	<270	5	<50
CC-30A	05-03-89	140	<160	<72	<3	28	<270	<3	<50
CC-36B	05-17-89	1,800	<180	<67	17	37	590	11	<49
CC-36C	05-17-89	980	<180	<67	6	34	<260	6	<49
CC-102B	05-22-89	1,400	260	<67	<3	29	<260	<3	<49
CC-102C	05-24-89	290	<180	<67	<3	42	<260	<3	<49
CC-104B	05-25-89	130	<180	<67	<3	12	<260	<3	<49
CC-104C	05-26-89	80	<180	<67	<3	13	<260	<3	<49
CC-107A	05-09-89	500	<180	<67	<3	74	<260	<3	<49
CC-107B	05-09-89	10,000	<180	<67	<3	210	<260	<3	<49
CC-108A	05-09-89	1,700	<180	<67	<3	88	270	<3	<49
CC-108B	05-09-89	680	<180	<67	<3	81	<260	<3	<49
CC-109A	05-08-89	320	<180	<67	<3	68	<260	<3	<49
CC-110A	05-01-89	1	240	<72	<3	120	<270	<3	<50
CC-111A	05-01-89	39	<160	<72	<3	38	<270	<3	<50

Copper, dis- solved (μg/L as Cu)	Lead, dis- solved (μg/L as Pb)	Mercury, dis- solved (μg/L as Hg)	Nickel, dis- solved (μg/L as Ni)	Sele- nium, dis- solved (μg/L as Se)	Silver, dis- solved (μg/L as Ag)	Thal- lium, dis- solved (μg/L as Tl)	Zinc, dis- solved (μg/L as Zn)	Local ident- ifier
<21	11	0.9	<30	<4	<0.3	180	350	CC-1B
<21	7	1.8	<30	<4	<.3	<45	44	CC-1B
<10	10	--	10	<1	1.0	--	10	CC-1B
<21	<5	<.6	<30	<4	<.3	<45	53	CC-1C
<21	7	1.0	<30	<4	<.3	<45	100	CC-7A
<21	9	<.6	<30	<4	<.3	<45	120	CC-7B
--	--	--	--	--	--	--	--	CC-7B
<21	6	<.6	68	<4	<.3	<45	240	CC-8B
<21	<5	<.6	63	<4	<.3	<45	220	CC-8B
<10	<10	--	60	<1	1.0	--	130	CC-8B
<21	<5	.6	100	<4	<.3	<45	180	CC-8C
<21	11	<.6	<30	<4	<.3	<45	89	CC-8D
<10	<10	--	10	<1	<1.0	--	82	CC-11A
<10	<10	--	<10	<1	<1.0	--	15	CC-11B
34	6	<.6	210	<4	<.3	<44	470	CC-13A
<22	<5	<.6	<32	<4	<.3	<44	120	CC-13B
<22	<5	<.6	<32	<4	<.3	<44	100	CC-16A
<22	<5	<.6	39	<4	.3	<44	460	CC-16B
26	<5	<.6	43	<4	<.3	<44	220	CC-17A
25	<5	<.6	<32	<4	<.3	<44	280	CC-17B
74	7	<.6	170	<4	<.3	<45	250	CC-18A
<21	11	<.6	<30	<4	<.3	<45	<44	CC-18B
<10	20	--	<10	1	3.0	--	9	CC-20C
<21	7	<.6	<30	<4	<.3	<45	94	CC-20D
<22	<5	<.6	33	<4	<.3	<44	140	CC-21A
<22	<5	<.6	<32	<4	<.3	<44	150	CC-21A
<21	<5	.8	<30	<4	<.3	<45	48	CC-22B
<21	8	<.6	<30	<4	<.3	<45	69	CC-23B
<21	<5	<.6	<30	<4	1.6	<45	120	CC-25A
210	<5	<.6	<30	<4	1.9	<45	<44	CC-25A
<22	<5	<.6	<32	<4	<.3	<44	45	CC-26A
<22	<5	<.6	<32	<4	<.3	<44	800	CC-26B
38	<5	<.6	51	<4	<.3	<44	270	CC-27A
53	<5	<.6	43	<4	<.3	<44	130	CC-27B
240	45	<.6	97	<4	<.3	<44	800	CC-28A
<22	<5	<.6	<32	<4	<.3	<44	970	CC-28B
<22	<5	<.6	51	<4	<.3	<44	120	CC-30A
<21	59	<.6	<30	<4	<.3	<45	110	CC-36B
<21	15	<.6	<30	<4	<.3	<45	59	CC-36C
<21	8	.8	170	<4	<.3	57	260	CC-102B
<21	<5	<.6	<30	<4	<.3	<45	49	CC-102C
<21	<5	<.6	<30	<4	<.3	<45	220	CC-104B
<21	12	<.6	<30	<4	<.3	<45	<44	CC-104C
<21	<5	<.6	<30	<4	<.3	<45	<44	CC-107A
<21	8	.6	140	<4	<.3	<45	200	CC-107B
<21	6	<.6	150	<4	<.3	<45	110	CC-108A
<21	<5	<.6	<82	<4	<.3	<45	80	CC-108B
<21	9	1.6	100	<4	<.3	<45	150	CC-109A
<22	<5	<.6	<32	<4	<.3	<44	<42	CC-110A
<22	<5	<.6	<32	<4	<.3	<44	92	CC-111A

Appendix B3.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Third sampling period (April-May 1989)--Continued

Local ident- ifier	Sampling date	Comments	Temper- ature, water (deg C)	Oxygen, dis- solved (mg/L)	Spe- cific con- duct- ance (μs/cm)	pH (stand- ard units)	Solids, residue at 180 deg C, dis- solved (mg/L)	Trit- ium, total (pci/L)	Calcium, dis- solved (mg/L as Ca)	Magne- sium, dis- solved (mg/L as Mg)	Sodium dis- solved (mg/L as Na
CANAL CREEK AQUIFER--Continued											
CC-111B	05-03-89	H	14.5	1.0	118	5.18	86	--	4.9	2.5	7.4
CC-111B	05-03-89	R,H	--	--	--	--	--	--	--	--	--
CC-112A	05-15-89		15.0	.3	58	4.99	44	--	1.6	.72	440
CC-112A	05-15-89	R	--	--	--	--	--	--	--	--	--
CC-113A	04-28-89		14.5	.9	698	5.45	444	--	19	>5.1	76
CC-113A	04-28-89	R	--	--	--	--	451	--	19	>5.1	71
CC-113A	04-28-89	R,H	--	--	--	--	--	--	--	--	--
CC-113B	04-28-89		15.0	1.8	368	6.00	215	--	13	8.7	>6.0
CC-114B	04-27-89		16.5	2.3	373	5.70	252	--	16	>5.1	>6.0
CC-114C	04-27-89		16.0	1.9	432	4.97	297	--	14	>5.1	>6.0
CC-115A	04-28-89		17.0	.2	422	5.35	297	--	26	8.7	13
CC-118A	05-08-89	H	15.0	4.4	2,660	5.57	1,590	--	36	22	350
CC-118A	05-08-89	R,H	--	--	--	--	--	--	--	--	--
CC-118B	05-08-89	H	16.0	1.6	1,290	5.27	814	--	41	15	130
CC-120A	05-15-89		20.0	.6	373	5.88	229	--	16	9.1	<49
CC-120A	05-15-89	R	--	--	--	--	--	--	--	--	--
CC-120A	05-15-89	R,H	--	--	--	--	219	--	16	11	<49
CC-120A	05-15-89	R,N	20.0	.6	373	5.88	--	--	17	9.9	33
CC-120B	05-09-89	G	18.0	.9	250	6.49	164	--	23	3.9	<49
CC-122A	04-26-89	B,H	14.0	1.5	308	5.97	200	--	11	5.0	21
CC-130A	05-04-89	H	15.0	.6	326	5.91	181	--	7.1	3.3	35
CC-130B	05-04-89	H	15.0	1.8	3,190	6.22	1,830	--	26	17	250
CC-133B	05-18-89	H	18.0	4.5	533	4.65	317	75	21	12	44
CC-136A	05-26-89	N,B	15.0	<.1	66	5.73	--	<5.7	1.8	.56	5.7
CC-136A	05-26-89	R,N,B	--	--	--	--	--	--	--	--	--
CC-136B	05-26-89	N,B	15.0	.2	49	5.68	--	<5.7	2.8	.50	2.7
SURFICIAL AQUIFER											
CC-1A	05-19-89	H	15.0	<0.1	223	6.32	123	100	12	4.6	9.2
CC-10A	04-25-89	H	12.5	2.6	254	6.21	--	--	--	--	--
CC-12A.1	04-25-89	H	13.0	.9	221	6.92	--	--	--	--	--
CC-20A	05-18-89	N	14.5	2.2	235	5.99	--	69	18	9.4	11
CC-20B	05-19-89	H	15.0	3.1	285	5.61	201	110	25	9.9	13
CC-33A	04-26-89	H	12.5	9.5	405	5.24	282	--	3.3	6.3	41
CC-33B	04-26-89	H	13.5	.5	2,460	3.97	1,460	--	23	46	230
CC-33B	04-26-89	R,H	--	--	--	--	1,450	--	22	45	220
CC-114A	04-27-89		14.5	6.5	295	6.80	229	--	3.6	>5.1	>6.0
CC-127A	04-25-89	U,H	15.0	11	65	4.82	--	--	--	--	--
CC-128A	04-25-89	H	11.5	10	74	5.30	--	--	--	--	--
CC-129A	04-25-89	H	15.0	1.0	89	4.95	--	--	--	--	--
CC-133A	05-18-89	H	16.5	6.6	245	5.80	148	110	19	6.7	14
CC-135A	04-25-89	H	12.5	.7	122	5.72	--	--	--	--	--
CC-138A	04-26-89	H	--	--	--	--	--	--	--	--	--
LOWER CONFINED AQUIFER											
CC-1D	06-01-89	N	15.0	0.4	35	5.25	--	<5.7	1.1	0.49	2.0
CC-1E	06-06-89	N,G	16.0	1.1	303	11.2	--	8.6	6.9	.21	27
CC-8E	06-01-89	N	16.5	.3	37	4.60	--	<5.7	1.2	.53	2.3
CC-8E	06-01-89	R,N	--	--	--	--	--	<5.7	.94	.46	2.2
CC-16C	06-07-89	N,G	17.5	.6	133	7.42	--	<5.7	20	.28	2.8
CC-17C	06-02-89	N	17.5	1.3	36	4.94	--	<5.7	1.4	.54	2.6
CC-17C	06-02-89	N,R	--	--	--	--	--	<5.7	1.2	.52	2.8
CC-26C	06-07-89	N	17.0	.2	63	5.77	--	<5.7	4.1	.79	2.5

Potassium, dissolved (mg/L as K)	Bicarbonate, (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L SiO_2)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Local identifier
--	10	18	19	90	4.9	0.31	<0.070	0.10	CC-111B
--	--	--	--	--	--	--	--	--	CC-111B
--	5	3.4	10	<2,400	4.8	<.031	.25	<.05	CC-112A
--	--	--	--	--	--	--	--	--	CC-112A
--	17	140	170	<30	4.8	1.1	<.071	<.53	CC-113A
--	--	140	170	<30	5.1	1.1	<.071	.19	CC-113A
--	--	--	--	--	--	--	--	--	CC-113A
--	40	45	73	<30	5.3	1.5	<.071	.11	CC-113B
--	34	52	79	<30	5.6	<3.1	<.071	.11	CC-114B
--	9	51	100	<30	5.7	<3.1	<.071	.12	CC-114C
--	7	150	89	<440	5.4	<.031	<.071	.11	CC-115A
--	22	28	950	<20	5.0	.57	<.071	.51	CC-118A
--	--	--	--	--	--	--	--	--	CC-118A
--	10	1.3	450	<20	5.7	> .22	<.071	.21	CC-118B
--	24	100	15	240	6.7	> .22	.19	1.1	CC-120A
--	--	--	--	--	--	--	--	--	CC-120A
--	--	>53	15	300	7.0	<.31	.18	1.1	CC-120A
7.0	24	110	15	280	15	.20	.20	1.3	CC-120A
--	83	35	11	<20	6.0	.46	<.071	.54	CC-120B
--	54	33	<33	<440	5.7	.20	.086	.06	CC-122A
--	56	28	44	>540	5.8	.10	.071	.19	CC-130A
--	74	26	1,200	1,900	5.2	.48	<.071	.54	CC-130B
--	<1	50	130	<20	3.8	3.3	<.071	.17	CC-133B
.90	21	4.0	6.8	5,800	9.1	--	.10	.12	CC-136A
--	--	--	--	--	--	--	--	--	CC-136A
1.2	19	3.0	3.6	3,600	9.7	.20	.10	.03	CC-136B
--	79	17	20	18,000	4.2	<0.031	0.11	0.08	CC-1A
--	--	--	--	--	--	--	--	--	CC-10A
--	--	--	--	--	--	--	--	--	CC-12A.1
3.3	57	30	16	20	6.5	--	.10	.02	CC-20A
--	32	50	50	50	3.7	2.2	<.071	<.05	CC-20B
--	15	75	80	<30	18	.033	<.071	.15	CC-33A
--	<1	86	860	<30	11	<.031	<.071	1.7	CC-33B
--	--	83	750	<30	12	.046	<.071	1.7	CC-33B
--	102	42	8.3	<30	5.6	1.3	.14	<.05	CC-114A
--	--	--	--	--	--	--	--	--	CC-127A
--	--	--	--	--	--	--	--	--	CC-128A
--	--	--	--	--	--	--	--	--	CC-129A
--	32	41	37	80	2.6	1.8	<.071	<.05	CC-133A
--	--	--	--	--	--	--	--	--	CC-135A
--	--	--	--	--	--	--	--	--	CC-138A
0.60	9	6.0	2.0	3,100	7.6	--	<0.10	0.04	CC-1D
68	209	--	--	10	4.9	--	--	<.01	CC-1E
.60	20	7.0	1.5	3,400	8.2	--	<.10	.04	CC-8E
.60	--	7.0	1.5	3,300	8.0	--	<.10	.04	CC-8E
1.7	63	9.0	2.0	640	8.0	--	.10	.05	CC-16C
.70		8.0	2.2	1,300	8.5	--	<.10	.03	CC-17C
.80	--	8.0	2.2	1,300	8.3	--	<.10	.04	CC-17C
1.9	22	7.0	2.1	3,800	8.6	--	.10	.05	CC-26C

Appendix B3.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Third sampling period (April-May 1989)--Continued

Local identifier	Sampling date	Manganese, dissolved (μg/L as Mn)	Aluminum, dissolved (μg/L as Al)	Antimony, dissolved (μg/L as Sb)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Boron, dissolved (μg/L as B)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)
					CANAL CREEK AQUIFER--Continued				
CC-111B	05-03-89	66	<160	<70	<3	27	<270	<3	<50
CC-111B	05-03-89	--	--	--	--	--	--	--	--
CC-112A	05-15-89	10,000	<180	<70	<3	11	<260	<3	<50
CC-112A	05-15-89	--	--	--	--	--	--	--	--
CC-113A	04-28-89	710	<160	<70	<1	31	<270	<3	<50
CC-113A	04-28-89	700	<160	<70	<1	32	<270	<3	<50
CC-113A	04-28-89	--	--	--	--	--	--	--	--
CC-113B	04-28-89	180	<160	<70	<1	59	<270	<3	<50
CC-114B	04-27-89	380	<160	<70	<1	73	340	22	<50
CC-114C	04-27-89	410	<160	<70	<1	120	<270	4	<50
CC-115A	04-28-89	250	<160	<70	<1	36	<270	<3	<50
CC-118A	05-08-89	260	190	<70	<3	260	<260	<3	<50
CC-118A	05-08-89	--	--	--	--	--	--	--	--
CC-118B	05-08-89	72,000	420	<70	--	270	<260	<3	<50
CC-120A	05-15-89	2,000	210	<70	<3	73	<260	<3	<50
CC-120A	05-15-89	--	--	--	--	--	--	--	--
CC-120A	05-15-89	2,000	190	<70	<3	70	<260	<3	<50
CC-120A	05-15-89	2,000	<10	<1	<1	68	--	<1	<5
CC-120B	05-09-89	18,000	<180	<70	<3	120	<260	<3	<50
CC-122A	04-26-89	1,900	<160	<70	<1	55	<270	<3	<50
CC-130A	05-04-89	64	<160	<70	<3	43	<270	<3	<50
CC-130B	05-04-89	780	<160	<70	<3	250	270	<3	<50
CC-133B	05-18-89	380	350	<70	<3	150	<260	<3	<50
CC-136A	05-26-89	130	<10	<1	<1	8	<10	<1	<5
CC-136A	05-26-89	--	--	--	--	--	--	--	--
CC-136B	05-26-89	85	<10	<1	<1	7	<10	<1	<5
					SURFFICIAL AQUIFER--Continued				
CC-1A	05-19-89	390	<180	<70	9	19	<260	5	<50
CC-10A	04-25-89	--	--	--	--	--	--	--	--
CC-12A.1	04-25-89	--	--	--	--	--	--	--	--
CC-20A	05-18-89	<1	<10	<1	<1	28	70	<1	<5
CC-20B	05-19-89	10	<180	<70	<3	52	<260	<3	<50
CC-33A	04-26-89	160	<160	<70	<1	24	<270	<3	<50
CC-33B	04-26-89	2,700	<160	<70	<1	77	<270	<3	<50
CC-33B	04-26-89	2,700	<160	<70	<1	74	<270	<3	<50
CC-114A	04-27-89	27	<160	<70	<1	20	1,400	<3	<50
CC-127A	04-25-89	--	--	--	--	--	--	--	--
CC-128A	04-25-89	--	--	--	--	--	--	--	--
CC-129A	04-25-89	--	--	--	--	--	--	--	--
CC-133A	05-18-89	6	<180	<70	<3	30	<260	<3	<50
CC-135A	04-25-89	--	--	--	--	--	--	--	--
CC-138A	04-26-89	--	--	--	--	--	--	--	--
					LOWER CONFINED AQUIFER--Continued				
CC-1D	06-01-89	82	<10	<1	<1	7	<10	<1	<5
CC-1E	06-06-89	<1	130	<1	1	15	<10	<1	<5
CC-8E	06-01-89	88	10	<1	<1	7	<10	<1	<5
CC-8E	06-01-89	85	<10	<1	<1	7	<10	<1	<5
CC-16C	06-07-89	22	90	<1	<1	9	<10	<1	<5
CC-17C	06-02-89	57	30	<1	<1	13	<10	<1	<5
CC-17C	06-02-89	57	30	<1	<1	13	<10	1	<5
CC-26C	06-07-89	130	10	<1	<1	20	<10	<1	<5

Copper, dissolved (µg/L as Cu)	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Thallium, dissolved (µg/L as Tl)	Zinc, dissolved (µg/L as Zn)	Local identifier
<20	<5	<0.6	39	<4	<0.3	<40	100	CC-111B
--	--	--	--	--	--	--	--	CC-111B
<20	<5	<.6	<30	<4	<.3	<40	<44	CC-112A
--	--	--	--	--	--	--	--	CC-112A
<20	<5	<.6	<32	<4	<.3	<40	<42	CC-113A
<20	<5	<.6	<32	<4	<.3	<40	<42	CC-113A
--	--	--	--	--	--	--	--	CC-113A
<20	<5	<.6	<32	<4	<.3	<40	74	CC-113B
<20	<5	<.6	<32	<4	<.3	<40	>970	CC-114B
<20	<5	<.6	<32	<4	<.3	<40	660	CC-114C
30	<5	<.6	97	<4	<.3	<40	140	CC-115A
30	11	<.6	120	<4	<.3	<40	160	CC-118A
--	--	--	--	--	--	--	--	CC-118A
<20	--	<.6	210	--	--	<40	280	CC-118B
<20	<5	<.6	120	<4	<.3	<40	120	CC-120A
--	--	--	--	--	--	--	--	CC-120A
<20	6	3.0	100	<4	<.3	<40	120	CC-120A
20	<10	<.1	110	1	2.0	--	120	CC-120A
<20	<5	1.7	<30	<4	<.3	<40	<44	CC-120B
<20	<5	<.6	<32	<4	<.3	<40	57	CC-122A
<20	<5	<.6	61	<4	.7	<40	110	CC-130A
<20	<5	<.6	110	<4	<.3	<40	210	CC-130B
<20	6	<.6	<30	<4	<.3	<40	68	CC-133B
<10	<10	--	<10	<1	<1.0	--	8	CC-136A
--	--	--	--	--	--	--	--	CC-136A
<10	<10	--	<10	<1	<1.0	--	460	CC-136B
120	<5	<0.6	80	<4	<0.3	<40	400	CC-1A
--	--	--	--	--	--	--	--	CC-10A
--	--	--	--	--	--	--	--	CC-12A.1
<10	<10	--	<10	1	<1.0	--	20	CC-20A
<20	7	<.6	<30	<4	<.3	<40	52	CC-20B
<20	<5	<.6	<32	<4	<.3	<40	<42	CC-33A
100	15	<.6	220	<4	2.6	<40	570	CC-33B
90	12	<.6	210	<4	<.3	<40	510	CC-33B
<20	<5	<.6	<32	<4	<.3	<40	<42	CC-114A
--	--	--	--	--	--	--	--	CC-127A
--	--	--	--	--	--	--	--	CC-128A
--	--	--	--	--	--	--	--	CC-129A
<20	6	<.6	<30	<4	<.3	<40	<44	CC-133A
--	--	--	--	--	--	--	--	CC-135A
--	--	--	--	--	--	--	--	CC-138A
<10	<10	--	<10	<1	<1.0	--	47	CC-1D
<10	<10	--	<10	<1	<1.0	--	100	CC-1E
<10	<10	--	<10	<1	<1.0	--	39	CC-8E
<10	<10	--	<10	<1	<1.0	--	20	CC-8E
<10	<10	--	<10	<1	<1.0	--	52	CC-16C
<10	<10	--	20	<1	<1.0	--	33	CC-17C
<10	<10	--	20	6	<1.0	--	45	CC-17C
<10	<10	--	10	<1	<1.0	--	39	CC-26C

Appendix B4.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland-- Third sampling period (April-May 1989)

[mg/L, milligrams per liter; µg/L, micrograms per liter; R, replicate sample; B, sample from background well site in Can Creek aquifer; G, suspected of grout contamination; U, sample from uncontaminated well site in surficial aquifer; H, halocarbon analysis for volatile organics; N, sample analyzed by the U.S. Geological Survey National Water Quality Laboratory; --, not analyzed for]

Local identifier	Sampling date	Comments	Carbon, organic total (mg/L as C)	Total organic halogen (µg/L as Cl)	Methane (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Benzene (µg/L)	Chlorobenzene (µg/L)	Carbon tetrachloride (µg/L)
CANAL CREEK AQUIFER										
CC-1B	05-22-89	H	1.3	1,100	2,400	--	--	--	1.1	<0.15
CC-1B	05-22-89	R,H	1.4	1,100	--	--	--	--	<1.0	<.15
CC-1B	05-22-89	R,N	2.0	--	2,400	<3.0	<3.0	<3.0	<3.0	<3.0
CC-1C	05-22-89	H	<.5	1,100	2,600	--	--	--	1.3	<.15
CC-7A	05-24-89	H	<.5	130	2,000	--	--	--	3.0	<.15
CC-7B	05-24-89	H	<.5	420	5,900	--	--	--	2.9	1.8
CC-7B	05-24-89	R,N	--	--	5,900	<3.0	<3.0	<3.0	3.3	<3.0
CC-8B	05-25-89	H	<.5	680	2,200	--	--	--	1.2	9.2
CC-8B	05-25-89	R,H	<.5	690	--	--	--	--	1.4	8.8
CC-8B	05-25-89	R,N	1.5	--	2,200	<3.0	<3.0	<3.0	<3.0	9.5
CC-8C	05-25-89	H	<.5	320	1,100	--	--	--	<1.0	2.0
CC-8D	05-25-89	H	<.5	340	2,400	--	--	--	<1.0	2.3
CC-11A	05-30-89	N,B	.4	--	15	<3.0	<3.0	<3.0	<3.0	<3.0
CC-11B	05-31-89	N,B	1.3	--	78	<3.0	<3.0	<3.0	<3.0	<3.0
CC-13A	05-04-89	H	<.5	430	--	--	--	--	<.81	--
CC-13B	05-04-89	H	<.5	86	--	--	--	--	<.81	--
CC-16A	05-03-89		4.7	2,100	--	<8.1	<9.6	170	9.5	<5.9
CC-16B	05-03-89		.9	210	--	<8.1	<9.6	<2.4	<1.4	23
CC-17A	05-03-89	H	.8	600	--	--	--	--	<1.0	91
CC-17B	05-03-89	H	<.5	400	--	--	--	--	<1.0	32
CC-18A	05-08-89	H	<.5	260	--	--	--	--	<1.0	--
CC-18B	05-08-89	H	.6	530	--	--	--	--	<1.0	--
CC-20C	05-18-89	N	.8	--	15	<3.0	<3.0	<3.0	<3.0	<3.0
CC-20D	05-19-89	H	<.5	<60	140	--	--	--	<1.0	<3.8
CC-21A	05-04-89	H	<.5	250	--	--	--	--	<.81	--
CC-21A	05-04-89	R,H	<.5	270	--	--	--	--	<.81	--
CC-22B	05-17-89	H	--	--	--	--	--	--	<1.0	<.15
CC-23B	05-15-89	H	--	--	--	--	--	--	<1.0	<.15
CC-25A	05-17-89	H	<.5	110	--	--	--	--	<1.0	<.15
CC-25A	05-17-89	R,H	.7	170	--	--	--	--	<1.0	<.15
CC-26A	04-27-89		<.5	620	--	<8.1	<9.6	<2.4	<1.4	1,100
CC-26B	04-27-89		1.0	480	--	<8.1	<9.6	57	<1.4	1,100
CC-27A	05-01-89		1.6	2,900	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-27B	05-01-89		.7	180	--	<8.1	<9.6	<2.4	<1.4	24
CC-28A	04-28-89		.9	1,100	--	<8.1	<9.6	<2.4	<1.4	950
CC-28B	04-28-89		<.5	630	--	<8.1	<9.6	<2.4	<1.4	420
CC-30A	05-03-89	H	<.5	980	--	--	--	--	<1.0	81
CC-36B	05-17-89	H	8.1	<60	--	--	--	--	<1.0	<.15
CC-36C	05-17-89	H	13	<60	--	--	--	--	<1.0	<.15
CC-102B	05-22-89	H	<.5	130	1,700	--	--	--	<1.0	<3.0
CC-102C	05-24-89	H	<.5	220	1,700	--	--	--	<1.0	.22
CC-104B	05-25-89	H	<.5	120	280	--	--	--	<1.0	8.6
CC-104C	05-26-89	H	<.5	80	290	--	--	--	<1.0	1.2
CC-107A	05-09-89	G,H	2.0	240	--	--	--	--	<1.0	--
CC-107B	05-09-89	H	<.5	270	--	--	--	--	<1.0	--
CC-108A	05-09-89		.5	2,400	--	<8.1	<9.6	<2.4	<1.4	3,200
CC-108B	05-09-89	G	<.5	2,100	--	<8.1	<9.6	<2.4	<1.4	1,000
CC-109A	05-08-89	H	<.5	200	--	--	--	--	<1.0	--
CC-110A	05-01-89	G,H	4.0	320	--	--	--	--	<1.0	160
CC-111A	05-01-89		<.5	450	--	<8.1	<9.6	<2.4	<1.4	320

Chloroform (μg/L)	Methylchloride (μg/L)	Methylene chloride (μg/L)	1,1,2,2-Tetrachloroethane (μg/L)	1,1,1-Trichloroethane (μg/L)	1,1,2-Trichloroethane (μg/L)	1,2-Dichloroethane (μg/L)	1,1-Dichloroethane (μg/L)	Local identifier
<0.73	<0.73	<2.4	<11	<0.18	<1.3	<5.1	0.32	CC-1B
<.73	<.73	<2.4	<11	<.18	1.9	<5.1	.42	CC-1B
<3.0	<3.0	<3.0	3.9	<3.0	<3.0	<3.0	<3.0	CC-1B
<.73	<.73	<2.4	<11	<.18	3.2	7.4	.56	CC-1C
<7.3	<.73	<2.4	13	<.18	1.0	1.9	<.27	CC-7A
11	<.73	<2.4	>200	<.18	8.5	4.7	<.27	CC-7B
5.8	<3.0	<3.0	490	<3.0	10	<3.0	<3.0	CC-7B
11	<.73	<2.4	>410	<.18	7.9	2.5	<.27	CC-8B
10	<.73	<2.4	>410	<.18	7.7	2.5	.27	CC-8B
8.2	<3.0	<3.0	540	<3.0	8.2	<3.0	<3.0	CC-8B
14	<.73	<2.4	>200	<.18	7.6	5.7	<.27	CC-8C
10	<.73	<2.4	>200	<.18	5.0	3.4	<.27	CC-8D
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-11A
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-11B
>1.7	<.72	<2.3	240	<.16	4.9	<.23	<.27	CC-13A
.70	<.72	<2.3	66	<.16	.90	<.23	<.27	CC-13B
26	<1.1	<5.3	<5.0	<4.5	<19	<6.9	8.5	CC-16A
3.4	<1.1	<5.3	200	<4.5	<19	<6.9	<1.1	CC-16B
18	<.70	<2.4	>41	<3.6	3.4	--	<.30	CC-17A
18	<.70	<2.4	36	<.20	14	9.1	<.30	CC-17B
<7.3	2.7	<2.4	160	<.18	1.2	<.26	<.27	CC-18A
<7.3	1.3	<2.4	>200	<.18	3.9	<.26	<.27	CC-18B
8.2	<3.0	<3.0	8.9	<3.0	<3.0	<3.0	<3.0	CC-20C
25	<.73	<2.4	21	<.18	.40	1.3	<.27	CC-20D
<6.1	1.1	<2.3	120	1.9	1.4	<.23	<.27	CC-21A
6.6	1.3	<2.3	87	1.8	1.6	<.23	<.27	CC-21A
<.73	<.73	<2.4	<.56	<.18	<.07	.85	<.27	CC-22B
<.73	<.73	<2.4	<.56	<.18	<.07	.42	<.27	CC-23B
<.72	<.73	<2.4	20	<.18	.96	<.26	<.27	CC-25A
<.73	<.73	<2.4	24	<.18	.93	<.26	<.27	CC-25A
94	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-26A
130	<1.1	<5.3	100	<4.5	<19	<6.9	<1.1	CC-26B
1.2	<1.1	<5.3	3,700	<4.5	27	<6.9	<1.1	CC-27A
30	<1.1	<5.3	14	<4.5	<19	<6.9	<1.1	CC-27B
400	<1.1	<5.3	99	<4.5	<19	<6.9	<1.1	CC-28A
130	<1.1	<5.3	44	<4.5	<19	<6.9	<1.1	CC-28B
>40	<.70	<2.4	>41	<.20	7.5	13	<.30	CC-30A
<.73	<.73	<2.4	<.56	<.18	<.07	<.26	<.27	CC-36B
<.73	<.73	<2.4	<.56	<.18	<.07	<.26	<.27	CC-36C
<14	<.73	<2.4	<110	<.18	<1.3	.65	<.27	CC-102B
<73	<.73	<2.4	91	<.18	6.9	4.3	<.27	CC-102C
<7.3	<.73	<2.4	66	<.18	1.7	1.4	<.27	CC-104B
1.3	<.73	<2.4	<56	<.18	.92	.32	.49	CC-104C
<7.3	1.4	<2.4	<56	<.18	1.2	<.26	<.27	CC-107A
1.4	1.2	<2.4	130	<.18	1.8	<.26	<.27	CC-107B
52	<1.1	<5.3	740	<4.5	<18	<6.9	<1.1	CC-108A
57	<1.1	<5.3	10,000	<4.5	<18	<6.9	<1.1	CC-108B
1.5	2.2	<2.4	91	<.18	.73	<.26	<.27	CC-109A
>40	<.70	<2.4	<.60	<.20	>2.0	13	<.30	CC-110A
23	<1.1	<5.3	320	<4.5	<19	<6.9	<1.1	CC-111A

Appendix B4.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Third sampling period (April-May 1989)--Continued

Local identifier	Sampling date	Tetrachloroethylene (μg/L)	Trichloroethylene (μg/L)	1,1-Dichloroethylene (μg/L)	1,2-trans-Dichloroethylene (μg/L)	Vinyl chloride (μg/L)	Bromoform (μg/L)	Chlorodibromomethane (μg/L)	Chloroethane (μg/L)
CANAL CREEK AQUIFER--Continued									
CC-1B	05-22-89	0.15	440	<5.1	<270	140	<0.73	<0.38	<0.86
CC-1B	05-22-89	.15	560	<5.1	<270	130	<.73	<.38	<.86
CC-1B	05-22-89	<3.0	450	4.4	1,100	140	<3.0	<3.0	<3.0
CC-1C	05-22-89	.50	600	1.8	<270	20	<.73	<.38	<.86
CC-7A	05-24-89	1.5	55	.41	100	4.0	<.73	<.38	<.86
CC-7B	05-24-89	6.5	170	1.1	120	67	<.73	<.38	<.86
CC-7B	05-24-89	4.4	170	<3.0	320	38	<3.0	<3.0	<3.0
CC-8B	05-25-89	3.6	190	<.26	<130	13	<.73	<.38	<.86
CC-8B	05-25-89	3.9	210	<.26	<130	14	<.73	<.38	<.86
CC-8B	05-25-89	6.8	75	<3.0	120	15	<3.0	<3.0	<3.0
CC-8C	05-25-89	1.5	110	<.26	21	10	<.73	<.38	<.86
CC-8D	05-25-89	1.2	110	<.26	<67	12	<.73	<.38	<.86
CC-11A	05-30-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-11B	05-31-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-13A	05-04-89	.86	110	<.26	3.8	<.40	<1.4	<.46	<.94
CC-13B	05-04-89	.50	17	<.26	<.67	<.40	<1.4	<.46	<.94
CC-16A	05-03-89	170	940	<16	3,200	250	<9.7	<7.1	<4.0
CC-16B	05-03-89	2.9	50	<16	33	<2.4	<9.7	<7.1	<4.0
CC-17A	05-03-89	2.1	>40	.40	<.70	<.50	<.70	<.40	1.7
CC-17B	05-03-89	2.5	>40	.30	<.70	<.50	<.70	<.40	<.90
CC-18A	05-08-89	1.3	<37	<.26	<.67	<.46	<.73	<.38	<.86
CC-18B	05-08-89	2.4	100	<.26	1.3	<.46	<.73	<.38	<.86
CC-20C	05-18-89	<3.0	8.6	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-20D	05-19-89	.26	>2.0	<.26	<17	.55	<.73	<.38	<.86
CC-21A	05-04-89	.83	<.34	<.26	<.67	<.40	<1.4	<.46	1.0
CC-21A	05-04-89	1.0	39	<.26	<.67	<.40	<1.4	<.46	1.2
CC-22B	05-17-89	<.03	<7.3	.50	22	8.6	<.73	<.38	<.86
CC-23B	05-15-89	<.03	<37	<.26	13	7.2	<.73	<.38	<.86
CC-25A	05-17-89	14	150	.83	15	<.46	<.73	<.38	<.86
CC-25A	05-17-89	17	180	.87	18	<.46	<.73	<.38	<.86
CC-26A	04-27-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-26B	04-27-89	66	72	<16	5.0	<2.4	<9.7	<7.1	<4.0
CC-27A	05-01-89	10	>190	<16	40	<2.4	<9.7	<7.1	<4.0
CC-27B	05-01-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-28A	04-28-89	15	59	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-28B	04-28-89	17	29	<16	4.9	<2.4	<9.7	<7.1	<4.0
CC-30A	05-03-89	5.9	>40	<.20	.90	<.50	<.70	<.40	<.90
CC-36B	05-17-89	.06	<.37	<.26	<.67	.48	<.73	<.38	<.86
CC-36C	05-17-89	<.03	<.37	<.26	<.67	.73	<.73	<.38	<.86
CC-102B	05-22-89	.54	24	<.26	18	22	<.73	<.38	<.86
CC-102C	05-24-89	<3.0	63	.32	68	61	<.73	<.38	<.86
CC-104B	05-25-89	.80	<37	<.26	9.9	1.3	<.73	<.38	<.86
CC-104C	05-26-89	.44	15	<.26	<6.7	<.46	<.73	<.38	<.86
CC-107A	05-09-89	.61	<37	.59	2.3	<.46	<.73	<.38	<.86
CC-107B	05-09-89	<.03	<37	<.26	<.67	<.46	<.73	<.38	<.86
CC-108A	05-09-89	4.9	140	<16	50	<2.4	<9.7	<7.1	<4.0
CC-108B	05-09-89	5.7	130	<16	46	<2.4	<9.7	<7.1	<4.0
CC-109A	05-08-89	.51	<37	<.26	<.67	<.46	<.73	<.38	<.86
CC-110A	05-01-89	1.9	130	1.3	<.70	<.50	<.70	<.40	<.90
CC-111A	05-01-89	2.9	45	<16	9.6	<2.4	<9.7	<7.1	<4.0

Bromo-di-chloro-methane (μg/L)	1,2-Di-chloro-benzene (μg/L)	1,3-Di-chloro-benzene (μg/L)	1,4-Di-chloro-benzene (μg/L)	1,2-Di-chloro-propane (μg/L)	trans-1,3-Di-chloro-propene (μg/L)	cis-1,3-Di-chloro-propene (μg/L)	Phenols, total (μg/L)	Local ident-ifier
<1.3	<0.55	0.59	<0.39	<0.13	<0.71	<1.0	<1	CC-1B
<1.3	<.55	.66	<.39	<.13	<.71	<1.0	<1	CC-1B
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	<1	CC-1B
<1.3	<.55	.73	<.39	<.13	<.71	<1.0	<1	CC-1C
<1.3	<.55	.32	<.39	<.13	<.71	<1.0	<1	CC-7A
<1.3	<.55	<.24	.48	<.13	<.71	<1.0	<1	CC-7B
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	CC-7B
<1.3	<.55	.62	<.39	<.13	<.71	<1.0	<1	CC-8B
<1.3	<.55	.72	<.39	<.13	<.71	<1.0	<1	CC-8B
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	2	CC-8B
<1.3	<.55	<.24	<.39	<.13	<.71	<11	<1	CC-8C
<1.3	<.55	.34	<.39	<.13	<.71	1.4	<1	CC-8D
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	5	CC-11A
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	3	CC-11B
<1.2	<.54	.40	<.39	<13	<.65	<.95	<1	CC-13A
<1.2	<.54	<.24	<.39	<.13	<.65	<.95	<1	CC-13B
<7.5	28	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-16A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-16B
1.5	<.50	.30	<.40	<.10	<.70	<1.1	<1	CC-17A
<1.3	<.50	.30	<.40	<.10	<.70	<1.1	<1	CC-17B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-18A
<1.3	<.55	.54	<.39	<.13	<.71	<1.0	<1	CC-18B
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	3	CC-20C
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-20D
<1.2	<.54	<.24	<.39	<.13	<.65	<.95	<1	CC-21A
<1.2	<.55	<.24	<.39	<1.3	<.65	<.95	<1	CC-21A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	--	CC-22B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	--	CC-23B
<1.3	<.55	.35	<.39	<.13	<.71	<1.0	<1	CC-25A
<1.3	<.55	.32	<.39	<.13	<.71	<1.0	<1	CC-25A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	25	CC-26A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-26B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-27A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-27B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-28A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-28B
<1.3	<.50	.40	<.40	<.10	<.70	<1.1	<1	CC-30A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-36B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-36C
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-102B
<1.3	<.55	<.24	<.39	<.13	<.71	2.2	<1	CC-102C
<1.3	<.55	<.24	<.39	<.13	<.71	1.1	<1	CC-104B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-104C
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-107A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-107B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-108A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-108B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-109A
<1.3	<.50	<.20	<.40	<.10	.90	<1.1	<1	CC-110A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-111A

Appendix B4.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Third sampling period (April-May 1989)--Continued

Local identifier	Sampling date	Comments	Carbon, organic total (mg/L as C)	Total organic halogen (μg/L as Cl)	Methane (μg/L)	Toluene (μg/L)	Ethylbenzene (μg/L)	Benzene (μg/L)	Chlorobenzene (μg/L)	Carbon tetrachloride (μg/L)
					CANAL CREEK AQUIFER--Continued					
CC-111B	05-03-89	H	<0.5	740	--	--	--	--	<1.0	>410
CC-111B	05-03-89	R,H	--	--	--	--	--	--	<1.0	>410
CC-112A	05-15-89		<.5	120	--	<8.7	<9.3	74	<1.4	59
CC-112A	05-15-89	R	--	--	--	--	--	--	--	--
CC-113A	04-28-89		<.5	900	--	<8.1	<9.6	<2.4	<1.4	420
CC-113A	04-28-89	R	<.5	990	--	<8.1	<9.6	<2.4	<1.4	420
CC-113A	04-28-89	R,H	--	--	--	--	--	--	<1.0	99
CC-113B	04-28-89		<.5	160	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-114B	04-27-89		<.5	240	--	<8.1	<9.6	<2.4	3.2	12
CC-114C	04-27-89		<.5	94	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-115A	04-28-89		<.5	89	--	<8.1	<9.6	<2.4	<1.4	52
CC-118A	05-08-89	H	.5	570	--	--	--	--	<1.0	--
CC-118A	05-08-89	R,H	--	--	--	--	--	--	<1.0	--
CC-118B	05-08-89	H	<.5	260	--	--	--	--	<1.0	--
CC-120A	05-15-89		1.3	3,300	--	<8.7	<9.3	43	95	1,100
CC-120A	05-15-89	R	--	--	--	<8.7	<9.3	33	93	11,000
CC-120A	05-15-89	R,H	.9	3,800	--	--	--	--	<200	>410
CC-120A	05-15-89	R,N	2.2	--	--	32	<3.0	99	<3.0	1,200
CC-120B	05-09-89	G	<.5	1,200	--	<8.1	<9.6	<2.4	5.5	210
CC-122A	04-26-89	B,H	.2	<60	--	--	--	--	<1.0	<.15
CC-130A	05-04-89	H	.5	<60	--	--	--	--	<.81	--
CC-130B	05-04-89	H	.5	350	--	--	--	--	<.81	--
CC-133B	05-18-89	H	<.5	--	--	--	--	--	<1.0	1.5
CC-136A	05-26-89	N,B	.8	--	36	<3.0	<3.0	<3.0	<3.0	<3.0
CC-136A	05-26-89	R,N	--	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-136B	05-26-89	N,B	.2	--	16	<3.0	<3.0	<3.0	<3.0	<3.0
					SURFICIAL AQUIFER					
CC-1A	05-19-89	H	<0.5	110	210	--	--	--	<1.0	<0.15
CC-10A	04-25-89	H	--	--	--	--	--	--	<1.0	.73
CC-12A.1	04-25-89	H	1.8	<60	--	--	--	--	<1.0	<.15
CC-20A	05-18-89	N	.8	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-20B	05-19-89	H	<.5	200	--	--	--	--	<1.0	4.2
CC-33A	04-26-89	H	6.1	720	--	--	--	--	<1.0	<.15
CC-33B	04-26-89	H	4.8	4,000	--	--	--	--	1.2	<.15
CC-33B	04-26-89	R,H	4.9	5,300	--	--	--	--	<1.0	<.15
CC-114A	04-27-89		.9	<60	--	<8.1	<9.6	<2.4	<1.4	31
CC-127A	04-25-89	U,H	--	--	--	--	--	--	<1.0	<.15
CC-128A	04-25-89	H	--	--	--	--	--	--	<1.0	<.15
CC-129A	04-25-89	H	<.5	<60	--	--	--	--	<1.0	<.15
CC-133A	05-18-89	H	--	--	--	--	--	--	<1.0	<1.5
CC-135A	04-25-89	H	<.5	<60	--	--	--	--	<1.0	<.15
CC-138A	04-26-89	H	--	--	--	--	--	--	<1.0	<.15
					LOWER CONFINED AQUIFER					
CC-1D	06-01-89	N	1.2	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-1E	06-06-89	N,G	2.6	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-8E	06-01-89	N	--	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-8E	06-01-89	R,N	.6	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-16C	06-07-89	N,G	.9	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-17C	06-02-89	N	.7	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-17C	06-02-89	N,R	.3	--	--	<3.0	<3.0	<3.0	<3.0	<3.0
CC-26C	06-07-89	N	20	--	--	<3.0	<3.0	<3.0	<3.0	<3.0

Chloroform (μg/L)	Methylchloride (μg/L)	Methylene chloride (μg/L)	1,1,2,2-Tetrachloroethane (μg/L)	1,1,1-Trichloroethane (μg/L)	1,1,2-Trichloroethane (μg/L)	1,2-Dichloroethane (μg/L)	1,1-Dichloroethane (μg/L)	Local identifier
>40	<0.70	<2.4	>410	<0.20	7.5	16	<0.30	CC-111B
>40	<.70	<2.4	>410	<.20	7.1	16	<.30	CC-111B
49	<1.6	<5.4	28	<4.1	<17	<7.6	<1.1	CC-112A
--	--	--	--	--	--	--	--	CC-112A
500	<1.1	<5.3	200	<4.5	<19	<6.9	<1.1	CC-113A
500	<1.1	<5.3	190	<4.5	<19	<6.9	<1.1	CC-113A
64	<.70	<2.4	>41	<.20	>2.0	--	<.30	CC-113A
34	<1.1	<5.3	9.3	<4.5	<19	<6.9	<1.1	CC-113B
100	<1.1	<5.3	58	<4.5	<19	<6.9	<1.1	CC-114B
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-114C
29	<1.1	<5.3	33	<4.5	<19	<6.9	<1.1	CC-115A
1.6	1.6	<2.4	>200	.44	3.4	<.26	<.27	CC-118A
<73	1.4	<2.4	>200	<.18	4.3	<.25	<.27	CC-118A
.81	1.9	<2.4	160	.35	1.2	<.25	<.27	CC-118B
160	<1.6	<5.4	3,200	<4.1	<17	<7.6	1.6	CC-120A
170	<1.6	<5.4	320	<4.1	<17	<7.6	<1.1	CC-120A
240	<.73	<2.4	>410	<.18	17	.68	<.27	CC-120A
<3.0	<3.0	<3.0	3,200	<3.0	32	<3.0	<3.0	CC-120A
20.1	<1.1	<5.3	630	<4.5	<19	<6.9	<1.1	CC-120B
.75	<.65	<2.0	.58	<.26	<.07	<.26	<.17	CC-122A
<.61	<.72	<2.3	16	.24	.43	<.23	.58	CC-130A
1.5	<.72	<2.3	230	<.16	4.1	<.23	<.27	CC-130B
<73	<.73	<2.4	34.0	<.18	.54	.88	<.27	CC-133B
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-136A
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-136A
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-136B
<0.73	<0.73	<2.4	87	<0.18	1.9	<0.26	<0.27	CC-1A
>2.0	<.65	<2.0	<.39	<.26	<.07	<.26	<.17	CC-10A
<.73	<.65	<2.0	<.39	<.26	<.07	<.26	3.2	CC-12A.1
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-20A
<14	<.73	<2.4	15	<.18	.16	<.26	<.27	CC-20B
<.73	<.65	<2.0	730	<.26	4.0	<.26	<.17	CC-33A
<.73	<.65	<2.0	>2.0	<.26	47	<.26	<.17	CC-33B
<.73	<.65	<2.0	>2.0	<.26	51	<.26	<.17	CC-33B
4.5	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-114A
<.73	<.65	<2.0	<.39	<.26	<.07	<.26	<.17	CC-127A
8.2	<.65	<2.0	.40	<.26	<.07	<.26	<.17	CC-128A
<.73	<.65	<2.0	<.39	<.26	.33	11	<.17	CC-129A
9.5	<.73	<2.4	.81	3.5	<.07	1.5	<.27	CC-133A
<.73	<.65	<2.0	<.39	<.26	<.07	<.26	<.17	CC-135A
<.73	<.65	<2.0	<.39	<.26	<.07	<.26	<.17	CC-138A
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-1D
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-1E
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-8E
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-8E
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-16C
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-17C
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-17C
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	CC-26C

Appendix B4.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--
Third sampling period (April-May 1989)--Continued

Local identifier	Sampling date	Tetrachloroethylene (µg/L)	Trichloroethylene (µg/L)	1,1-Dichloroethylene (µg/L)	1,2-trans-Dichloroethylene (µg/L)	Vinyl chloride (µg/L)	Bromoform (µg/L)	Chlorodibromomethane (µg/L)	Chloroethane (µg/L)
CANAL CREEK AQUIFER--Continued									
CC-111B	05-03-89	5.3	73	<0.20	0.80	<0.50	<0.70	<0.40	1.4
CC-111B	05-03-89	4.6	<73	.30	.80	<.50	<.70	<.40	1.5
CC-112A	05-15-89	<2.7	<7.0	<18	32	<2.9	<8.2	<6.5	<5.0
CC-112A	05-15-89	--	--	--	--	--	--	--	--
CC-113A	04-28-89	3.3	100	<16	6.6	<2.4	<9.7	<7.1	<4.0
CC-113A	04-28-89	3.7	110	<16	6.7	<2.4	<9.7	<7.1	<4.0
CC-113A	04-28-89	2.7	>40	.50	<.70	<.50	<.70	<.40	1.9
CC-113B	04-28-89	10	190	<16	10	<2.4	<9.7	<7.1	<4.0
CC-114B	04-27-89	3.4	24	<16	6.5	<2.4	<9.7	<7.1	<4.0
CC-114C	04-27-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-115A	04-28-89	<2.7	16	<16	1.4	<2.4	<9.7	<7.1	<4.0
CC-118A	05-08-89	3.4	100	<.26	2.0	<.46	<.73	<.38	<.86
CC-118A	05-08-89	4.6	110	<.26	1.7	<.46	<.73	<.38	<.86
CC-118B	05-08-89	1.1	<37	<.26	<.67	<.46	<.73	<.38	<.86
CC-120A	05-15-89	52	470	<18	23	<2.9	<8.2	<6.5	<5.0
CC-120A	05-15-89	57	4,700	<18	27	<2.9	<8.2	<6.5	<5.0
CC-120A	05-15-89	40	>400	1.3	<13	.90	1.7	<.38	<.86
CC-120A	05-15-89	94	460	<3.0	6.5	<1.0	<3.0	150	<3.0
CC-120B	05-09-89	5.8	170	<16	4.0	<2.4	<9.7	<7.1	<4.0
CC-122A	04-26-89	<.03	<.36	<.26	<.67	<.46	<.73	<.38	<.86
CC-130A	05-04-89	.24	6.2	<.26	<.67	<.40	<1.4	<.46	<.94
CC-130B	05-04-89	2.0	110	.42	2.1	<.40	<1.4	<.46	<.94
CC-133B	05-18-89	.63	<7.3	<.26	<.67	<.46	<.73	<.38	<.86
CC-136A	05-26-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-136A	05-26-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-136B	05-26-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
SURFICIAL AQUIFER-Continued									
CC-1A	05-19-89	0.35	61	<0.26	<0.67	1.4	<0.73	<0.38	<0.86
CC-10A	04-25-89	.14	<.36	<.26	<.67	<.46	<.73	<.38	<.86
CC-12A.1	04-25-89	<.03	<.36	<.26	<.67	<.46	<.73	<.38	5.5
CC-20A	05-18-89	<3.0	43	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-20B	05-19-89	.35	220	<.26	<.67	<.46	<.73	<.38	<.86
CC-33A	04-26-89	11	200	<.26	<.67	<.46	<.73	<.38	<.86
CC-33B	04-26-89	200	800	.61	99	.81	<.73	<.38	<.86
CC-33B	04-26-89	26	1,100	.59	120	.75	<.73	<.38	<.86
CC-114A	04-27-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-127A	04-25-89	<.03	<.36	<.26	<.67	<.46	<.73	<.38	<.86
CC-128A	04-25-89	<.03	<.36	<.26	<.67	<.46	<.73	<.38	<.86
CC-129A	04-25-89	.08	.52	<.26	1.1	.50	<.73	<.38	<.86
CC-133A	05-18-89	.06	<.37	.78	<.67	<.46	<.73	<.38	<.86
CC-135A	04-25-89	<.03	19	<.26	<.67	<.46	<.73	<.38	<.86
CC-138A	04-26-89	.32	<.37	<.26	<.67	<.46	<.73	<.38	<.86
LOWER CONFINED AQUIFER--Continued									
CC-1D	06-01-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-1E	06-06-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-8E	06-01-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-8E	06-01-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-16C	06-07-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-17C	06-02-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-17C	06-02-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0
CC-26C	06-07-89	<3.0	<3.0	<3.0	<3.0	<1.0	<3.0	<3.0	<3.0

Bromo-di-chloro-methane ($\mu g/L$)	1,2-Di-chloro-benzene ($\mu g/L$)	1,3-Di-chloro-benzene ($\mu g/L$)	1,4-Di-chloro-benzene ($\mu g/L$)	1,2-Di-chloro-propane ($\mu g/L$)	trans-1,3-Di-chloro-propene ($\mu g/L$)	cis-1,3-Di-chloro-propene ($\mu g/L$)	Phenols, total ($\mu g/L$)	Local ident-ifier
<1.3	<0.50	<0.20	<0.40	<0.10	<0.70	<1.1	<1	CC-111B
<1.3	<.50	.30	<.40	<.10	<.70	<1.1	--	CC-111B
<7.9	<9.7	<9.2	<8.1	<2.8	<5.0	<5.0	<1	CC-112A
--	--	--	--	--	--	--	--	CC-112A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-113A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	22	CC-113A
2.5	<.50	1.6	1.3	<.10	<.70	<1.1	--	CC-113A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-113B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-114B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-114C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	19	CC-115A
<1.3	<.55	.53	<.39	<.13	<.71	<1.0	<1	CC-118A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	--	CC-118A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-118B
<7.9	18	<9.2	35	<2.8	<5.0	<5.0	<1	CC-120A
<7.9	19	<9.2	35	<2.8	<5.0	<5.0	--	CC-120A
<1.3	13	<9.8	19	<.13	<.71	<1.0	<1	CC-120A
--	14	<3.0	27	<3.0	<3.0	<3.0	4	CC-120A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-120B
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	32	CC-122A
<1.2	<.54	<.24	<.39	.07	<.65	<.95	<1	CC-130A
<1.2	<.54	.36	<.39	<.13	<.65	<.95	<1	CC-130B
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-133B
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	2	CC-136A
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	CC-136A
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	2	CC-136B
<1.3	<0.55	<0.24	<0.39	<0.13	<0.71	<1.0	<1	CC-1A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-10A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-12A.1
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	CC-20A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	<1	CC-20B
<1.3	<.55	.35	<.35	<.13	<.71	<1.0	<1	CC-33A
<1.3	<.55	2.0	<.35	<.13	<.71	<1.0	<1	CC-33B
<1.3	<.55	1.7	<.35	<.13	<.71	<1.0	<1	CC-33B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	<1	CC-114A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-127A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-128A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	<1	CC-129A
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	--	CC-133A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-135A
<1.3	<.55	<.24	<.35	<.13	<.71	<1.0	--	CC-138A
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	3	CC-1D
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	3	CC-1E
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	2	CC-8E
--	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	1	CC-8E
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	1	CC-16C
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	3	CC-17C
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	2	CC-17C
--	<5.0	<5.0	<5.0	<3.0	<3.0	<3.0	1	CC-26C

Appendix B5.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Fourth sampling period (September-October 1989)

[mg/L, milligrams per liter; µg/L, micrograms per liter; deg C, degrees Celsius; µs/cm, microsiemens per centimeter at 2 degrees Celsius; R, replicate sample; B, sample from background well site in Canal Creek aquifer; G, suspected of grout contamination; U, sample from uncontaminated well site in surficial aquifer; H, halocarbon analysis for volatile organics; --, not analyzed for]

Local identifier	Sampling date	Comments	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance (µs/cm)	pH (standard units)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
CANAL CREEK AQUIFER										
CC-1B	10-13-89		14.5	<0.1	372	6.41	27	12	19	1.6
CC-1B	10-13-89	R	--	--	--	--	26	12	20	2.2
CC-1B	10-13-89	R,H	--	--	--	--	--	--	--	--
CC-5C	10-10-89		14.0	.3	287	5.86	21	3.4	28	6.9
CC-W6	10-10-89		14.5	1.3	68	5.04	2.1	.93	11	.77
CC-7A	10-16-89		15.5	<.1	185	5.78	3.5	2.6	20	1.2
CC-7B	10-16-89		15.5	<.1	178	5.51	4.8	2.2	20	1.4
CC-7B	10-16-89	R,H	--	--	--	--	--	--	--	--
CC-8B	10-16-89		15.0	.2	127	4.87	4.6	1.7	19	<.44
CC-8B	10-16-89	R	--	--	--	--	4.8	1.7	18	1.1
CC-8B	10-16-89	R,H	--	--	--	--	--	--	--	--
CC-8B	10-16-89	R,H	--	--	--	--	--	--	--	--
CC-8C	10-16-89		14.5	<.1	212	4.72	14	7.6	15	1.1
CC-8D	10-16-89		14.5	<.1	107	5.34	4.1	1.4	14	1.2
CC-11A	10-20-89	B	14.0	<.1	41	5.38	1.7	.44	3.4	.64
CC-11B	10-20-89	B	14.5	<.0	68	5.84	5.0	1.0	4.1	1.2
CC-13A	09-14-89		15.0	4.7	1,980	4.43	>2.2	>5.1	480	5.5
CC-13B	09-14-89		15.0	2.0	89	5.19	>2.2	1.8	15	2.8
CC-16A	09-15-89		19.0	1.6	336	5.61	>2.2	3.6	50	4.4
CC-16A	09-15-89	R	--	--	--	--	>2.2	3.7	59	4.3
CC-16A	09-15-89	R,H	--	--	--	--	--	--	--	--
CC-16B	09-15-89		18.0	2.0	1,040	6.44	>2.2	>5.1	300	4.3
CC-17A	09-15-89		18.0	1.8	214	4.81	>2.2	4.9	24	5.1
CC-17B	09-15-89		18.0	1.6	137	5.70	>2.2	1.5	21	12
CC-18A	09-28-89		15.0	2.2	1,980	4.43	50	27	410	4.2
CC-18B	09-28-89		14.5	2.0	94	5.58	10	1.5	22	2.1
CC-20C	10-12-89		15.5	.4	404	6.19	31	9.1	42	4.0
CC-20D	10-12-89		15.5	<.1	128	5.67	6.6	2.8	14	<.44
CC-20D	10-12-89	R,H	--	--	--	--	--	--	--	--
CC-21A	09-14-89		19.5	3.1	160	5.56	>2.2	2.2	33	5.1
CC-22B	10-11-89		15.0	.4	453	6.62	42	15	15	1.4
CC-22C	10-11-89		15.0	1.2	426	7.00	29	8.5	35	5.2
CC-23B	09-27-89		16.0	.8	432	6.50	36	15	39	4.2
CC-25A	09-21-89		17.0	1.2	437	6.16	45	10	51	4.2
CC-26A	09-21-89		17.0	1.7	376	6.66	75	9.3	26	3.6
CC-26B	09-21-89		17.0	3.2	437	5.85	39	16	160	4.8
CC-27A	09-18-89		15.5	5.5	424	4.52	>2.2	>5.1	57	3.0
CC-27A	09-18-89	R	--	--	--	--	--	--	--	--
CC-27A	09-18-89	R,H	--	--	--	--	--	--	--	--
CC-27B	09-18-89		15.0	3.9	483	4.74	>2.2	>5.1	130	2.7
CC-28A	09-27-89		15.0	1.5	3,890	4.15	<8.4	26	>6.0	<4.4
CC-28B	09-27-89		14.0	1.7	1,750	4.49	25	12	>600	<4.4
CC-30A	09-28-89		16.5	2.0	144	4.82	11	3.4	23	1.2
CC-36B	10-11-89		14.5	.4	499	6.54	16	13	33	2.0
CC-36C	10-11-89		15.0	.6	442	6.40	44	12	13	2.9
CC-102B	10-13-89		15.5	.3	248	5.40	13	5.0	23	3.1
CC-102C	10-13-89		14.5	<.1	216	5.09	14	7.7	14	1.1
CC-104B	10-18-89		13.5	.2	58	5.23	3.5	.64	5.4	.94
CC-104C	10-18-89		14.0	<.1	--	5.81	1.7	.63	5.4	1.8
CC-107A	09-29-89	G	15.5	1.2	880	6.70	22	9.8	130	44

Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Fluoride, dissolved (mg/L as F)	Local identifier
124	62	19	30,000	2.7	0.45	0.34	<0.071	CC-1B
--	61	17	30,000	2.7	<.18	1.0	<.071	CC-1B
--	--	--	--	--	--	--	--	CC-1B
56	43	<33	4,300	6.0	.55	1.1	.24	CC-5C
6	2.0	17	220	5.2	.62	<.054	<.071	CC-W6
34	17	<33	12,000	4.5	<.18	.24	.25	CC-7A
27	15	<33	12,000	6.1	<.18	.29	.24	CC-7B
--	--	--	--	--	--	--	--	CC-7B
5	15	21	890	6.6	<.18	<.054	<.071	CC-8B
--	16	21	890	6.5	<.18	<.054	<.071	CC-8B
--	--	--	--	--	--	--	--	CC-8B
--	--	--	--	--	--	--	--	CC-8B
4	49	15	180	4.8	<.18	<.054	<.071	CC-8C
12	12	14	4,000	5.6	<.18	<.054	<.071	CC-8D
7	3.9	3.6	2,500	5.1	<.18	<.054	<.071	CC-11A
23	3.3	5.0	4,400	5.4	<.18	<.054	<.071	CC-11B
0	33	>240	56	4.4	.77	<.21	<.071	CC-13A
6	2.0	20	370	4.0	<.18	<.21	.21	CC-13B
72	28	42	>540	5.4	<.18	1.4	.096	CC-16A
--	28	51	>540	5.3	<.18	1.1	.10	CC-16A
--	--	--	--	--	--	--	--	CC-16A
111	22	>240	>540	6.2	.24	<.21	.32	CC-16B
3	45	<33	62	4.9	1.8	.31	<7.1	CC-17A
21	17	15	>540	4.3	.28	<.21	.18	CC-17B
0	12	>240	<26	4.4	.22	<.32	<.071	CC-18A
16	6.4	18	160	4.7	.29	<.32	<.071	CC-18B
68	55	57	14,000	3.5	2.7	.11	.096	CC-20C
28	13	17	6,800	4.0	<.17	<.054	<.071	CC-20D
--	--	--	--	--	--	--	--	CC-20D
21	16	48	64	4.9	.23	<.21	.21	CC-21A
155	59	<33	38,000	2.5	2.5	.15	.38	CC-22B
127	46	52	27,000	6.6	<.18	.28	.46	CC-22C
137	57	48	>540	3.6	.19	<.32	<.071	CC-23B
79	78	43	12,000	3.0	<.18	<.32	.11	CC-25A
176	39	12	<26	4.1	3.3	<.32	.31	CC-26A
55	70	6.1	<26	2.6	.52	<.32	<.071	CC-26B
0	120	44	300	14	.62	<.21	.25	CC-27A
--	--	--	--	--	--	--	--	CC-27A
--	--	--	--	--	--	--	--	CC-27A
6	110	85	200	6.6	1.3	.48	.36	CC-27B
0	190	>240	190	5.6	2.2	<.32	<.071	CC-28A
0	130	>240	2,000	4.2	2.7	<.32	<.071	CC-28B
3	31	23	350	4.8	.47	<.32	<.071	CC-30A
273	.23	36	>54,000	2.2	<.18	.46	.40	CC-36B
283	.82	13	50,000	2.6	<.18	.56	.26	CC-36C
21	63	18	340	7.7	<.18	<.054	.25	CC-102B
10	59	18	380	3.4	<.18	<.054	<.071	CC-102C
7	6.5	6.3	150	5.4	<.18	<.054	<.071	CC-104B
27	2.0	<3.3	4,000	4.7	<.18	<.054	<.071	CC-104C
80	7.2	>240	1,300	5.0	.61	.30	.57	CC-107A

Appendix B5.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Fourth sampling period (September-October 1989)--Continued

Local identifier	Sampling date	Bromide, dissolved (mg/L as Br)	Manganese, dissolved (μg/L as Mn)	Aluminum, dissolved (μg/L as Al)	Antimony, dissolved (μg/L as Sb)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Boron, dissolved (μg/L as B)	Cadmium, dissolved (μg/L as Cd)
					CANAL CREEK AQUIFER				
CC-1B	10-13-89	0.20	1,000	180	<72	82	16	360	<3
CC-1B	10-13-89	.06	980	200	<72	63	15	805	<3
CC-1B	10-13-89	--	--	--	--	--	--	--	--
CC-5C	10-10-89	.32	420	<160	<72	<3	66	<270	4
CC-W6	10-10-89	<.53	14	250	<72	<3	9	<270	<3
CC-7A	10-16-89	.09	400	<160	<72	<3	14	<270	<3
CC-7B	10-16-89	.08	240	<160	<72	3	21	<270	<3
CC-7B	10-16-89	--	--	--	--	--	--	--	--
CC-8B	10-16-89	.07	130	<160	<72	<3	19	<270	<3
CC-8B	10-16-89	.22	130	180	<72	<3	18	<270	<3
CC-8B	10-16-89	--	--	--	--	--	--	--	--
CC-8B	10-16-89	--	--	--	--	--	--	--	--
CC-8C	10-16-89	.26	360	230	<72	<3	38	<270	<3
CC-8D	10-16-89	.25	160	<160	<72	<3	13	440	<3
CC-11A	10-20-89	<.05	78	170	<72	<3	7	540	4
CC-11B	10-20-89	.22	140	230	<72	<3	12	620	<3
CC-13A	09-14-89	.19	340	6,800	<72	<3	240	<270	9
CC-13B	09-14-89	.15	54	220	<72	<3	19	<270	<3
CC-16A	09-15-89	.93	750	<160	<72	5	21	<270	4
CC-16A	09-15-89	.94	750	230	<72	5	23	<270	8
CC-16A	09-15-89	--	--	--	--	--	--	--	--
CC-16B	09-15-89	.18	270	<160	<72	3	110	<270	<3
CC-17A	09-15-89	.17	180	<160	<72	<3	41	<270	<3
CC-17B	09-15-89	.08	260	<160	<72	<3	27	<270	<3
CC-18A	09-28-89	.27	600	740	<72	<3	150	<270	<3
CC-18B	09-28-89	.22	66	200	<72	<3	9	<270	<3
CC-20C	10-12-89	<.53	69	<160	<72	6	33	330	4
CC-20D	10-12-89	.20	430	<160	<72	<3	18	<270	<3
CC-20D	10-12-89	--	--	--	--	--	--	--	--
CC-21A	09-14-89	.17	61	240	<72	<3	19	<270	4
CC-22B	10-11-89	.16	1,600	210	<72	3	38	780	<3
CC-22C	10-11-89	.18	1,700	190	<72	<3	76	360	6
CC-23B	09-27-89	<.05	410	260	<72	>18	32	280	<3
CC-25A	09-21-89	.17	85	220	<72	13	27	<270	10
CC-26A	09-21-89	<.05	340	210	<72	<3	39	1,200	9
CC-26B	09-21-89	.17	340	210	<72	<3	39	440	<3
CC-27A	09-18-89	.10	650	<160	<72	<3	43	<270	10
CC-27A	09-18-89	--	--	--	--	--	--	--	--
CC-27A	09-18-89	--	--	--	--	--	--	--	--
CC-27B	09-18-89	.16	2,100	<16,000	<72	<3	40	<270	9
CC-28A	09-27-89	<.05	770	29,000	<72	9	34	340	<3
CC-28B	09-27-89	.20	890	5,000	<72	4	28	350	<3
CC-30A	09-28-89	.64	150	220	<72	<3	24	<270	<3
CC-36B	10-11-89	.22	2,100	260	<72	45	33	990	<30
CC-36C	10-11-89	.10	1,500	200	<72	6	29	360	<3
CC-102B	10-13-89	.28	1,300	200	<72	4	31	<270	<3
CC-102C	10-13-89	.23	280	180	<72	<3	40	<270	<3
CC-104B	10-18-89	6.1	110	<160	<72	<3	9	520	<3
CC-104C	10-18-89	<.05	83	<160	<72	<3	11	580	<3
CC-107A	09-29-89	<.05	1,300	270	<72	<3	76	<270	5

Chromium, dissolved (μg/L as Cr)	Copper, dissolved (μg/L as Cu)	Lead, dissolved (μg/L as Pb)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Silver, dissolved (μg/L as Ag)	Thallium, dissolved (μg/L as Tl)	Zinc, dissolved (μg/L as Zn)	Local identifier
<50	<22	<5	<32	<4	<0.3	45	<42	CC-1B
<50	<22	<5	<32	<4	<.3	45	<42	CC-1B
--	--	--	--	--	--	--	--	CC-1B
<50	<22	<5	<32	<4	<.3	<44	63	CC-5C
<50	<22	<5	<32	<4	<.3	<44	<42	CC-W6
<50	<22	<5	<32	<4	<.3	<44	<42	CC-7A
<50	<22	<5	<32	<4	<.3	51	<42	CC-7B
--	--	--	--	--	--	--	--	CC-7B
<50	<22	<5	62	<4	<.3	<44	94	CC-8B
<50	<22	<5	66	<4	<.3	53	95	CC-8B
--	--	--	--	--	--	--	--	CC-8B
--	--	--	--	--	--	--	--	CC-8B
<50	<22	15	95	<4	<.3	<44	120	CC-8C
<50	<22	<5	<32	<4	<.3	<44	<42	CC-8D
<50	<22	<5	<32	<4	<.3	48	45	CC-11A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-11B
<50	26	<5	200	<4	<.3	<44	270	CC-13A
<50	<22	6	<32	<4	<.3	<44	43	CC-13B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-16A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-16A
--	--	--	--	--	--	--	--	CC-16A
<50	<22	7	50	<4	<.3	<44	<42	CC-16B
<50	<22	<5	<32	<4	<.3	<44	90	CC-17A
<50	<22	67	<32	<4	<.3	<44	<42	CC-17B
<50	44	19	130	<4	<.3	<44	230	CC-18A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-18B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-20C
<50	<22	<5	<32	<4	<.3	<44	<42	CC-20D
--	--	--	--	--	--	--	--	CC-20D
<50	<22	<5	<32	<4	<.3	<44	<42	CC-21A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-22B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-22C
<50	<22	<5	<32	<4	<.3	<44	<42	CC-23B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-25A
<50	23	<5	<32	<4	<.3	<44	70	CC-26A
<50	<22	<5	<32	<4	<.3	<44	660	CC-26B
<50	32	<5	51	<4	<.3	<44	190	CC-27A
--	--	--	--	--	--	--	--	CC-27A
--	--	--	--	--	--	--	--	CC-27A
<50	<22	<5	<32	<4	<.3	<44	91	CC-27B
<50	170	>91	63	<4	<.3	<44	720	CC-28A
<50	<22	<5	<32	<4	<.3	<44	950	CC-28B
<50	<22	<5	34	<4	<.3	<44	45	CC-30A
<500	<22	9	<32	<4	<.3	<44	<42	CC-36B
<50	<22	<5	<32	<4	<.3	<44	100	CC-36C
<50	<22	<5	160	<4	<.3	48	270	CC-102B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-102C
<50	<22	<5	33	<4	<.3	<44	<42	CC-104B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-104C
<50	<22	6	<32	<4	<.3	<44	<42	CC-107A

Appendix B5.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Fourth sampling period (September-October 1989)--Continued

Local identifier	Sampling date	Comments	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance (µs/cm)	pH (standard units)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
CANAL CREEK AQUIFER--Continued										
CC-107B	09-29-89		14.5	1.9	3,870	5.13	86	30	>600	4.9
CC-108A	10-10-89		15.5	1.0	486	6.49	12	6.2	27	3.3
CC-108A	10-10-89	R	--	--	--	--	--	--	--	--
CC-108A	10-10-89	R,H	--	--	--	--	--	--	--	--
CC-108B	10-10-89	G	16.0	.6	216	5.32	16	4.9	40	4.2
CC-109A	09-28-89		16.5	3.4	636	4.72	32	16	>600	3.6
CC-110A	09-18-89	G	15.0	.6	253	7.44	>2.2	1.3	35	21
CC-111A	09-15-89		17.5	1.9	149	5.59	>2.2	2.2	24	1.6
CC-111B	09-15-89		17.0	2.1	113	4.79	>2.2	2.6	23	1.2
CC-112A	09-18-89		16.0	1.6	58	5.17	1.6	1.0	5.0	.80
CC-112A	09-18-89	R	--	--	--	--	1.6	1.0	5.1	.64
CC-112A	09-18-89	R,H	--	--	--	--	--	--	--	--
CC-113A	09-27-89		16.5	1.8	839	5.60	36	10	180	3.5
CC-113A	09-27-89	R	--	--	--	--	35	11	250	3.4
CC-113B	09-27-89		17.0	3.0	334	5.40	17	8.1	50	5.5
CC-114B	09-21-89		18.0	3.8	341	5.29	27	9.2	47	6.0
CC-114C	09-21-89		17.5	3.4	401	4.79	19	13	49	4.2
CC-115A	09-21-89		19.0	1.4	364	5.47	43	11	35	25
CC-117A	10-18-89		14.0	.3	--	5.02	13	7.4	11	.72
CC-118A	09-28-89		15.5	4.6	2,770	5.29	44	24	>600	5.8
CC-118B	09-28-89		16.5	2.2	1,310	5.09	62	28	370	<4.4
CC-120A	09-29-89		17.5	2.1	315	4.90	10	5.5	31	3.0
CC-120A	09-29-89	R	--	--	--	--	19	6.9	57	3.4
CC-120B	09-29-89	G	17.5	1.9	224	6.13	22	4.4	28	5.4
CC-122A	09-12-89	B	16.5	1.6	269	5.90	>2.2	>5.1	29	3.5
CC-130A	09-14-89		17.0	2.0	291	5.44	>2.2	4.3	45	9.8
CC-130B	09-14-89		18.0	3.2	3,230	5.88	>2.2	>5.1	600	25
CC-133B	10-12-89		17.5	4.7	533	4.51	17	13	57	2.6
CC-133B	10-12-89	R	--	--	--	--	18	14	61	4.8
CC-134A	09-12-89	B	15.0	7.3	63	5.11	>2.2	1.1	5.2	.81
CC-136A	10-18-89	B	13.5	<.1	--	5.85	1.8	.60	8.7	<.44
CC-136B	10-18-89	B	14.0	<.1	--	5.60	3.9	.59	3.1	<.44
SURFICIAL AQUIFER										
CC-1A	10-13-89		15.0	<0.1	230	6.41	10	5.8	13	2.2
CC-20A	10-12-89		17.0	2.5	266	5.99	24	10	16	3.7
CC-20B	10-12-89		15.5	3.0	286	5.56	17	8.1	21	3.8
CC-23A	09-27-89		16.5	.8	481	6.73	81	21	35	3.9
CC-33A	10-11-89		15.5	2.6	376	5.23	4.5	6.2	80	2.1
CC-33B	10-11-89		14.5	.4	2,310	4.00	27	44	370	4.0
CC-33B	10-11-89	R	--	--	--	--	24	46	320	4.7
CC-33B	10-11-89	R,H	--	--	--	--	--	--	--	--
CC-114A	09-21-89		20.0	8.0	381	6.42	65	10	29	4.5
CC-133A	10-12-89		18.0	7.6	319	5.82	17	9.0	36	.93

Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Iron, dissolved (µg/L as Fe)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Fluoride, dissolved (mg/L as F)	Local identifier
10	7.0	<0.33	290	5.7	<0.18	0.14	2.0	CC-107B
10	89	38	42	6.3	.30	<.054	.37	CC-108A
--	--	--	--	--	--	--	--	CC-108A
--	--	--	--	--	--	--	--	CC-108A
14	<.15	<33	<26	5.9	.87	<.054	.18	CC-108B
4	7.9	130	<26	4.6	.24	<.32	<.071	CC-109A
97	18	15	64	4.4	.32	.72	.20	CC-110A
16	13	21	<26	4.4	1.0	<.21	<.071	CC-111A
4	17	17	170	4.6	.30	.37	<.071	CC-111B
6	3.6	12	<26	4.1	<.18	<.21	.26	CC-112A
--	3.7	10	>540	4.1	<.18	<.21	<.071	CC-112A
--	--	--	--	--	--	--	--	CC-112A
17	200	120	<26	4.1	<.18	<.32	.20	CC-113A
--	210	150	<26	4.1	1.3	<.32	<.071	CC-113A
15	120	51	<26	4.5	<.18	<.32	<.071	CC-113B
14	52	48	180	4.8	.99	<.32	.081	CC-114B
6	63	68	91	4.8	3.5	<.32	<.071	CC-114C
24	110	45	12,000	4.3	2.0	<.32	<.071	CC-115A
5	57	9.7	58	6.0	.18	<.054	<.071	CC-117A
19	35	>240	76	4.3	.87	<.32	<.071	CC-118A
8	1.4	>240	<26	4.7	.31	<.32	<.071	CC-118B
5	110	<33	500	6.8	.27	<.054	.33	CC-120A
--	110	17	420	6.9	<.18	<.054	.43	CC-120A
54	48	17	240	6.2	<.18	<.054	.17	CC-120B
42	37	33	>540	4.8	.34	.28	.11	CC-122A
18	34	63	>540	5.2	.19	.24	.12	CC-130A
38	27	>240	>540	4.7	.49	<.21	<.071	CC-130B
0	48	120	<26	3.6	3.7	<.054	.16	CC-133B
--	47	120	<26	--	3.9	--	.16	CC-133B
4	5.7	6.7	69	6.0	1.8	<.21	.24	CC-134A
24	4.7	6.2	5,900	4.4	<.18	<.054	<.071	CC-136A
23	3.8	<3.3	4,800	5.0	<.18	<.054	<.071	CC-136B
96	17	<33	23,000	3.8	<0.18	<0.054	0.24	CC-1A
77	36	24	61	3.2	<.18	<.054	.12	CC-20A
26	52	38	95	3.4	1.8	.059	.27	CC-20B
264	51	15	1,400	5.4	<.18	<.32	.091	CC-23A
13	85	50	310	18	<.18	.16	.36	CC-33A
0	96	>240	4,900	12	<.18	.28	1.3	CC-33B
--	100	>240	4,300	12	<.18	.38	1.4	CC-33B
--	--	--	--	--	--	--	--	CC-33B
85	48	<33	<26	4.8	<.18	<.32	.11	CC-114A
38	33	49	<26	2.6	2.3	<.054	<.071	CC-133A

Appendix B5.--Inorganic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Ground, Maryland--Fourth sampling period (September-October 1989)--Continued

Local ident-ifier	Bromide, dissolved (mg/L as Br)	Manganese, dissolved (µg/L as Mn)	Aluminum, dissolved (µg/L as Al)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmimum, dissolved (µg/L as Cd)
CANAL CREEK AQUIFER--Continued								
CC-107B	0.87	1,700	2,800	<72	<3	240	510	<3
CC-108A	.42	2,000	340	<72	<3	58	870	4
CC-108A	--	--	--	--	--	--	--	--
CC-108A	--	--	--	--	--	--	--	--
CC-108B	<.053	700	200	<72	<3	48	330	<3
CC-109A	.15	440	450	<72	<3	66	<270	<3
CC-110A	.20	15	220	<72	<3	100	<270	<3
CC-111A	.25	50	250	<72	<3	28	<270	6
CC-111B	.092	82	230	<72	<3	21	<270	<3
CC-112A	.12	110	<160	<72	<3	7	<270	7
CC-112A	<.053	120	190	<72	<3	9	<270	<3
CC-112A	--	--	--	--	--	--	--	--
CC-113A	.19	880	200	<72	<3	24	<270	8
CC-113A	.20	860	200	<72	<3	25	<270	<3
CC-113B	.20	240	200	<72	<3	54	<270	7
CC-114B	.21	400	250	<72	<3	67	300	13
CC-114C	.22	480	240	<72	<3	100	<270	<3
CC-115A	.20	240	300	<72	<3	29	<270	10
CC-117A	.094	410	170	<72	<3	31	520	<3
CC-118A	<.53	310	480	<72	<3	220	<270	<3
CC-118B	.23	890	<1,600	<72	<3	260	<270	4
CC-120A	1.4	2,400	440	<72	<3	47	420	4
CC-120A	2.0	4,200	510	<72	<3	52	460	<3
CC-120B	.83	260	170	<72	--	120	340	<3
CC-122A	.07	1,300	<160	<72	<3	58	<270	<3
CC-130A	.25	80	260	<72	<3	37	<270	7
CC-130B	<.053	980	<160	<72	<3	300	<270	7
CC-133B	.24	380	470	<72	<3	150	<270	<3
CC-133B	.24	380	500	<72	<3	150	290	<3
CC-134A	<.053	160	<160	<72	<3	8	<270	9
CC-136A	<.053	130	170	<72	<3	12	560	<3
CC-136B	.21	94	170	<72	<3	11	540	<3
SURFICIAL AQUIFER--Continued								
CC-1A	0.078	350	180	<72	87	18	<270	<3
CC-20A	.16	4	<160	<72	<3	32	<270	4
CC-20B	<.53	13	<160	<72	<3	52	<270	<3
CC-23A	<.053	92	310	<72	3	37	270	<3
CC-33A	.23	140	200	<72	<3	24	<270	5
CC-33B	2.9	3,900	4,000	<72	<3	68	<270	<3
CC-33B	3.1	4,300	4,200	<72	<3	69	<270	<3
CC-33B	--	--	--	--	--	--	--	--
CC-114A	<.053	7	200	<72	<3	27	430	7
CC-133A	<.053	1	<160	<72	<3	27	<270	<3

Chromium, dissolved (μg/L as Cr)	Copper, dissolved (μg/L as Cu)	Lead, dissolved (μg/L as Pb)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Silver, dissolved (μg/L as Ag)	Thallium, dissolved (μg/L as Tl)	Zinc, dissolved (μg/L as Zn)	Local ident-ifier
<50	53	7	200	<4	0.9	<44	380	CC-107B
<50	33	<5	130	<4	<.3	<44	180	CC-108A
--	--	--	--	--	--	--	--	CC-108A
--	--	--	--	--	--	--	--	CC-108A
<50	<22	<5	53	<4	<.3	<44	100	CC-108B
<50	31	<5	110	<4	<.3	<44	180	CC-109A
<50	<22	<5	<32	<4	.4	<44	<42	CC-110A
<50	<22	<5	<32	<4	<.3	<44	49	CC-111A
<50	23	<5	<32	<4	<.3	<44	67	CC-111B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-112A
<50	25	<5	<32	<4	<.3	<44	<42	CC-112A
--	--	--	--	--	--	--	--	CC-112A
<50	23	<5	<32	<4	<.3	<44	<42	CC-113A
<50	<22	10	<32	<4	2.5	<44	54	CC-113A
<50	<22	26	<32	<4	<.3	<44	230	CC-113B
<50	<22	<5	<32	<4	5.4	<44	6,100	CC-114B
<50	23	<5	<32	<4	<.3	<44	500	CC-114C
<50	22	<5	68	<4	<.3	<44	71	CC-115A
<50	<22	8	36	<4	<.3	67	<42	CC-117A
<50	29	<5	97	<4	<.3	<44	140	CC-118A
<50	23	<5	250	<4	<.3	<44	320	CC-118B
<50	<22	<5	100	<4	<.3	<44	120	CC-120A
<50	43	<5	110	<4	<.3	<44	100	CC-120A
<50	<22	<5	<32	<4	<.3	<44	53	CC-120B
<50	<22	6	<32	<4	<.3	<44	<42	CC-122A
<50	24	<5	72	<4	<.3	<44	65	CC-130A
<50	<22	10	120	<4	<.3	<44	140	CC-130B
<50	<22	7	<32	<4	.5	<44	<42	CC-133B
<50	<22	9	<32	<4	<.3	<44	<42	CC-133B
<50	<22	<5	<32	<4	<.3	<44	<42	CC-134A
<50	<22	<5	<32	<4	<.3	48	<42	CC-136A
<50	<22	<5	<32	<4	<.3	50	550	CC-136B
<50	<22	<5	<32	9	<0.3	<44	<42	CC-1A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-20A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-20B
<50	<22	<5	<32	<4	<.3	<44	>970	CC-23A
<50	<22	<5	48	<4	.3	<44	<42	CC-33A
<50	<22	12	170	<4	<.3	<44	440	CC-33B
<50	<22	<5	150	<4	<.3	<44	430	CC-33B
--	--	--	--	--	--	--	--	CC-33B
<50	23	<5	<32	<4	<.3	<44	<42	CC-114A
<50	<22	<5	<32	<4	<.3	<44	<42	CC-133A

Appendix B6.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Grou
Maryland--
Fourth sampling period (September-October 1989)

[mg/L, milligrams per liter; μg/L, micrograms per liter; R, replicate sample; B, sample from background well site in Cana
Creek aquifer; G, suspected of grout contamination; U, sample from uncontaminated well site in surficial aquifer; H, halocarbon analysis for volatile organics; --, not analyzed]

Local identifier	Sampling date	Comments	Carbon, organic total (mg/L as C)	Total organic halide (μg/L as Cl)	Methane (μg/L)	Toluene (μg/L)	Ethylbenzene (μg/L)	Benzene (μg/L)	Chlorobenzene (μg/L)	Carbon tetrachloride (μg/L)
					CANAL CREEK AQUIFER					
CC-1B	10-13-89		--	1,200	3,700	<8.1	<9.6	<2.4	<1.4	<5.9
CC-1B	10-13-89	R	--	1,200	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-1B	10-13-89	R,H	--	--	--	--	--	--	<1.0	<.15
CC-5C	10-10-89		<0.50	580	--	<8.1	<9.6	<2.4	9.2	<5.9
CC-W6	10-10-89		<.50	76	--	<8.1	<9.6	<2.4	<1.4	20
CC-7A	10-16-89		.70	140	1,900	<8.1	<9.6	<2.4	3.5	<5.9
CC-7B	10-16-89		<.50	790	6,200	<8.1	<9.6	2.4	3.1	<5.9
CC-7B	10-16-89	R,H	--	--	--	--	--	--	2.9	<3.0
CC-8B	10-16-89		<.50	680	2,400	<8.1	<9.6	<2.4	<1.4	15
CC-8B	10-16-89	R	<.50	690	--	<8.1	<9.6	<2.4	<1.4	15
CC-8B	10-16-89	R,H	--	--	--	--	--	--	1.3	9.1
CC-8B	10-16-89	R,H	--	--	--	--	--	--	1.2	10
CC-8C	10-16-89		<.50	280	960	<8.1	<9.6	<2.4	<1.4	<5.9
CC-8D	10-16-89		<.50	330	2,200	<8.1	<9.6	<2.4	<1.4	<5.9
CC-11A	10-20-89	B	<.50	<5.0	20	<8.1	<9.6	<2.4	<1.4	<5.9
CC-11B	10-20-89	B	<.50	<5.0	100	<8.1	<9.6	<2.4	<1.4	<5.9
CC-13A	09-14-89		.60	510	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-13B	09-14-89		<.50	90	--	<8.1	<9.6	<2.4	<1.4	6.6
CC-16A	09-15-89		.51	1,300	--	<8.1	<9.6	150	<7.4	<5.9
CC-16A	09-15-89	R	4.4	1,700	--	<8.1	<9.6	150	7.1	<5.9
CC-16A	09-15-89	R,H	--	--	--	--	--	--	<16	<.15
CC-16B	09-15-89		.60	220	--	<8.1	<9.6	<2.4	<1.4	21
CC-17A	09-15-89		<.50	800	--	<8.1	<9.6	<2.4	<1.4	420
CC-17B	09-15-89		<.50	540	--	<8.1	<9.6	<2.4	<1.4	78
CC-18A	09-28-89		<.50	390	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-18B	09-28-89		<.50	580	--	<8.1	<9.6	<2.4	<1.4	110
CC-20C	10-12-89		<.50	27	17	<8.1	<9.6	<2.4	<1.4	<5.9
CC-20D	10-12-89		<.50	66	170	<8.1	<9.6	<2.4	<1.4	<5.9
CC-20D	10-12-89	R,H	--	--	--	--	--	--	<1.0	4.4
CC-21A	09-14-89		<.50	270	--	<8.1	<9.6	72	4.9	63
CC-22B	10-11-89		.90	140	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-22C	10-11-89		1.2	26	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-23B	09-27-89		1.6	140	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-25A	09-21-89		12	230	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-26A	09-21-89		1.5	1,200	--	<8.1	<9.6	200	5.9	1,100
CC-26B	09-21-89		1.1	380	--	<8.1	<9.6	7.8	<1.4	127
CC-27A	09-18-89		.90	3,600	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-27A	09-18-89	R	--	--	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-27A	09-18-89	R,H	--	--	--	--	--	--	<.81	1.4
CC-27B	09-18-89		<.50	140	--	<8.1	<9.6	<2.4	<1.4	62
CC-28A	09-27-89		1.1	1,000	--	<8.1	<9.6	<2.4	<1.4	740
CC-28B	09-27-89		<.50	770	--	<8.1	<9.6	<2.4	<1.4	740
CC-30A	09-28-89		<.50	1,100	--	<8.1	<9.6	<2.4	<1.4	630
CC-36B	10-11-89		8.1	<20	--	<8.1	<9.6	2.8	<1.4	<5.9
CC-36C	10-11-89		21	<20	--	<8.1	<9.6	<2.4	<1.4	<5.9
CC-102B	10-13-89		--	170	640	<8.1	<9.6	<2.4	<1.4	<5.9
CC-102C	10-13-89		--	260	1,800	<8.1	<9.6	<2.4	<1.4	<5.9
CC-104B	10-18-89		<.50	<5.0	280	<8.1	<9.6	<2.4	<1.4	15
CC-104C	10-18-89		<.50	65	400	<8.1	<9.6	<2.4	<1.4	<5.9
CC-107A	09-29-89	G	1.1	250	--	<8.1	<9.6	<2.4	<1.4	<5.9

Chloro- form (µg/L)	Methyl- chlo- ride (µg/L)	Methyl- ene chlo- ride (µg/L)	1,1,2,2- Tetra- chloro- ethane (µg/L)	1,1,1- Tri- chloro- ethane (µg/L)	1,1,2- Tri- chloro- ethane (µg/L)	1,2-Di- chloro- ethane (µg/L)	1,1-Di- chloro- ethane (µg/L)	Local ident- ifier
<0.84	<1.1	<5.3	10	<4.5	<19	<6.9	<1.1	CC-1B
<.84	<1.1	<5.3	10	<4.5	<19	<6.9	<1.1	CC-1B
<.73	<.73	<2.4	12	<.18	>1.0	<5.1	<.27	CC-1B
2.3	<1.1	<5.3	27	<4.5	<19	<6.9	<1.1	CC-5C
7.0	2.1	<5.3	70	<4.5	<19	<6.9	2.0	CC-W6
2.8	<1.1	<5.3	15	<4.5	<19	<6.9	<1.1	CC-7A
<5.9	<1.1	<5.3	530	<4.5	<19	<6.9	<1.1	CC-7B
<12	<.72	<2.3	>370	<.16	12	5.6	.40	CC-7B
<12	<1.1	<5.3	840	<4.5	<19	<6.9	<1.1	CC-8B
<11	<1.1	<5.3	100	<4.5	<19	<6.9	<1.1	CC-8B
<12	<.72	<2.3	>370	<.16	.48	<4.7	<.27	CC-8B
<12	<.72	<2.3	>370	<.16	9.6	<4.7	<.27	CC-8B
17	<1.1	<5.3	320	<4.5	<19	<6.9	<1.1	CC-8C
11	<1.1	<5.3	210	<4.5	<19	<6.9	<1.1	CC-8D
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-11A
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-11B
2.4	<1.1	<5.3	>210	<4.5	<19	<6.9	<1.1	CC-13A
1.5	<1.1	<5.3	51	<4.5	<19	<6.9	<1.1	CC-13B
33	<1.9	<5.3	<5.0	<4.5	<19	<6.9	9.4	CC-16A
33	1.2	<5.3	<5.0	<4.5	<19	<6.9	8.8	CC-16A
30	<.72	<2.3	<.51	<3.3	.20	160	.39	CC-16A
4.9	<1.1	<5.3	150	<4.5	<19	<6.9	<1.1	CC-16B
33	<1.1	<5.3	320	<4.5	<19	<6.9	<1.1	CC-17A
25	<1.1	<5.3	320	<4.5	<19	<6.9	<1.1	CC-17B
2.3	<1.1	<5.3	170	<4.5	<19	<6.9	<1.1	CC-18A
16	<1.1	<5.3	950	<4.5	<19	<6.9	<1.1	CC-18B
8.4	<1.1	<5.3	8.4	<4.5	<19	<6.9	<1.1	CC-20C
14	<1.1	<5.3	24	<4.5	<19	<6.9	<1.1	CC-20D
17	<.73	<2.4	19	<.18	.50	1.3	<.27	CC-20D
19	<1.1	<5.3	170	<4.5	<19	<6.9	4.4	CC-21A
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-22B
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-22C
<.84	<1.1	<5.3	<5.0	<4.5	<19	12	<1.1	CC-23B
<.84	<1.1	<5.3	16	<4.5	<19	18	<1.1	CC-25A
200	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-26A
97	<1.1	<5.3	82	<4.5	<19	<6.9	<1.1	CC-26B
2.0	<1.1	<5.3	3,200	<4.5	38	<11	<1.1	CC-27A
2.0	<1.1	<5.3	3,200	<4.5	38	11	<1.1	CC-27A
1.5	<.72	<2.3	>370	<.16	>43	<.23	<.27	CC-27A
94	<1.1	<5.3	64	<4.5	<19	<6.9	<1.1	CC-27B
300	<1.1	<5.3	81	<4.5	<19	<6.9	<1.1	CC-28A
170	<1.1	<5.3	47	<4.5	<19	<6.9	<1.1	CC-28B
40	<1.1	<5.3	950	<4.5	<19	14	<1.1	CC-30A
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-36B
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	CC-36C
1.7	<1.1	<5.3	160	<4.5	<19	<6.9	<1.1	CC-102B
2.1	<1.1	<5.3	160	<4.5	<19	<6.9	<1.1	CC-102C
5.6	<1.1	<5.3	170	<4.5	<19	<6.9	<1.1	CC-104B
1.3	<1.1	<5.3	89	<4.5	<19	<6.9	<1.1	CC-104C
3.0	<1.1	<5.3	61	<4.5	<19	<6.9	<1.1	CC-107A

Appendix B6.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Grou
Maryland--
Fourth sampling period (September-October 1989)--Continued

Local identifier	Sampling date	Tetrachloroethylene (µg/L)	Trichloroethylene (µg/L)	1,1-Dichloroethylene (µg/L)	1,2-trans-Di chloroethylene (µg/L)	Vinyl chloride (µg/L)	Bromoform (µg/L)	Chlorodibromomethane (µg/L)	Chloroethane (µg/L)
				CANAL CREEK AQUIFER--Continued					
CC-1B	10-13-89	<2.7	>190	<16	110	>160	<9.7	<7.1	<4.0
CC-1B	10-13-89	<2.7	>190	<16	99	>160	<9.7	<7.1	<4.0
CC-1B	10-13-89	.17	>400	5.2	<130	16	<.73	<.38	<.86
CC-5C	10-10-89	10	570	<16	76	22	<9.7	<7.1	<4.0
CC-W6	10-10-89	3.4	10	<16	2.7	2.5	<9.7	<7.1	<4.0
CC-7A	10-16-89	<2.7	34	<16	76	6.0	<9.7	<7.1	<4.0
CC-7B	10-16-89	5.7	190	<16	170	33	<9.7	<7.1	<4.0
CC-7B	10-16-89	5.3	220	1.2	180	43	<1.4	<.46	<.94
CC-8B	10-16-89	11	110	<16	110	21	<9.7	<7.1	<4.0
CC-8B	10-16-89	10	100	<16	110	20	<9.7	<7.1	<4.0
CC-8B	10-16-89	9.1	130	.31	<130	21	<1.4	<.46	<.94
CC-8B	10-16-89	10	120	.30	140	19	<1.4	<.46	<.94
CC-8C	10-16-89	5.9	94	<16	27	15	<9.7	<7.1	<4.0
CC-8D	10-16-89	4.6	69	<16	58	18	<9.7	<7.1	<4.0
CC-11A	10-20-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-11B	10-20-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-13A	09-14-89	<2.7	43	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-13B	09-14-89	<2.7	10	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-16A	09-15-89	130	940	<16	2,200	240	<9.7	<7.1	<4.0
CC-16A	09-15-89	120	940	<16	160	<24	<9.7	<7.1	<4.0
CC-16A	09-15-89	120	>370	21	<13	120	<1.4	<.46	<.94
CC-16B	09-15-89	3.5	59	<16	3.0	3.0	<9.7	<7.1	<4.0
CC-17A	09-15-89	2.8	94	<16	13	<2.4	<9.7	<7.1	<4.0
CC-17B	09-15-89	4.6	70	<16	8.4	<2.4	<9.7	<7.1	<4.0
CC-18A	09-28-89	<2.7	17	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-18B	09-28-89	3.2	65	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-20C	10-12-89	<2.7	<6.6	<16	1.8	<2.4	<9.7	<7.1	<4.0
CC-20D	10-12-89	<2.7	6.7	<16	6.5	<2.4	<9.7	<7.1	<4.0
CC-20D	10-12-89	.28	5.9	<.26	<6.7	<.46	<.73	<.38	<.86
CC-21A	09-14-89	130	<66	<16	77	26	<9.7	<7.1	<4.0
CC-22B	10-11-89	<2.7	<6.6	<16	20	13	<9.7	<7.1	<4.0
CC-22C	10-11-89	<2.7	<6.6	<16	2.8	6.1	<9.7	<7.1	<4.0
CC-23B	09-27-89	<2.7	24	<16	<1.1	14	<9.7	<7.1	<4.0
CC-25A	09-21-89	28	280	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-26A	09-21-89	4.0	<6.6	<16	6.2	<2.4	<9.7	<7.1	<4.0
CC-26B	09-21-89	81	70	<16	2.1	<2.4	<9.7	<7.1	<4.0
CC-27A	09-18-89	22	380	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-27A	09-18-89	21	280	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-27A	09-18-89	18	300	.28	<13	<.40	<1.4	<.46	<.94
CC-27B	09-18-89	<2.7	15	<16	1.8	<2.4	<9.7	<7.1	<4.0
CC-28A	09-27-89	26	67	<16	3.7	<2.4	<9.7	<7.1	<4.0
CC-28B	09-27-89	33	38	<16	2.0	<2.4	<9.7	<7.1	<4.0
CC-30A	09-28-89	4.8	69	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-36B	10-11-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-36C	10-11-89	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0
CC-102B	10-13-89	<2.7	23	<16	15	20	<9.7	<7.1	<4.0
CC-102C	10-13-89	3.3	59	<16	52	60	<9.7	<7.1	<4.0
CC-104B	10-18-89	<2.7	24	<16	13	<2.4	<9.7	<7.1	<4.0
CC-104C	10-18-89	<2.7	13	<16	9.7	<2.4	<9.7	<7.1	<4.0
CC-107A	09-29-89	<2.7	67	<16	3.0	<2.4	<9.7	<7.1	<4.0

Bromo-di-chloro-methane (μg/L)	1,2-Di-chloro-benzene (μg/L)	1,3-Di-chloro-benzene (μg/L)	1,4-Di-chloro-benzene (μg/L)	1,2-Di-chloro-propane (μg/L)	trans-1,3-Di-chloro-propene (μg/L)	cis 1,3-Di-chloro-propene (μg/L)	Local ident-ifier
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-1B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-1B
<1.3	<.55	.48	<.39	<.13	<.71	<1.0	CC-1B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-5C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-W6
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-7A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-7B
<1.2	<.54	.72	<.39	<.13	<.65	<.95	CC-7B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-8B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-8B
<1.2	<.54	.52	<.39	<.13	<.65	<.95	CC-8B
<1.2	<.54	.50	<.39	<.13	<.65	<.95	CC-8B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-8C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-8D
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-11A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-11B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-13A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-13B
<7.5	32	<9.8	<9.1	<2.8	<5.0	<5.0	CC-16A
<7.5	34	<9.8	<9.1	<2.8	<5.0	<5.0	CC-16A
<1.2	24	1.2	2.6	.48	<.65	<.95	CC-16A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-16B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-17A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-17B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-18A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-18B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-20C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-20D
<1.3	<.55	<.24	<.39	<.13	<.71	<1.0	CC-20D
<7.5	43	<9.8	<9.1	<2.8	<5.0	<5.0	CC-21A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-22B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-22C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-23B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-25A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-26A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-26B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-27A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-27A
<1.2	<.54	1.2	<.39	<.13	<.65	<.95	CC-27A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-27B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-28A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-28B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-30A
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-36B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-36C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-102B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-102C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-104B
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-104C
<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-107A

Appendix B6.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Grou
Maryland--
Fourth sampling period (September-October 1989)--Continued

Local identifier	Sampling date	Comments	Carbon, organic total (mg/L as C)	Total organic halide (μg/L as Cl)	Methane (μg/L)	Toluene (μg/L)	Ethylbenzene (μg/L)	Benzene (μg/L)	Chlorobenzene (μg/L)
					CANAL CREEK AQUIFER--Continued				
CC-107B	09-29-89		<0.50	370	--	<8.1	<9.6	<2.4	<1.4
CC-108A	10-10-89		.80	2,600	--	<8.1	<9.6	<2.4	<1.4
CC-108A	10-10-89	R	--	--	--	<8.1	<9.6	<2.4	<1.4
CC-108A	10-10-89	R,H	--	--	--	--	--	--	<1.0
CC-108B	10-10-89	G	<.50	1,500	--	<8.1	<9.6	<2.4	<1.4
CC-109A	09-28-89		<.50	350	--	<8.1	<9.6	<2.4	<1.4
CC-110A	09-18-89	G	1.1	410	--	<8.1	<9.6	<2.4	2.9
CC-111A	09-15-89		<.50	670	--	<8.1	<9.6	<2.4	<1.4
CC-111B	09-15-89		<.50	850	--	<8.1	<9.6	<2.4	<1.4
CC-112A	09-18-89		<.50	110	--	<8.1	<9.6	81	<1.4
CC-112A	09-18-89	R	<.50	140	--	<8.1	<9.6	84	<1.4
CC-112A	09-18-89	R,H	--	--	--	--	--	--	<.81
CC-113A	09-27-89		<.50	990	--	<8.1	<9.6	<2	<1.4
CC-113A	09-27-89	R	<.50	1,000	--	<8.1	<9.6	<2	<1.4
CC-113B	09-27-89		<.50	170	--	<8.1	<9.6	<2	<1.4
CC-114B	09-21-89		<.50	190	--	<8.1	<9.6	35	6.4
CC-114C	09-21-89		<.50	110	--	<8.1	<9.6	<2	<1.4
CC-115A	09-21-89		<.50	130	--	<8.1	<9.6	<2	<1.4
CC-117A	10-18-89		<.50	150	78	<8.1	<9.6	2.8	<1.4
CC-118A	09-28-89		<.50	620	--	<8.1	<9.6	<2.4	<1.4
CC-118B	09-28-89		<.50	250	--	<8.1	<9.6	<2.4	<1.4
CC-120A	09-29-89		1.5	4,800	--	<8.1	<9.6	48	<1.4
CC-120A	09-29-89	R	1.3	4,400	--	<8.1	<9.6	50	<1.4
CC-120B	09-29-89	G	<.50	1,400	--	<8.1	<9.6	<2.4	5.9
CC-122A	09-12-89	B	<.50	<30	--	<8.1	<9.6	<2.4	<1.4
CC-130A	09-14-89		<.50	60	--	<8.1	<9.6	<2.4	1.6
CC-130B	09-14-89		.70	410	--	<8.1	<9.6	<2.4	<1.4
CC-133B	10-12-89		<.50	76	--	<8.1	<9.6	<2.4	<1.4
CC-133B	10-12-89	R	<.50	--	<10	<8.1	<9.6	<2.4	<1.4
CC-134A	09-12-89	B	<.50	<30	--	<8.1	<9.6	<2.4	<1.4
CC-136A	10-18-89	B	<.50	<5	31	<8.1	<9.6	<2.4	<1.4
CC-136B	10-18-89	B	<.50	5	14	<8.1	<9.6	<2.4	<1.4
					SURFICIAL AQUIFER				
CC-1A	10-13-89		--	98	33	<8.1	<9.6	<2.4	<1.4
CC-20A	10-12-89		<0.50	160	<10	<8.1	<9.6	<2.4	<1.4
CC-20B	10-12-89		<.50	280	27	<8.1	<9.6	<2.4	<1.4
CC-23A	09-27-89		.70	34	--	<8.1	<9.6	<2.4	<1.4
CC-33A	10-11-89		3.8	670	--	<8.1	<9.6	<2.4	<1.4
CC-33B	10-11-89		5.2	6,200	--	<8.1	<9.6	<2.4	<1.4
CC-33B	10-11-89	R	4.9	6,100	--	<8.1	<9.6	<2.4	<1.4
CC-33B	10-11-89	R,H	--	--	--	--	--	--	1.1
CC-114A	09-21-89		<.50	170	--	<8.1	<9.6	<2.4	2.5
CC-133A	10-12-89		<.50	<20	<10	<8.1	<9.6	<2.4	<1.4

Carbon tetra-chlo-ride (μg/L)	Chloro-form (μg/L)	Methyl-chlo-ride (μg/L)	Methyl-ene chlo-ride (μg/L)	1,1,2,2-Tetra-chloro-ethane (μg/L)	1,1,1-Tri-chloro-ethane (μg/L)	1,1,2-Tri-chloro-ethane (μg/L)	1,2-Di-chloro-ethane (μg/L)	Local ident-ifier
<5.9	<0.84	<1.1	<5.3	170	<4.5	<19	<6.9	CC-107B
3,200	110	<1.1	<5.3	1,000	<4.5	<19	91	CC-108A
3,200	110	<1.1	<5.3	1,000	<4.5	<19	91	CC-108A
>410	180	1.3	<2.4	>410	<.18	9.6	110	CC-108A
2,100	66	<1.1	<5.3	950	<4.5	<19	40	CC-108B
9.0	1.6	<1.1	<5.3	140	<4.5	<19	<6.9	CC-109A
210	40	<1.1	<5.3	35	<4.5	<19	<6.9	CC-110A
320	32	<1.1	<5.3	320	<4.5	<19	<6.9	CC-111A
420	41	<1.1	<5.3	420	<4.5	<19	<6.9	CC-111B
61	33	<1.1	<5.3	26	<4.5	<19	<6.9	CC-112A
66	34	<1.1	<5.3	24	<4.5	<19	<6.9	CC-112A
57	32	<.72	<2.3	>37	<3.3	.3	24	CC-112A
320	600	<1.1	<5.3	210	<4.5	<19	<6.9	CC-113A
320	600	<1.1	<5.3	210	<4.5	<19	<6.9	CC-113A
6.3	36	<1.1	<5.3	14	<4.5	<19	<6.9	CC-113B
9.9	100	<1.1	<5.3	42	<4.5	<19	<6.9	CC-114B
<5.9	64	<1.1	<5.3	26	<4.5	<19	<6.9	CC-114C
37	30	<1.1	<5.3	67	<4.5	<19	<6.9	CC-115A
59	11	<1.1	<5.3	100	<4.5	<19	<6.9	CC-117A
<5.9	2.2	<1.1	<5.3	950	<4.5	<19	<6.9	CC-118A
<5.9	<.84	<1.1	<5.3	190	<4.5	<19	<6.9	CC-118B
1,100	200	<1.1	<5.3	>2,100	<4.5	19	<6.9	CC-120A
>210	180	<1.1	<5.3	>210	<4.5	<19	<6.9	CC-120A
<59	<8.4	<1.1	<5.3	320	<4.5	<19	<6.9	CC-120B
<5.9	<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-122A
<5.9	<.84	<1.1	<5.3	28	<4.5	<19	<6.9	CC-130A
<5.9	2.5	<1.1	<5.3	320	<4.5	<19	<6.9	CC-130B
<5.9	42	<1.1	<5.3	46	<4.5	<19	<6.9	CC-133B
<5.9	43	<1.1	<5.3	48	<4.5	<19	<6.9	CC-133B
<5.9	.90	<1.1	<5.3	5.1	<4.5	<19	<6.9	CC-134A
<5.9	<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-136A
<5.9	<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-136B
<5.9	<0.84	<1.1	<5.3	62	<4.5	<19	<6.9	CC-1A
<5.9	3.4	<1.1	<5.3	6.7	<4.5	<19	<6.9	CC-20A
9.9	7.6	<1.1	<5.3	18	<4.5	<19	<6.9	CC-20B
<5.9	<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-23A
<5.9	6.9	<1.1	<5.3	840	<4.5	<19	<6.9	CC-33A
<5.9	<13	<1.1	<5.3	9,500	<4.5	56	<6.9	CC-33B
<5.9	14	<1.1	<5.3	9,500	<4.5	56	<6.9	CC-33B
<.15	<14	<.73	<2.4	>410	<.18	48	<.26	CC-33B
210	3.8	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-114A
<5.9	3.4	<1.1	<5.3	<5.0	<4.5	<19	<6.9	CC-133A

Appendix B6.--Quantitative volatile-organic-chemical data for ground water in the Canal Creek area, Aberdeen Proving Grou
Maryland--
Fourth sampling period (September-October 1989)--Continued

Local identifier	Sampling date	1,1-Dichloroethane (µg/L)	Tetrachloroethylene (µg/L)	Trichloroethylene (µg/L)	1,1-Dichloroethylene (µg/L)	1,2-trans-Dichloroethylene (µg/L)	Vinyl chloride (µg/L)	Bromoform (µg/L)	Chlorodibromomethane (µg/L)
				CANAL CREEK AQUIFER--Continued					
CC-107B	09-29-89	<1.1	<2.7	7.9	<16	<1.1	<2.4	<9.7	<7.1
CC-108A	10-10-89	<1.1	11	170	<16	3.9	<2.4	<9.7	<7.1
CC-108A	10-10-89	<1.1	11	170	<16	3.7	<2.4	<9.7	<7.1
CC-108A	10-10-89	<.27	110	200	.72	2.8	<.46	<.73	<.38
CC-108B	10-10-89	<1.1	7.1	110	<16	2.1	<2.4	<9.7	<7.1
CC-109A	09-28-89	<1.1	<2.7	18	<16	<1.1	<2.4	<9.7	<7.1
CC-110A	09-18-89	<1.1	5.9	190	<16	13	<2.4	<9.7	<7.1
CC-111A	09-15-89	<1.1	<2.7	48	<16	9.9	<2.4	<9.7	<7.1
CC-111B	09-15-89	<1.1	6.4	63	<16	13	<2.4	<9.7	<7.1
CC-112A	09-18-89	<1.1	<2.7	<6.6	<16	23	<2.4	<9.7	<7.1
CC-112A	09-18-89	<1.1	<2.7	<6.6	<16	24	<2.4	<9.7	<7.1
CC-112A	09-18-89	<.27	.43	<6.8	.33	<.67	<.40	<1.4	<.46
CC-113A	09-27-89	<1.1	5.9	130	<16	6.6	<2.4	<9.7	<7.1
CC-113A	09-27-89	<1.1	<2.7	120	<16	6.3	<2.4	<9.7	<7.1
CC-113B	09-27-89	<1.1	16	180	<16	2.7	<2.4	<9.7	<7.1
CC-114B	09-21-89	<1.1	5.0	24	<16	6.5	<2.4	<9.7	<7.1
CC-114C	09-21-89	<1.1	<2.7	32	<16	6.6	<2.4	<9.7	<7.1
CC-115A	09-21-89	<1.1	<2.7	32	<16	1.5	<2.4	<9.7	<7.1
CC-117A	10-18-89	<1.1	<2.7	30	<16	12	<2.4	<9.7	<7.1
CC-118A	09-28-89	<1.1	5.0	34	<16	2.0	<2.4	<9.7	<7.1
CC-118B	09-28-89	<1.1	<2.7	14	<16	<1.1	<2.4	<9.7	<7.1
CC-120A	09-29-89	<1.1	63	660	<16	30	<2.4	<9.7	<7.1
CC-120A	09-29-89	<1.1	60	>190	<16	20	<2.4	<9.7	<7.1
CC-120B	09-29-89	<1.1	7.9	<66	<16	<1.1	<2.4	<9.7	<7.1
CC-122A	09-12-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
CC-130A	09-14-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
CC-130B	09-14-89	<1.1	5.0	43	<16	<1.1	<2.4	<9.7	<7.1
CC-133B	10-12-89	<1.1	<2.7	7.8	<16	<1.1	<2.4	<9.7	<7.1
CC-133B	10-12-89	<1.1	<2.7	8.4	<16	<1.1	<2.4	<9.7	<7.1
CC-134A	09-12-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
CC-136A	10-18-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
CC-136B	10-18-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
				SURFICIAL AQUIFER--Continued					
CC-1A	10-13-89	<1.1	<2.7	55	<16	<1.1	2.4	<9.7	<7.1
CC-20A	10-12-89	<1.1	<2.7	100	<16	<1.1	<2.4	<9.7	<7.1
CC-20B	10-12-89	<1.1	<2.7	280	<16	<1.1	<2.4	<9.7	<7.1
CC-23A	09-27-89	<1.1	<2.7	11	<16	<1.1	<2.4	<9.7	<7.1
CC-33A	10-11-89	<1.1	15	100	<16	<1.1	<2.4	<9.7	<7.1
CC-33B	10-11-89	<1.1	41	570	<16	170	<2.4	<9.7	<7.1
CC-33B	10-11-89	<1.1	41	470	<16	140	<2.4	<9.7	<7.1
CC-33B	10-11-89	<.27	40	>400	.70	160	<.46	<.73	<.38
CC-114A	09-21-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1
CC-133A	10-12-89	<1.1	<2.7	<6.6	<16	<1.1	<2.4	<9.7	<7.1

Chloro-ethane (µg/L)	Bromo-di-chloro-methane, (µg/L)	1,2-Di-chloro-benzene (µg/L)	1,3-Di-chloro-benzene (µg/L)	1,4-Di-chloro-benzene (µg/L)	1,2-Di-chloro-propane (µg/L)	trans-1,3-Di-chloro-propene (µg/L)	cis 1,3-Di-chloro-propene (µg/L)	Local ident-ifier
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-107B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-108A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-108A
<.86	<1.3	<.55	.38	.45	<.13	<.71	<21	CC-108A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-108B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-109A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-110A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-111A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-111B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-112A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-112A
<.94	<1.2	<.54	<.23	<.39	.18	<.65	<.95	CC-112A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-113A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-113A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-113B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-114B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-114C
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-115A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-117A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-118A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	(CC-118B
<4.0	<7.5	<27	<9.8	47	<2.8	<5.0	<5.0	CC-120A
<4.0	<7.5	<18	<9.8	33	<2.8	<5.0	<5.0	CC-120A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-120B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-122A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-130A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-130B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-133B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-133B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-134A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-136A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-136B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-1A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-20A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-20B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-23A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-33A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-33B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-33B
<.86	1.5	<.55	1.5	<.40	<.13	<.71	<1.0	CC-33B
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-114A
<4.0	<7.5	<10	<9.8	<9.1	<2.8	<5.0	<5.0	CC-133A

Appendix C1.--Concentrations of inorganic constituents detected in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, September 1988

[U, unfiltered sample; F, filtered sample; R, replicate sample; deg C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; <, less than; --, not analyzed for; beryllium and selenium were analyzed for but not detected in any samples (at <10 and <1 μg/L, respectively)]

Local identifier	Sampling date	Sampling time	Temperature, water (deg C)	Specific conductance, (μS/cm)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Solids, residue at 180 deg C (mg/L)	Calcium (mg/L) as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Sulfate (mg/L as SO_4)
CCSW-2U	9-15-88	1400	25.5	5,900	5.30	7	3,280	24	85	750	34	320
CCSW-2F	9-15-88	1400	--	--	--	--	3,290	31	110	1,000	47	300
CCSW-3U	9-15-88	1440	25.5	5,850	5.40	--	3,300	26	91	830	37	300
CCSW-4U	9-15-88	1455	26.0	5,650	5.53	--	3,310	24	85	980	34	290
CCSW-5U	9-15-88	1510	25.5	5,570	5.54	--	--	--	--	--	--	--
CCSW-6U	9-15-88	1600	24.5	5,670	5.72	--	--	--	--	--	--	--
CCSW-7U	9-15-88	1610	25.1	5,660	5.72	--	3,330	26	88	890	36	320
CCSW-7UR	9-15-88	1610	--	--	--	--	3,360	30	91	700	37	300
CCSW-7F	9-15-88	1615	--	--	--	--	3,150	29	110	1,300	46	290
CCSW-8U	9-15-88	1540	25.0	5,730	5.72	--	3,290	25	87	950	35	310
CCSW-9U	9-15-88	1520	25.2	5,560	5.54	--	3,250	25	88	810	35	300
CCSW-10U	9-15-88	1400	21.5	4,460	6.47	--	2,430	28	71	680	24	120
CCSW-11U	9-15-88	--	20.0	4,930	6.91	--	2,810	27	82	720	32	260
CCSW-12U	9-15-88	--	24.8	309	6.76	52	197	28	6.4	19	3.0	50
CCSW-12F	9-15-88	--	--	--	--	--	215	28	6.2	19	2.9	38
CCSW-13U	9-15-88	1610	24.5	162	7.45	--	97	16	5.2	10	2.5	16
CCSW-14U	9-15-88	1510	27.0	5,700	6.73	--	3,120	29	88	920	35	300
CCSW-14F	9-15-88	1630	--	--	--	--	3,120	35	110	800	42	250
CCSW-16U	9-13-88	--	22.7	363	7.32	--	200	28	8.7	27	3.3	42
CCSW-16F	9-13-88	--	--	--	--	--	--	26	8.1	26	3.2	--
CCSW-17U	9-13-88	--	25.0	345	7.28	80	180	32	9.0	23	3.5	40
CCSW-17UR	9-13-88	--	--	--	--	--	190	29	8.6	22	3.3	38
CCSW-18U	9-13-88	--	23.0	326	7.15	--	170	31	8.7	19	3.3	41
CCSW-19U	9-13-88	--	23.5	434	7.08	125	236	40	12	26	4.5	58
CCSW-19UR	9-13-88	--	--	--	--	--	234	38	11	24	4.5	40
CCSW-19F	9-13-88	--	--	--	--	--	235	42	12	25	4.5	38
CCSW-19FR	9-13-88	--	--	--	--	--	230	35	10	22	4.1	38
CCSW-20U	9-13-88	1400	23.7	2,550	6.96	--	1,550	39	59	590	23	170
CCSW-21U	9-13-88	1345	23.8	4,670	6.92	--	2,710	36	97	570	41	230
CCSW-21F	9-13-88	1350	--	--	--	--	2,740	34	92	910	38	220
CCSW-22U	9-13-88	1245	24.0	5,970	6.92	--	3,450	33	120	810	52	340
CCSW-22UR	9-13-88	1245	--	--	--	--	3,380	34	120	950	54	340
CCSW-22F	9-13-88	1250	--	--	--	--	3,430	33	120	1,200	52	300
CCSW-22FR	9-13-88	1250	--	--	--	--	3,390	33	110	770	49	310
CCSW-23U	9-13-88	1420	24.0	4,170	7.09	--	2,630	43	93	920	39	270
CCSW-24U	9-13-88	--	23.0	647	6.66	125	390	43	7.9	57	3.9	70
CCSW-25U	9-13-88	1440	23.2	3,080	6.95	--	2,040	33	68	640	27	180
CCSW-25F	9-13-88	1445	--	--	--	--	1,860	30	63	520	24	190
CCSW-25UC	9-15-88	1045	21.0	2,090	7.16	--	1,160	26	35	300	12	90
CCSW-26UC	9-15-88	1100	20.0	961	7.18	--	320	23	18	94	5.8	44
CCSW-27U	9-13-88	1400	23.0	1,910	7.05	62	469	26	19	92	7.4	50
CCSW-27UR	9-13-88	1400	--	--	--	--	458	25	19	93	7.5	50
CCSW-27F	9-13-88	1405	--	--	--	--	463	22	18	89	7.0	40
CCSW-27FR	9-13-88	1405	--	--	--	--	451	27	19	92	7.2	38
CCSW-27UC	9-15-88	1010	17.8	486	6.76	--	278	20	11	43	3.6	36
CCSW-28U	9-13-88	1400	22.0	915	6.96	--	564	24	22	190	8.8	65
CCSW-29U	9-13-88	1450	21.5	256	6.92	--	183	20	8.8	18	3.9	33
CCSW-30U	9-13-88	1500	22.5	562	7.00	--	322	--	--	--	--	42
CCSW-30UR	9-13-88	1500	--	--	--	--	310	--	--	--	--	60
CCSW-31U	9-13-88	1320	23.5	251	7.29	--	170	24	6.3	17	3.1	36
CCSW-32U	9-13-88	1310	20.5	214	6.73	--	136	16	7.8	11	3.9	34
CCSW-32UR	9-13-88	1310	--	--	--	--	145	16	7.7	11	3.8	34
CCSW-32F	9-13-88	1315	--	--	--	--	148	16	7.8	12	3.8	41
CCSW-32FR	9-13-88	1315	--	--	--	--	146	16	7.8	11	3.9	34
CCSW-33U	9-13-88	--	23.0	315	7.24	62	191	25	7.6	24	2.6	400

Appendix C1.--Concentrations of inorganic constituents detected in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, September 1988--Continued

Local identifier	Sampling date	Iron (µg/L as Fe)	Silica (mg/L as Si)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br	Phosphorus (mg/L as P)	Ammonia (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, $NO_2 + NO_3$ (mg/L as N)	Manganese (µg/L as Mn)	Cyanide (mg/L as CN)
CCSW-2U	9-15-88	950	3.2	1,800	0.21	0.24	0.05	0.22	0.02	0.50	840	<0.01
CCSW-2F	9-15-88	100	3.1	1,800	.24	<.10	<.01	.42	.03	.35	1,100	--
CCSW-3U	9-15-88	1,500	3.7	1,800	.20	1.2	<.01	.18	.02	.36	900	<.01
CCSW-4U	9-15-88	3,800	4.6	1,700	.19	1.0	<.01	.19	.02	.52	970	.08
CCSW-5U	9-15-88	--	--	--	--	--	--	--	--	--	--	--
CCSW-6U	9-15-88	--	--	--	--	--	--	--	--	--	--	--
CCSW-7U	9-15-88	1,200	3.3	1,800	.18	1.0	.05	<.10	.02	.42	790	<.01
CCSW-7UR	9-15-88	1,200	3.6	1,900	.19	.95	.07	<.10	<.02	.27	820	<.01
CCSW-7F	9-15-88	40	2.8	1,700	.18	1.2	<.01	.10	.06	.34	950	.02
CCSW-8U	9-15-88	920	3.3	1,800	.18	.80	.06	<.10	<.02	.30	810	<.01
CCSW-9U	9-15-88	1,000	3.4	1,800	.18	1.2	.08	<.10	<.02	.34	800	<.01
CCSW-10U	9-15-88	8,000	7.1	1,400	.15	4.5	.02	.90	.02	.32	1,100	<.01
CCSW-11U	9-15-88	1,300	1.7	1,630	.27	6.5	.16	<.10	<.02	.52	330	<.01
CCSW-12U	9-15-88	5,600	7.3	34	.63	<.10	.14	.21	.22	2.3	82	<.01
CCSW-12F	9-15-88	1,500	6.7	31	.60	<.10	.05	.17	.24	2.0	81	.01
CCSW-13U	9-15-88	840	2.5	17	.14	<.10	.05	<.10	.02	.54	55	<.01
CCSW-14U	9-15-88	1,600	2.6	1,800	.22	5.0	.03	<.10	.02	.21	420	<.01
CCSW-14F	9-15-88	190	2.9	1,700	.22	6.5	.02	<.10	.02	.11	960	.03
CCSW-16U	9-13-88	1,500	6.0	45	.24	<.10	.04	<.10	.02	.18	84	<.01
CCSW-16F	9-13-88	120	5.7	--	--	--	.01	.10	--	.17	87	--
CCSW-17U	9-13-88	900	4.7	39	.23	<.10	.04	<.10	.05	1.1	90	<.01
CCSW-17UR	9-13-88	840	6.2	41	.23	<.10	.04	<.10	.04	1.0	83	<.01
CCSW-18U	9-13-88	2,100	4.3	31	.21	<.10	.47	.12	.06	.96	120	<.01
CCSW-19U	9-13-88	2,000	4.8	46	.17	<.10	.11	.32	.08	.75	140	<.01
CCSW-19UR	9-13-88	2,000	4.6	46	.16	<.10	.07	.34	.07	.87	150	<.01
CCSW-19F	9-13-88	70	4.6	41	.32	<.10	<.01	.34	.07	.84	140	<.01
CCSW-19FR	9-13-88	90	4.3	41	.23	<.10	.01	.34	.07	.76	140	<.01
CCSW-20U	9-13-88	1,700	3.5	820	<.10	3.6	.10	<.10	<.02	.07	480	<.01
CCSW-21U	9-13-88	1,400	3.0	1,400	<.10	2.7	.13	<.10	<.02	.03	700	<.01
CCSW-21F	9-13-88	80	2.6	1,100	.22	2.6	.05	<.10	<.02	.65	630	<.01
CCSW-22U	9-13-88	940	3.2	1,900	<.10	<.10	.09	<.10	<.02	.05	840	--
CCSW-22UR	9-13-88	1,000	3.1	1,800	<.10	<.10	.09	<.10	<.02	.03	860	<.01
CCSW-22F	9-13-88	60	2.7	1,800	<.10	<.10	<.01	<.10	<.02	<.03	770	<.01
CCSW-22FR	9-13-88	30	2.7	1,900	.19	<.10	<.01	<.10	<.02	<.03	750	<.01
CCSW-23U	9-13-88	2,500	3.6	1,400	.20	4.8	.20	<.10	<.02	.32	430	<.01
CCSW-24U	9-13-88	1,300	8.6	94	.12	<.10	.10	<.10	<.02	.29	250	<.01
CCSW-25U	9-13-88	1,800	3.4	990	.18	--	.21	<.10	<.02	.08	460	<.01
CCSW-25F	9-13-88	120	2.9	1,000	.18	--	.01	<.10	<.02	.19	420	<.01
CCSW-25UC	9-15-88	1,400	4.5	540	.19	.85	.31	<.10	<.02	.36	520	.01
CCSW-26UC	9-15-88	1,800	5.5	270	.18	<.10	.03	<.10	.05	.27	400	<.01
CCSW-27U	9-13-88	1,600	4.1	170	.17	<.10	.75	.14	.09	.39	170	<.01
CCSW-27UR	9-13-88	1,500	4.2	170	.16	<.10	.69	.12	.09	.36	170	<.01
CCSW-27F	9-13-88	180	4.0	170	.16	<.10	.02	<.10	.04	.30	130	<.01
CCSW-27FR	9-13-88	70	4.0	170	.17	.18	.02	<.10	.04	.32	140	<.01
CCSW-27UC	9-15-88	1,600	5.5	100	.16	<.10	.26	<.10	.10	1.2	280	<.01
CCSW-28U	9-13-88	1,900	4.1	250	.16	<.10	.31	<.10	.04	.29	190	<.01
CCSW-29U	9-13-88	1,800	5.2	48	.16	<.10	.14	<.10	.05	1.1	100	<.01
CCSW-30U	9-13-88	--	--	110	.17	<.10	.28	<.10	.03	.10	--	--
CCSW-30UR	9-13-88	--	--	110	.18	<.10	.29	<.10	.03	.09	--	--
CCSW-31U	9-13-88	430	5.8	27	.28	<.10	.06	<.10	.04	1.3	32	<.01
CCSW-32U	9-13-88	2,300	5.2	24	.12	<.10	.07	<.10	.04	2.6	78	<.01
CCSW-32UR	9-13-88	2,000	5.2	22	.12	<.10	.07	<.10	.05	2.5	75	<.01
CCSW-32F	9-13-88	800	5.1	24	.12	<.10	.01	<.10	.04	2.5	90	<.01
CCSW-32FR	9-13-88	1,100	5.2	19	.12	<.10	.01	<.10	.04	2.6	86	<.01
CCSW-33U	9-13-88	2,000	6.0	36	.15	<.10	.09	<.10	.02	.34	170	<.01

Appendix C1.--Concentrations of inorganic constituents detected in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, September 1988--Continued

Local ident- ifier	Sampling date	Arsenic (μg/L as As)	Zinc (μg/L as Zn)	Antimony (μg/L as Sb)	Mercury (μg/L as Hg)	Nickel (μg/L as Ni)	Boron (μg/L as B)	Cadmium (μg/L as Cd)	Chromium (μg/L as Cr)	Copper (μg/L as Cu)	Lead (μg/L as Pb)
CCSW-2U	9-15-88	<1	38	<3	<0.5	12	460	1	2	4	2
CCSW-2F	9-15-88	<1	58	<3	<.5	8	470	<1	2	4	<1
CCSW-3U	9-15-88	<1	38	<3	<.5	10	470	1	<1	7	4
CCSW-4U	9-15-88	2	43	<3	<.5	10	450	2	4	7	6
CCSW-5U	9-15-88	--	--	--	--	--	--	--	--	--	--
CCSW-6U	9-15-88	--	--	--	--	--	--	--	--	--	--
CCSW-7U	9-15-88	<1	33	<3	<.5	8	450	1	2	4	3
CCSW-7UR	9-15-88	<1	94	<3	<.5	8	450	<1	1	4	4
CCSW-7F	9-15-88	<1	11	<3	<.5	5	460	<1	<1	2	<1
CCSW-8U	9-15-88	<1	19	<3	<.5	5	470	<1	1	3	<1
CCSW-9U	9-15-88	<1	54	<3	<.5	12	470	<1	2	4	2
CCSW-10U	9-15-88	2	57	<3	<.5	9	350	2	8	12	11
CCSW-11U	9-15-88	<1	29	<3	<.5	6	380	1	2	5	4
CCSW-12U	9-15-88	<1	62	<3	1.5	<1	150	1	<1	12	7
CCSW-12F	9-15-88	<1	20	<3	<.5	2	150	<1	<1	2	<1
CCSW-13U	9-15-88	<1	160	<3	<.5	2	<50	<1	<1	10	5
CCSW-14U	9-15-88	<1	77	<3	<.5	4	440	<1	2	5	4
CCSW-14F	9-15-88	<1	22	<3	<.5	3	430	<1	<1	2	<1
CCSW-16U	9-13-88	1	10	<3	<.5	2	100	<1	1	3	3
CCSW-16F	9-13-88	<1	<10	<3	<.5	2	90	<1	<1	<1	<1
CCSW-17U	9-13-88	1	35	<3	<.5	<1	80	<1	<1	3	3
CCSW-17UR	9-13-88	<1	13	<3	<.5	2	90	<1	<1	3	2
CCSW-18U	9-13-88	1	26	<3	<.5	1	80	<1	1	5	4
CCSW-19U	9-13-88	<1	41	<3	<.5	2	120	<1	<1	3	4
CCSW-19UR	9-13-88	<1	52	<3	<.5	3	110	1	<1	4	5
CCSW-19F	9-13-88	<1	62	<3	<.5	3	110	<1	<1	1	2
CCSW-19FR	9-13-88	<1	30	<3	<.5	3	100	<1	<1	2	1
CCSW-20U	9-13-88	3	38	<3	<.5	2	250	<1	1	3	2
CCSW-21U	9-13-88	2	39	<3	<.5	3	380	<1	<1	4	5
CCSW-21F	9-13-88	1	14	<3	<.5	3	370	<1	<1	1	<1
CCSW-22U	9-13-88	1	30	<3	<.5	3	470	<1	<1	3	16
CCSW-22UR	9-13-88	1	33	<3	<.5	4	460	<1	<1	3	5
CCSW-22F	9-13-88	<1	15	<3	<.5	3	460	<1	1	2	41
CCSW-22FR	9-13-88	<1	18	<3	<.5	2	460	<1	<1	2	<1
CCSW-23U	9-13-88	3	70	<3	<.5	3	380	<1	2	11	15
CCSW-24U	9-13-88	1	19	<3	<.5	2	180	<1	2	4	3
CCSW-25U	9-13-88	3	64	<3	<.5	5	290	<1	2	6	5
CCSW-25F	9-13-88	2	11	<3	<.5	3	280	<1	2	2	1
CCSW-25UC	9-15-88	3	39	<3	<.5	4	210	<1	<1	5	11
CCSW-26UC	9-15-88	3	84	<3	<.5	5	130	<1	3	7	12
CCSW-27U	9-13-88	2	100	<3	<.5	5	100	<1	4	7	11
CCSW-27UR	9-13-88	2	86	<3	<.5	5	110	<1	3	5	8
CCSW-27F	9-13-88	1	24	<3	<.5	5	100	<1	3	2	1
CCSW-27FR	9-13-88	1	100	<3	<.5	5	100	<1	2	2	3
CCSW-27UC	9-15-88	2	120	<3	<.5	8	80	<1	2	7	14
CCSW-28U	9-13-88	3	71	<3	<.5	5	110	<1	4	5	9
CCSW-29U	9-13-88	<1	40	<3	<.5	3	50	<1	2	3	3
CCSW-30U	9-13-88	--	--	--	--	--	--	--	--	--	--
CCSW-30UR	9-13-88	--	--	--	--	--	--	--	--	--	--
CCSW-31U	9-13-88	<1	42	12	<.5	3	50	<1	2	11	18
CCSW-32U	9-13-88	<1	14	<3	<.5	3	<50	<1	2	2	<1
CCSW-32UR	9-13-88	<1	13	<3	<.5	3	<50	<1	2	2	<1
CCSW-32F	9-13-88	<1	14	<3	<.5	5	<50	<1	3	2	<1
CCSW-32FR	9-13-88	<1	16	<3	<.5	4	<50	<1	<1	2	<1
CCSW-33U	9-13-88	2	25	4	<.5	4	70	<1	<1	2	<1

APPENDIX C2.--FOLLOWS

Appendix C2.--Concentrations of volatile organic constituents quantitated in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, September 1988

[All concentrations are for unfiltered samples in units of micrograms per liter. #, value estimated because peak was present bu concentration was below detection limit; *, compound detected in method blank; MB, method blank; R, replicate sample; (Re), repeat analysis by laboratory; <, less than]

Sample number	Sampling date	Date of analysis	Toluene	Benzene	Ethyl-benzene	Chloro-benzene	Carbon tetra-chloride	Chloro-form	Methy-lene chloride	1,1,2,2-Tetra-chloro-ethane	1,1,2-Tri-chloro-ethane	1,2-Di chloro ethane
MB1	--	9-24-88	<5	<5	<5	<5	<5	<5	10	<10	<5	<10
MB2	--	9-28-88	<5	<5	<5	<5	<5	<5	13	<10	<5	<10
MB3	--	9-29-88	<5	<5	<5	<5	<5	<5	7	<10	<5	<10
MB4	--	10-04-88	<5	<5	<5	<5	<5	<5	15	<10	<5	<10
MB5	--	10-11-88	<5	<5	<5	<5	<5	<5	10	<10	<5	<10
MB6	--	10-13-88	<5	<5	<5	<5	<5	<5	7	<10	<5	<10
CCSW-2	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	8*	<10	<5	<10
CCSW-3	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	2*#	10	<5	<10
CCSW-4	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	7*	<10	<5	<10
CCSW-5	9-15-88	9-28-88	<5	<5	<5	<5	<5	<5	13*	<10	<5	<10
CCSW-6	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	2*#	<10	<5	<10
CCSW-7	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	3*#	<10	<5	<10
CCSW-8	9-15-88	9-28-88	<5	<5	<5	<5	<5	<5	20*	<10	<5	<10
CCSW-9	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	3*#	<10	<5	<10
CCSW-10	9-15-88	10-04-88	<5	<5	<5	<5	<5	<5	5*	<10	<5	<10
CCSW-11	9-15-88	9-29-88	<5	<5	<5	<5	<5	<5	3*#	<10	<5	<10
CCSW-12	9-15-88	10-04-88	<5	<5	<5	<5	<5	56	23*	<10	<5	<10
CCSW-12R	9-15-88	9-29-88	<5	<5	<5	<5	<5	58	10*	<10	<5	<10
CCSW-13	9-15-88	9-28-88	<5	<5	<5	<5	<5	<5	6*	<10	<5	<10
CCSW-14	9-15-88	10-04-88	<5	<5	<5	<5	<5	<5	15*	<10	<5	<10
CCSW-16	9-13-88	9-24-88	<5	<5	<5	<5	<5	<5	3*#	<10	<5	<10
CCSW-17	9-13-88	10-11-88	<5	<5	<5	<5	<5	<5	6*	18	<5	<10
CCSW-18	9-13-88	9-28-88	<5	<5	<5	<5	<5	<5	32*	10	<5	<10
CCSW-19	9-13-88	10-13-88	<5	<5	<5	<5	<5	<5	9*	8#	<5	<10
CCSW-19R	9-13-88	9-24-88	<5	<5	<5	2#	<5	<5	10*	8#	<5	<10
CCSW-20	9-13-88	9-24-88	<5	<5	<5	<5	<5	3#	6*	5#	<5	<10
CCSW-20(Re)	9-13-88	10-13-88	<5	<5	<5	<5	1#	<5	5*	3#	<5	<10
CCSW-21	9-13-88	9-24-88	<5	<5	1#	<5	<5	4#	8*	1#	<5	<10
CCSW-22	9-13-88	9-28-88	8	7	8	8	7	7	38*	8#	8	8#
CCSW-22R	9-13-88	9-24-88	<5	<5	1#	<5	<5	<5	6*	<10	<5	<10
CCSW-22R(Re)	9-13-88	10-13-88	<5	<5	<5	<5	<5	<5	9*	<10	<5	<10
CCSW-23	9-13-88	10-04-88	<5	<5	<5	<5	<5	<5	14*	<10	<5	<10
CCSW-24	9-13-88	9-28-88	<5	<5	<5	<5	<5	<5	13*	<10	<5	<10
CCSW-24(Re)	9-13-88	10-04-88	<5	<5	34	<5	10	<5	17*	<10	<5	<10
CCSW-25	9-13-88	9-28-88	<5	<5	<5	<5	4#	6	28*	<10	<5	<10
CCSW-25C	9-15-88	9-28-88	<5	<5	<5	<5	7	11	10*	<10	<5	<10
CCSW-26C	9-15-88	9-28-88	<5	<5	<5	<5	19	23	6*	4#	<5	<10
CCSW-27C	9-15-88	9-28-88	<5	<5	<5	<5	5	5	16*	7#	<5	<10
CCSW-28	9-13-88	9-24-88	<5	<5	<5	<5	8	9	8*	5#	<5	<10
CCSW-28(Re)	9-13-88	10-13-88	<5	<5	<5	<5	4#	<5	5*	4#	<5	<10
CCSW-29	9-13-88	9-24-88	<5	<5	<5	<5	<5	<5	3*#	<10	<5	<10
CCSW-30	9-13-88	9-24-88	<5	<5	<5	<5	<5	2#	4*#	4#	<5	<10
CCSW-30R	9-13-88	9-24-88	<5	<5	1#	<5	<5	2#	8*	4#	<5	<10
CCSW-31	9-13-88	10-04-88	<5	<5	1#	<5	<5	<5	8*	<10	<5	<10
CCSW-32	9-13-88	10-11-88	<5	<5	<5	<5	<5	<5	13*	<10	<5	<10
CCSW-32R	9-13-88	9-24-88	<5	<5	<5	<5	<5	21	8*	<10	<5	<10
CCSW-33	9-13-88	9-28-88	<5	<5	<5	<5	<5	<5	8*	<10	<5	<10

1,1-Dichloroethane	Tetrachloroethylene	Trichloroethylene	1,1-Dichloroethylene	1,2-trans-Dichloroethylene	Vinyl chloride	1,3-cis-Dichloropropene	Trichlorofluoromethane	1,1,1-Trichloroethane	Bromodichloromethane	1,2-Dichloropropane	Dibromochloroethane	Bromoform	Sample number
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	MB1
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	MB2
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	MB3
<5	<5	<5	<5	1#	<10	<5	4#	<5	<5	<5	<5	<10	MB4
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<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-2
<5	<5	3#	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-3
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-4
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-5
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<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-7
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<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-9
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-10
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-11
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<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-12R
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-13
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-14
<5	<5	3#	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-16
<5	<5	11	7	7	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-17
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-18
<5	<5	3#	<5	2#	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-19
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-19R
<5	<5	7	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-20
<5	<5	3#	<5	2#	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-20(Re)
<5	<5	8	<5	<5	<10	<5	4#	<5	<5	<5	<5	<10	CCSW-21
8	10	8	8	10	5#	10	10	7	9	9#	11	9#	CCSW-22
<5	<5	7	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-22R
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-22R(Re)
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-23
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-24
<5	<5	<5	<5	<5	<10	2#	<5	<5	<5	<5	<5	<10	CCSW-24(Re)
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-25
<5	2#	4#	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-25C
<5	5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-26C
<5	<5	3#	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-27C
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-28
<5	<5	1#	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-28(Re)
<5	<5	11	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-29
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-30
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-30R
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-31
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-32
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-32R
<5	<5	<5	<5	<5	<10	<5	<5	<5	<5	<5	<5	<10	CCSW-33

Appendix C3.--Concentrations of inorganic constituents detected in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, June 1989

[U, unfiltered sample; F, filtered sample; R, replicate sample; deg C, degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius, ppt, parts per thousand, --, not analyzed for]

Local identifier	Sampling date	Time	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Specific conductance (μs/cm)	pH (standard units)	Salinity (ppt)	Solids, residue at 180 deg C (mg/L)	Residue, total at 105 deg C, suspended (mg/L)	Calcium (mg/L as Ca)
CCSW-2U	06-15-89	1030	25.5	7.1	470	6.75	21	352	25	4.9
CCSW-3U	06-15-89	1100	--	7.1	470	6.93	27	334	14	4.9
CCSW-3UR	06-15-89	1100	--	--	--	--	21	344	9	4.9
CCSW-3F	06-15-89	1100	--	--	--	--	20	322	<5	5.2
CCSW-4U	06-15-89	1130	22.5	7.6	471	6.97	20	344	14	4.9
CCSW-5U	06-15-89	1400	24.5	8.0	480	6.93	24	362	31	5.4
CCSW-6U	06-15-89	1230	23.0	6.7	472	6.86	--	350	38	--
CCSW-7U	06-15-89	1245	23.5	6.8	478	6.96	21	332	17	4.5
CCSW-8U	06-15-89	1300	24.0	7.0	477	7.04	27	350	25	4.4
CCSW-9U	06-15-89	1315	23.5	6.9	476	7.02	--	--	--	--
CCSW-10U	06-15-89	1115	21.0	3.2	511	6.45	21	536	191	10
CCSW-12U	06-15-89	1200	24.5	6.4	395	6.28	13	260	16	25
CCSW-12UR	06-15-89	1200	--	--	--	--	--	250	14	-
CCSW-12F	06-15-89	1210	--	--	--	--	13	234	<5	27
CCSW-13U	06-15-89	1330	22.5	6.4	209	6.59	.65	142	23	21
CCSW-14U	06-15-89	1415	22.0	21	258	6.73	.76	244	54	62
CCSW-14UR	06-15-89	1415	--	--	--	--	--	--	--	--
CCSW-16U	06-13-89	1330	22.5	8.4	359	6.89	9.5	260	<5	120
CCSW-17U	06-13-89	1445	23.0	8.8	360	6.57	9.1	280	33	44
CCSW-17UR	06-13-89	1445	--	--	--	--	--	273	31	--
CCSW-17F	06-13-89	1445	--	--	--	--	8.6	--	--	43
CCSW-18U	06-13-89	1230	23.5	16	369	6.65	8.8	260	6	63
CCSW-19U	06-13-89	1100	21.5	9.2	410	6.98	8.2	324	<5	53
CCSW-19UR	06-13-89	1100	--	--	--	--	8.4	290	<5	53
CCSW-19F	06-13-89	1100	--	--	--	--	8.2	277	<5	58
CCSW-19FR	06-13-89	1100	--	--	--	--	8.4	--	--	58
CCSW-20U	06-13-89	1330	23.5	6.6	395	6.72	12	278	27	30
CCSW-20UR	06-13-89	1330	--	--	--	--	--	272	28	--
CCSW-21U	06-13-89	1255	23.0	4.6	383	6.83	11	255	36	22
CCSW-21UR	06-13-89	1255	--	--	--	--	--	--	--	--
CCSW-21F	06-13-89	1255	--	--	--	--	11	--	--	21
CCSW-22U	06-13-89	1057	23.0	3.8	325	6.89	11	262	20	15
CCSW-22UR	06-13-89	1057	--	--	--	--	15	236	30	15
CCSW-22F	06-13-89	1057	--	--	--	--	11	217	<5	14
CCSW-22FR	06-13-89	1057	--	--	--	--	12	--	--	14
CCSW-23U	06-13-89	1355	25.5	7.4	534	7.12	15	368	40	46
CCSW-24U	06-13-89	1000	20.0	19	581	6.32	17	608	256	63
CCSW-24UR	06-13-89	1000	--	--	--	--	--	--	--	--
CCSW-25U	06-13-89	1415	23.5	4.8	382	6.93	11	278	34	32
CCSW-25UR	06-13-89	1415	--	--	--	--	--	260	13	--
CCSW-26U	06-13-89	1300	23.5	5.5	693	6.84	9.3	234	20	21
CCSW-26UR	06-13-89	1300	--	--	--	--	--	--	--	--
CCSW-27U	06-13-89	1100	22.0	5.4	864	6.81	.91	216	20	21
CCSW-27UR	06-13-89	1100	--	--	--	--	.90	216	14	21
CCSW-27F	06-13-89	1100	--	--	--	--	.41	--	--	21
CCSW-28U	06-13-89	1200	21.0	5.4	360	6.97	.83	184	<5	30
CCSW-29U	06-13-89	1130	19.0	6.8	490	6.78	.64	188	<5	18
CCSW-30U	06-13-89	1100	22.0	4.0	238	6.48	.70	172	<5	26
CCSW-31U	06-13-89	1430	24.5	6.2	325	6.57	8.8	182	<5	21
CCSW-32U	06-13-89	1445	20.0	7.0	250	7.16	.68	178	<5	17
CCSW-32UR	06-13-89	1445	--	--	--	--	--	192	<5	--
CCSW-32F	06-13-89	1445	--	--	--	--	.75	--	--	17
CCSW-33U	06-13-89	1400	20.0	7.6	248	6.54	8.7	174	<5	25

Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Bicarbonate (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Iron (ug/L as Fe)	Nitrogen, NO_2+NO_3 (mg/L as N)	Phosphorus (mg/L as P)	Fluoride (mg/L as F)	Local identifier
13	<51	--	29	120	1,600	0.70	0.066	0.22	CCSW-2U
12	54	--	29	150	1,400	.76	.083	.15	CCSW-3U
13	51	--	30	120	1,400	.80	.069	.14	CCSW-3UR
13	<51	--	28	110	77	.75	<.025	<.071	CCSW-3F
12	68	--	28	120	1,300	.75	.058	<.071	CCSW-4U
13	<51	--	28	140	1,600	.66	.052	.14	CCSW-5U
--	--	--	--	--	--	--	.081	--	CCSW-6U
13	100	--	29	120	1,600	.73	.077	<.071	CCSW-7U
12	<51	--	28	150	3,400	.70	.069	.13	CCSW-8U
--	>60	--	29	110	--	.77	.087	<.071	CCSW-9U
14	68	--	27	120	7,700	<.031	.28	<.071	CCSW-10U
9.6	37	47	32	66	2,900	.53	.087	.22	CCSW-12U
--	--	--	--	--	--	--	.056	--	CCSW-12UR
9.7	40	--	32	64	3,000	.57	--	.21	CCSW-12F
7.5	20	--	22	23	2,000	.78	.28	.10	CCSW-13U
8.7	23	--	5.8	<33	5,100	.098	--	.30	CCSW-14U
--	--	--	--	--	--	--	.085	--	CCSW-14UR
10	37	83	34	43	1,600	.18	.031	.20	CCSW-16U
16	47	89	33	41	1,900	.78	.039	.28	CCSW-17U
		--	--	--	--	--	.050	--	CCSW-17UR
11	29	--	34	37	240	.81	<.025	.17	CCSW-17F
12	24	95	38	38	2,800	.82	.087	.30	CCSW-18U
15	40	123	41	35	1,000	.81	.044	.20	CCSW-19U
16	41	--	42	36	990	.84	.035	.17	CCSW-19UR
17	36	--	39	35	97	.77	<.025	.46	CCSW-19F
12	25	--	39	36	160	.78	--	.18	CCSW-19FR
16	59	85	26	60	1,800	<.31	.17	<.071	CCSW-20U
--	--	--	--	--	--	--	--	--	CCSW-20UR
12	43	77	27	55	2,400	<.31	.18	.21	CCSW-21U
--	--	--	--	--	--	--	--	--	CCSW-21UR
10	37	--	28	51	230	<.31	--	.20	CCSW-21F
14	55	48	23	56	1,200	.14	.13	.18	CCSW-22U
12	48	--	19	81	1,300	.13	.13	.18	CCSW-22UR
10	43	--	21	52	130	.11	.23	.85	CCSW-22F
11	41	--	20	61	97	.14	<.025	.20	CCSW-22FR
14	210	108	39	80	1,900	.036	.16	.52	CCSW-23U
9.6	220	141	44	92	1,000	.12	.14	<.071	CCSW-24U
--	--	--	--	--	--	--	--	--	CCSW-24UR
12	51	72	28	54	1,700	<.31	.16	.16	CCSW-25U
--	--	--	--	--	--	--	--	--	CCSW-25UR
14	44	70	27	42	2,000	.56	.21	.18	CCSW-26U
--	--	--	--	--	--	--	--	--	CCSW-26UR
8.7	23	65	25	<33	1,900	.80	.21	.16	CCSW-27U
12	30	--	25	<33	2,300	.78	.19	.76	CCSW-27UR
13	33	--	26	7.5	450	--	--	.22	CCSW-27F
10	26	55	19	<33	1,500	.93	.16	.16	CCSW-28U
11	18	52	22	23	1,400	1.5	.079	.24	CCSW-29U
7.5	24	78	12	<33	1,600	.13	.24	.19	CCSW-30U
8.2	32	66	15	38	2,300	<3.1	.13	.26	CCSW-31U
8.4	10	44	20	<33	2,700	<3.1	.083	.13	CCSW-32U
--	--	--	--	--	--	--	.077	--	CCSW-32UR
8.3	11	--	20	36	1,100	<3.1	--	.25	CCSW-32F
7.2	28	43	21	37	1,500	<.31	.018	.15	CCSW-33U

Appendix C3.--Concentrations of inorganic constituents detected in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, June 1989--Continued

Local identifier	Sampling date	Bromide (mg/L as Br)	Manganese (μg/L as Mn)	Aluminum (μg/L as Al)	Antimony (μg/L as Sb)	Arsenic, total (μg/L as As)	Barium (μg/L as Ba)	Beryllium (μg/L as Be)	Boron (μg/L as B)	Cadmium (μg/L as Cd)
CCSW-2U	06-15-89	0.41	190	2,600	<72	<3	13	12	<27	<3.0
CCSW-3U	06-15-89	.38	180	720	<72	<3	11	<1.6	34	<3.0
CCSW-3UR	06-15-89	.38	190	2,700	<72	<3	12	10	<27	<3.0
CCSW-3F	06-15-89	.37	160	<160	<72	<3	10	<1.6	<27	<3.0
CCSW-4U	06-15-89	.40	190	2,300	<72	<3	12	9.3	<27	6.6
CCSW-5U	06-15-89	.42	170	3,300	<72	<3	13	13	28	<3.0
CCSW-6U	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-7U	06-15-89	.41	190	2,500	<72	<3	11	12	<27	<3.0
CCSW-8U	06-15-89	.41	240	2,300	<72	<3	12	24	<27	4.2
CCSW-9U	06-15-89	.38	--	--	--	--	--	--	--	--
CCSW-10U	06-15-89	.44	660	6,200	<72	4	34	43	29	<3.0
CCSW-12U	06-15-89	.10	220	220	<72	<3	55	44	42	4.4
CCSW-12UR	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-12F	06-15-89	.10	210	<160	<72	<3	54	19	<27	<3.0
CCSW-13U	06-15-89	<.053	120	560	<72	<3	20	17	31	4.6
CCSW-14U	06-15-89	.074	1,300	2,400	<72	<3	43	39	<27	<3.0
CCSW-14UR	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-16U	06-13-89	.083	210	320	<72	<3	50	12	<27	<3.0
CCSW-17U	06-13-89	.073	160	240	<72	<3	41	<1.6	<27	<3.0
CCSW-17UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-17F	06-13-89	.074	180	<160	<72	<3	43	<1.6	<27	<3.0
CCSW-18U	06-13-89	.065	110	310	<72	<3	43	<1.6	<27	<3.0
CCSW-19U	06-13-89	.068	90	210	<72	<3	78	7.1	<27	<3.0
CCSW-19UR	06-13-89	.062	96	190	<72	<3	83	7.6	33	5.7
CCSW-19F	06-13-89	.061	86	180	<72	<3	92	<1.6	<27	<3.0
CCSW-19FR	06-13-89	.063	88	220	<72	<3	86	<1.6	<27	<3.0
CCSW-20U	06-13-89	.16	270	680	<72	4	37	16	<27	<3.0
CCSW-20UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-21U	06-13-89	.17	220	2,400	<72	3	34	<1.6	<27	<3.0
CCSW-21UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-21F	06-13-89	.16	160	210	<72	<3	26	<1.6	<27	<3.0
CCSW-22U	06-13-89	.19	140	420	<72	<3	19	<1.6	<27	<3.0
CCSW-22UR	06-13-89	.20	140	510	<72	<3	19	<1.6	<27	<3.0
CCSW-22F	06-13-89	.14	110	180	<72	<3	15	<1.6	<27	<3.0
CCSW-22FR	06-13-89	.19	99	210	<72	<3	15	<1.6	<27	<3.0
CCSW-23U	06-13-89	.17	280	510	<72	5	29	<1.6	<27	<3.0
CCSW-24U	06-13-89	<.053	140	250	<72	<3	48	<1.6	<27	<3.0
CCSW-24UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-25U	06-13-89	.17	210	640	<72	3	30	<1.6	<27	<3.0
CCSW-25UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-26U	06-13-89	.13	190	500	<72	<3	39	<1.6	<27	3.1
CCSW-26UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-27U	06-13-89	.11	160	500	<72	<3	44	<1.6	<27	<3.0
CCSW-27UR	06-13-89	.085	170	370	<72	<3	47	<1.6	<27	<3.0
CCSW-27F	06-13-89	<.053	160	<160	<72	<3	44	<1.6	<27	<3.0
CCSW-28U	06-13-89	.091	180	320	<72	<3	52	<1.6	39	5.0
CCSW-29U	06-13-89	.086	160	230	<72	<3	35	<1.6	<27	<3.0
CCSW-30U	06-13-89	<.053	340	230	<72	<3	62	<1.6	<27	<3.0
CCSW-31U	06-13-89	<.053	120	300	<72	<3	100	<1.6	<27	<3.0
CCSW-32U	06-13-89	<.053	270	340	<72	<3	43	<1.6	<27	<3.0
CCSW-32UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-32F	06-13-89	<.053	260	180	<72	<3	38	<1.6	<27	<3.0
CCSW-33U	06-13-89	.091	550	300	<72	<3	52	11	<27	<3.0

Chromium (µg/L as Cr)	Copper (µg/L as Cu)	Lead (µg/L as Pb)	Mercury (µg/L as Hg)	Nickel (µg/L as Ni)	Selenium (µg/L as Se)	Silver (µg/L as Ag)	Thallium (µg/L as Tl)	Zinc (µg/L as Zn)	Local identifier
<50	<22	8	<0.6	<32	<4	0.8	44	56	CCSW-2U
<50	<22	<5	<.6	<32	<4	<.3	<44	<42	CCSW-3U
<50	<22	6	<.6	<32	<4	<.3	<44	43	CCSW-3UR
<50	<22	<5	<.6	<32	<4	<.3	<44	<42	CCSW-3F
<50	<22	7	<.6	<32	<4	<.3	<44	55	CCSW-4U
<50	<22	13	<.6	<32	<4	<.3	<44	51	CCSW-5U
--	--	--	--	--	--	--	--	--	CCSW-6U
<50	<22	<5	<.6	<32	<4	<.3	<44	44	CCSW-7U
<50	<22	7	1.7	<32	<4	<.3	<44	180	CCSW-8U
--	--	--	--	--	--	--	--	--	CCSW-9U
<50	<22	43	<.6	33	<4	<.3	45	100	CCSW-10U
<50	44	<5	<.6	34	<4	<.3	<44	50	CCSW-12U
--	--	--	--	--	--	--	--	--	CCSW-12UR
<50	<22	14	<.6	<32	<4	<.3	<44	58	CCSW-12F
<50	23	21	2.4	<32	<4	<.3	<44	390	CCSW-13U
<50	<22	12	<.6	<32	<4	<.3	<44	110	CCSW-14U
--	--	--	--	--	--	--	--	--	CCSW-14UR
<50	<22	7	<.6	<32	<4	.5	<44	60	CCSW-16U
<50	<22	15	<.6	<32	<4	<.3	<44	130	CCSW-17U
--	--	--	--	--	--	--	--	--	CCSW-17UR
<50	<22	<5	<.6	<32	<4	<.3	<44	<42	CCSW-17F
<50	<22	11	<.6	<32	<4	<.3	<44	69	CCSW-18U
<50	<22	<5	<.6	<32	<4	<.3	<44	54	CCSW-19U
<50	<22	<5	<.6	<32	<4	<.3	<44	60	CCSW-19UR
<50	33	<5	<.6	<32	<4	.4	<44	58	CCSW-19F
<50	<22	17	<.6	<32	<4	<.3	<44	130	CCSW-19FR
<50	<22	14	<.6	<32	<4	<.3	50	50	CCSW-20U
--	--	--	--	--	--	--	--	--	CCSW-20UR
<50	<22	24	<.6	<32	<4	<.3	<44	60	CCSW-21U
--	--	--	--	--	--	--	--	--	CCSW-21UR
<50	<22	7	<.6	<32	<4	<.3	<44	<42	CCSW-21F
<50	<22	12	<.6	<32	<4	<.3	<44	140	CCSW-22U
<50	<22	11	<.6	<32	<4	<.3	<44	58	CCSW-22UR
<50	<22	<5	<.6	<32	<4	<.3	<44	<42	CCSW-22F
<50	<22	<5	<.6	<32	<4	.3	<44	<42	CCSW-22FR
<50	<22	21	<.6	<32	<4	<.3	<44	<42	CCSW-23U
<50	<22	9	<.6	<32	<4	.6	<44	300	CCSW-24U
--	--	--	--	--	--	--	--	--	CCSW-24UR
<50	<22	14	<.6	<32	<4	.6	<44	52	CCSW-25U
--	--	--	--	--	--	--	--	--	CCSW-25UR
<50	<22	34	<.6	<32	<4	<.3	<44	78	CCSW-26U
--	--	--	--	--	--	--	--	--	CCSW-26UR
<50	<22	11	<.6	<32	<4	<.3	<44	60	CCSW-27U
<50	<22	18	<.6	<32	<4	<.3	<44	74	CCSW-27UR
<50	<22	8	<.6	<32	<4	<.3	<44	<42	CCSW-27F
<50	<22	6	.7	<32	<4	<.3	<44	68	CCSW-28U
<50	<22	13	<.6	<32	<4	<.3	<44	<42	CCSW-29U
<50	<22	6	<.6	<32	<4	<.3	<44	56	CCSW-30U
<50	<22	15	<.6	<32	<4	.5	<44	110	CCSW-31U
<50	<22	<5	<.6	<32	<4	<.3	<44	61	CCSW-32U
--	--	--	--	--	--	--	--	--	CCSW-32UR
<50	<22	<5	<.6	<32	<4	<.3	<44	94	CCSW-32F
<50	<22	<5	<.6	<32	<4	<.3	<44	52	CCSW-33U

Appendix C4.--Concentrations of volatile organic constituents quantitated in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, June 1989

[mg/L, milligrams per liter; µg/L, micrograms per liter; R, replicate sample; --, not analyzed for]

Local identifier	Sampling date	Time	Carbon, organic total (mg/L as C)	Carbon, organic dissolved (mg/L as C)	Toluene (µg/L)	Ethylbenzene (µg/L)	Benzene (µg/L)	Chlorobenzene (µg/L)	Carbon tetrachloride (µg/L)
CCSW-2U	06-15-89	1030	3.6	3.2	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-3U	06-15-89	1100	3.6	3.2	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-3UR	06-15-89	1100	3.3	3.1	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-3F	06-15-89	1100	--	--	--	--	--	--	--
CCSW-4U	06-15-89	1130	3.6	3.2	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-5U	06-15-89	1400	3.8	3.1	31	39	26	21	31
CCSW-6U	06-15-89	1230	3.6	3.0	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-7U	06-15-89	1245	3.8	3.2	17	18	16	13	36
CCSW-8U	06-15-89	1300	3.6	3.2	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-9U	06-15-89	1315	--	--	--	--	--	--	--
CCSW-10U	06-15-89	1115	10	9.8	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-12U	06-15-89	1200	4.3	4.0	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-12UR	06-15-89	1200	4.2	4.1	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-12F	06-15-89	1210	--	--	--	--	--	--	--
CCSW-13U	06-15-89	1330	--	4.3	--	--	--	--	--
CCSW-14U	06-15-89	1415	17	17	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-14UR	06-15-89	1415	17	16	--	--	--	--	--
CCSW-16U	06-13-89	1330	5.5	5.3	<8.7	<9.3	<2.4	<1.4	<5.6
CCSW-17U	06-13-89	1445	4.2	3.7	<8.7	<9.3	<2.4	<1.4	<5.6
CCSW-17UR	06-13-89	1445	4.2	4.1	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-17F	06-13-89	1445	--	--	--	--	--	--	--
CCSW-18U	06-13-89	1230	4.8	4.4	<8.7	<9.3	<2.4	1.4	<5.6
CCSW-19U	06-13-89	1100	4.6	4.5	<8.7	<9.3	<2.4	<1.4	<5.6
CCSW-19UR	06-13-89	1100	4.8	5.1	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-19F	06-13-89	1100	--	--	--	--	--	--	--
CCSW-19FR	06-13-89	1100	--	--	--	--	--	--	--
CCSW-20U	06-13-89	1330	8.0	6.6	<8.7	<9.3	<2.4	<1.4	<5.6
CCSW-20UR	06-13-89	1330	8.0	6.6	--	--	--	--	--
CCSW-21U	06-13-89	1255	6.9	6.5	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-21UR	06-13-89	1255	7.0	6.2	--	--	--	--	--
CCSW-21F	06-13-89	1255	--	--	--	--	--	--	--
CCSW-22U	06-13-89	1057	17	18	--	--	--	--	--
CCSW-22UR	06-13-89	1057	5.5	5.5	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-22F	06-13-89	1057	--	--	--	--	--	--	--
CCSW-22FR	06-13-89	1057	--	--	--	--	--	--	--
CCSW-23U	06-13-89	1355	8.0	7.3	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-24U	06-13-89	1000	1.5	1.4	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-24UR	06-13-89	1000	1.4	1.1	--	--	--	--	--
CCSW-25U	06-13-89	1415	6.8	6.0	<8.7	<9.3	<2.4	1.5	<5.6
CCSW-25UR	06-13-89	1415	7.0	6.5	--	--	--	--	--
CCSW-26U	06-13-89	1300	8.4	7.4	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-26UR	06-13-89	1300	7.7	7.4	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-27U	06-13-89	1100	8.1	7.4	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-27UR	06-13-89	1100	8.1	7.2	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-27F	06-13-89	1100	--	--	--	--	--	--	--
CCSW-28U	06-13-89	1200	8.3	6.7	<8.7	<9.3	<2.4	1.5	<5.6
CCSW-29U	06-13-89	1130	7.1	6.3	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-30U	06-13-89	1100	8.5	7.4	<8.7	<9.3	<2.4	<1.4	<5.6
CCSW-31U	06-13-89	1430	7.4	6.0	<8.7	<9.3	<2.4	1.5	<5.6
CCSW-32U	06-13-89	1445	8.4	7.8	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-32UR	06-13-89	1445	8.0	7.4	<8.1	<9.6	<2.4	<1.4	<5.9
CCSW-32F	06-13-89	1445	--	--	--	--	--	--	--
CCSW-33U	06-13-89	1400	5.5	5.6	<8.7	<9.3	<2.4	1.5	<5.6

Chloroform (μg/L)	Methylchloride (μg/L)	Methylene chloride (μg/L)	1,1,2,2-Tetrachloroethane (μg/L)	1,1,1-Trichloroethane (μg/L)	1,1,2-Trichloroethane (μg/L)	1,2-Dichloroethane (μg/L)	1,1-Dichloroethane (μg/L)	Tetrachloroethylene (μg/L)	Local identifier
<0.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-2U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-3U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-3UR
--	--	--	--	--	--	--	--	--	CCSW-3F
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	1.2	<2.7	CCSW-4U
23	31	11	5.1	42	<19	37	71	59	CCSW-5U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-6U
15	24	17	5.7	<4.5	<19	20	33	26	CCSW-7U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-8U
--	--	--	--	--	--	--	--	--	CCSW-9U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-10U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-12U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-12UR
--	--	--	--	--	--	--	--	--	CCSW-12F
--	--	--	--	--	--	--	--	--	CCSW-13U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-14U
--	--	--	--	--	--	--	--	--	CCSW-14UR
<.83	<1.6	<5.4	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-16U
<.83	<1.6	<5.4	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-17U
<.84	<1.1	<5.3	49	<4.5	<19	<6.9	<1.1	<2.7	CCSW-17UR
--	--	--	--	--	--	--	--	--	CCSW-17F
<.83	<1.6	<5.4	21	<4.1	<17	<7.6	<1.1	<2.7	CCSW-18U
<.83	<1.6	<5.4	18	<4.1	<17	<7.6	<1.1	<2.7	CCSW-19U
<.84	<1.1	<5.3	20	<4.5	<19	<6.9	<1.1	<2.7	CCSW-19UR
--	--	--	--	--	--	--	--	--	CCSW-19F
--	--	--	--	--	--	--	--	--	CCSW-19FR
9.0	<1.6	<5.4	5.2	<4.1	<17	<7.6	<1.1	<2.7	CCSW-20U
--	--	--	--	--	--	--	--	--	CCSW-20UR
6.6	<1.1	<5.4	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-21U
--	--	--	--	--	--	--	--	--	CCSW-21UR
--	--	--	--	--	--	--	--	--	CCSW-21F
--	--	--	--	--	--	--	--	--	CCSW-22U
2.2	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-22UR
--	--	--	--	--	--	--	--	--	CCSW-22F
--	--	--	--	--	--	--	--	--	CCSW-22FR
1.3	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-23U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-24U
--	--	--	--	--	--	--	--	--	CCSW-24UR
12	<1.6	<5.4	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-25U
--	--	--	--	--	--	--	--	--	CCSW-25UR
8.2	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-26U
8.2	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-26UR
5.3	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-27U
5.6	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-27UR
--	--	--	--	--	--	--	--	--	CCSW-27F
2.4	<1.6	7.8	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-28U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-29U
2.4	<1.6	<5.4	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-30U
<.83	<1.6	<5.4	18	<4.1	<17	<7.6	<1.1	<2.7	CCSW-31U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-32U
<.84	<1.1	<5.3	<5.0	<4.5	<19	<6.9	<1.1	<2.7	CCSW-32UR
--	--	--	--	--	--	--	--	--	CCSW-32F
<.83	<1.6	22	<4.7	<4.1	<17	<7.6	<1.1	<2.7	CCSW-33U

Appendix C4.--Concentrations of volatile organic constituents quantitated in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, June 1989--Continued

Local identifier	Sampling date	Trichloroethylene (μg/L)	1,1-Dichloroethylene (μg/L)	1,2-trans-Dichloroethylene (μg/L)	Vinyl chloride (μg/L)	Bromoform (μg/L)	Chlorodibromomethane (μg/L)	Chloroethane (μg/L)	Bromodichloromethane (μg/L)	1,2-Dichlorobenzene (μg/L)
CCSW-2U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-3U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-3UR	06-15-89	16	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-3F	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-4U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-5U	06-15-89	37	20	6.8	39	<9.7	<7.1	32	10	14
CCSW-6U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-7U	06-15-89	19	16	7.0	33	<9.7	<7.1	22	8.4	<10
CCSW-8U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-9U	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-10U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-12U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-12UR	06-15-89	16	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-12F	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-13U	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-14U	06-15-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-14UR	06-15-89	--	--	--	--	--	--	--	--	--
CCSW-16U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-17U	06-13-89	10	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-17UR	06-13-89	10	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-17F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-18U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-19U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-19UR	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-19F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-19FR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-20U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-20UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-21U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-21UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-21F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-22U	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-22UR	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-22F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-22FR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-23U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-24U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-24UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-25U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-25UR	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-26U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-26UR	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-27U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-27UR	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-27F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-28U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-29U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-30U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-31U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7
CCSW-32U	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-32UR	06-13-89	<6.6	<16	<1.1	<2.4	<9.7	<7.1	<4.0	<7.5	<10
CCSW-32F	06-13-89	--	--	--	--	--	--	--	--	--
CCSW-33U	06-13-89	<7.0	<18	<1.1	<2.9	<8.2	<6.5	<5.0	<7.9	<9.7

1,3-Di-chloro-benzene (µg/L)	1,4-Di-chloro-benzene (µg/L)	1,2-Di-chloro-propane (µg/L)	trans-1,3-Di-chloro-propene (µg/L)	cis-1,3-Di-chloro-propene (µg/L)	Tri-chloro-fluoro-methane (µg/L)	2-Chloro-ethyl-vinyl-ether (µg/L)	Phenols, total (µg/L)	Local ident-ifier
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-2U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-3U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-3UR
--	--	--	--	--	--	--	--	CCSW-3F
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-4U
<9.8	15	14.0	5.7	11	<5.0	<88	<21	CCSW-5U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-6U
<9.8	<9.1	11.0	6.2	11	40.0	<88	<21	CCSW-7U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-8U
--	--	--	--	--	--	--	--	CCSW-9U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-10U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-12U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-12UR
--	--	--	--	--	--	--	--	CCSW-12F
--	--	--	--	--	--	--	<21	CCSW-13U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-14U
--	--	--	--	--	--	--	<21	CCSW-14UR
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-16U
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-17U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-17UR
--	--	--	--	--	--	--	--	CCSW-17F
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-18U
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-19U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-19UR
--	--	--	--	--	--	--	--	CCSW-19F
--	--	--	--	--	--	--	--	CCSW-19FR
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-20U
--	--	--	--	--	--	--	<21	CCSW-20UR
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-21U
--	--	--	--	--	--	--	<21	CCSW-21UR
--	--	--	--	--	--	--	--	CCSW-21F
--	--	--	--	--	--	--	<21	CCSW-22U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-22UR
--	--	--	--	--	--	--	--	CCSW-22F
--	--	--	--	--	--	--	--	CCSW-22FR
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-23U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-24U
--	--	--	--	--	--	--	<21	CCSW-24UR
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-25U
--	--	--	--	--	--	--	<21	CCSW-25UR
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-26U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-26UR
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-27U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-27UR
--	--	--	--	--	--	--	--	CCSW-27F
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-28U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-29U
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-30U
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-31U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-32U
<9.8	<9.1	<2.8	<5.0	<5.0	<5.0	<88	<21	CCSW-32UR
--	--	--	--	--	--	--	--	CCSW-32F
<9.2	<8.1	<2.8	<5.0	<5.0	<5.0	<82	<21	CCSW-33U

Appendix C5. *Concentrations of volatile organic compounds measured in surface water in the Canal Creek area, Aberdeen Proving Ground, Maryland, in December 1989 (under ice cover) and in September 1988 and June 1989*

[All concentrations are in micrograms per liter; R, replicate sample; Re, repeat analyses by laboratory; #, value estimated because peak was present but concentration was below detection limit]

Sample no.	Site no.	Sampling date	Carbon tetrachloride	Chloroform	Tetrachloro-ethylene	1,1,2,2-Tetra-chloroethane	1,2-*trans*-Dichloroethylene	Vinyl-chloride	Trichloro-ethylene
CCSW-40	27	12-27-89	4.8	<3.0	<3.0	18	<3.0	<1.0	<3.0
CCSW-27C	27	9-15-88	5	5	<5	7#	<5	<10	3#
CCSW-27U	27	6-13-89	<5.9	5.3	<2.7	<5.0	<1.1	<2.4	<6.6
CCSW-27UR	27	6-13-89	<5.9	5.6	<2.7	<5.0	<1.1	<2.4	<6.6
CCSW-42	17	12-27-89	<3.0	<3.0	<3.0	33	7.9	1.5	9.5
CCSW-17	17	9-13-88	<5	<5	<5	18	7	<10	11
CCSW-17U	17	6-13-89	<5.6	<.83	<2.7	<4.7	<1.1	<2.9	10
CCSW-17UR	17	6-13-89	<5.9	<.84	<2.7	49	<1.1	<2.4	10
CCSW-41	20	12-27-89	<3.0	<3.0	<3.0	25	17	1.3	21
CCSW-20	20	9-13-88	<5	3#	<5	5#	<5	<10	7
CCSW-20(Re)	20	9-13-88	1#	<5	<5	3#	2#	<10	3#
CCSW-20U	20	6-13-89	<5.6	9.0	<2.7	5.2	<1.1	<2.9	<7.0
GR-1	22	12-27-89	25	36	3.8	11	3.4	<1.0	5.1
GR-1R	22	12-27-89	24	38	3.8	11	3.2	<1.0	5.3
CCSW-22	22	9-13-88	7	7	10	8#	10	5#	8
CCSW-22R	22	9-13-88	<5	<5	<5	<10	<5	<10	7
CCSW-22(Re)	22	9-13-88	<5	<5	<5	<10	<5	<10	<5
CCSW-22U	22	6-13-89	<5.9	2.2	<2.7	<5.0	<1.1	<2.4	<6.6

APPENDIX D1--FOLLOWS

Appendix D1.--Inorganic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland

[All concentration units in micrograms per gram dry soil. R, replicate sample. Boron and cadmium not detected in any of the samples (at <33 and <3.0 micrograms per gram, respectively)]

Sample no.	Sampling date	Moisture, percent wet weight	Calcium	Magnesium	Sodium	Silica	Nitrogen, ammonia + organic	Phosphorus	Iron	Manganese	Antimony	Arsenic	Chromium	Copper	Lead	Mercury	Selenium	Zinc
CCSL-1	9-26-89	17.6	240	1,200	310	350	600	--	11,000	210	<3.8	3.8	<13	<59	21	<0.050	<0.25	<30
CCSL-2	9-26-89	14.5	560	840	270	330	1,000	--	6,000	210	<3.8	4.9	<13	<59	48	<.050	<.25	<30
CCSL-3	9-26-89	15.4	510	680	290	340	900	--	6,000	66	<3.8	3.4	<13	<59	24	<.050	<.25	<30
CCSL-4	9-25-89	16.3	2,700	1,200	320	420	--	--	11,000	320	<3.8	5.2	<13	<59	41	<.050	<.25	<30
CCSL-5	9-25-89	15.5	3,400	1,700	320	310	900	--	9,900	320	<3.8	4.7	37	<59	36	<.050	<.25	98
CCSL-6	9-25-89	11.3	38,000	11,000	760	1,600	700	--	8,000	1,300	<3.8	5.0	<13	<59	16	<.050	<.25	<30
CCSL-7	9-25-89	14.2	19,000	4,900	340	450	1,000	--	11,000	240	<3.8	3.6	42	<59	15	<.050	<.25	<30
CCSL-8	9-25-89	16.9	2,800	1,100	320	650	700	--	13,000	140	<3.8	4.6	28	<59	30	<.050	<.25	66
CCSL-9	9-25-89	15.0	6,400	1,400	400	480	600	--	12,000	140	<3.8	4.2	<13	<59	76	.10	<.25	66
CCSL-10	9-25-89	12.3	1,000	3,900	260	510	400	--	10,000	140	<3.8	2.6	<13	<59	28	<.050	<.25	120
CCSL-11	9-25-89	12.9	1,500	740	270	420	600	--	20,000	79	8.7	4.4	45	<59	18	<.050	<.25	<30
CCSL-12	9-25-89	12.7	16,000	3,300	370	290	1,000	--	7,400	230	<3.8	11	24	<59	46	<.050	<.25	64
CCSL-13	9-25-89	8.6	5,700	1,800	240	410	--	--	47,000	530	16	4.7	72	<59	380	<.050	<.25	160
CCSL-14	9-25-89	11.2	1,000	1,900	250	300	500	--	14,000	130	<3.8	4.7	31	<59	20	<.050	<.25	<30
CCSL-14R	9-25-89	16.5	1,100	2,200	400	100	--	--	19,000	84	<3.8	5.0	35	<59	2.5	<.050	<.25	<30
CCSL-15	9-11-89	7.1	27,000	14,000	320	360	2,000	190	17,000	290	8.2	5.3	26	<59	52	.10	<.25	68
CCSL-16	9-11-89	4.8	58,000	13,000	1,600	320	1,000	200	55,000	2,400	21	4.2	140	<59	100	.60	<.25	100
CCSL-17	9-11-89	11.7	1,400	1,300	320	430	2,000	190	13,000	180	11	6.4	28	<59	61	.25	<.25	120
CCSL-18	9-11-89	11.8	20,000	2,100	450	470	1,000	180	16,000	220	8.3	5.3	32	<59	1,100	.91	1.2	190
CCSL-19	9-11-89	8.0	2,400	2,000	320	220	1,000	190	12,000	300	9.9	4.5	24	100	100	.32	<.25	230
CCSL-20	9-11-89	7.1	2,800	3,100	360	210	1,000	170	16,000	200	13	7.8	35	<59	61	.12	<.25	150
CCSL-21	9-11-89	1.1	1,700	1,300	250	330	600	110	9,300	320	<3.8	3.8	<13	<59	57	.20	<.25	120
CCSL-21R	9-11-89	7.2	1,600	1,200	310	82	700	94	7,900	270	<3.8	2.6	<13	<59	31	.14	<.25	120
CCSL-22	9-11-89	3.1	1,400	400	280	420	400	42	1,400	63	<3.8	<.50	<13	<59	17	<.050	<.25	170
CCSL-23	9-11-89	9.4	1,900	2,700	340	220	1,000	190	17,000	400	12	7.6	33	<59	94	.33	<.25	360
CCSL-24	9-11-89	8.0	1,600	910	290	420	900	140	7,900	110	<3.8	4.9	<13	<59	2.1	.29	<.25	67
CCSL-25	9-11-89	3.9	330	660	260	300	400	97	6,500	110	<3.8	4.1	<13	<59	25	<.050	<.25	<30
CCSL-26	9-11-89	5.5	1,500	1,500	240	260	600	200	10,000	150	<3.8	3.1	<13	<59	46	<.050	<.25	69
CCSL-27	9-25-89	9.8	730	490	260	400	--	--	6,400	100	<3.8	3.7	68	<59	18	<.050	<.25	<30
CCSL-28	9-25-89	15.7	590	1,400	300	290	1,000	--	12,000	400	8.8	6.6	32	<59	58	.48	<.25	110
CCSL-29	9-25-89	11.8	220	1,200	280	320	400	--	10,000	150	10	7.2	<13	<59	19	.11	<.25	<30
CCSL-30	9-25-89	18.5	1,600	1,500	290	320	800	--	14,000	3,000	11	4.2	29	<59	89	<.050	<.25	150
CCSL-30R	9-25-89	18.6	1,700	1,600	450	84	--	--	15,000	1,100	<3.8	5.4	26	<59	110	<.050	<.25	120
CCSL-31	9-25-89	10.1	1,000	1,500	340	220	1,000	--	17,000	190	<3.8	7.2	41	<59	88	<.050	<.25	92
CCSL-32	9-25-89	8.8	3,200	2,100	310	110	500	--	12,000	270	<3.8	3.1	28	<59	24	<.050	<.25	<30
CCSL-33	9-26-89	14.0	6,500	2,900	260	170	800	--	7,900	130	<3.8	2.8	<13	<59	51	<.050	<.25	<30
CCSL-34	9-26-89	11.8	11,000	2,000	400	97	1,000	--	12,000	400	<3.8	8.5	48	150	66	<.050	<.25	420
CCSL-35	9-26-89	8.8	1,400	610	320	120	100	--	5,000	120	<3.8	9.6	<13	<59	4.9	<.050	<.25	<30
CCSL-36	9-26-89	15.1	2,100	1,200	290	76	900	--	21,000	190	<3.8	6.2	110	<59	110	<.050	<.25	76
CCSL-37	9-26-89	16.7	5,700	6,600	330	280	1,000	--	13,000	760	<3.8	7.5	26	<59	74	<.050	<.25	1,000
CCSL-38	9-26-89	10.8	610	1,800	280	190	800	--	17,000	230	<3.8	7.6	40	<59	71	.52	<.25	72
CCSL-39	9-26-89	12.2	1,000	910	350	98	--	--	13,000	250	<3.8	5.9	28	<59	110	.059	<.25	110
CCSL-40	9-26-89	11.0	170	860	300	77	--	--	5,700	87	<3.8	2.4	<13	<59	33	<.050	<.25	<30
CCSL-41	9-26-89	15.5	670	1,200	260	58	--	--	8,800	590	<3.8	4.5	<13	<59	38	<.050	<.25	<30
CCSL-42	9-26-89	12.1	1,000	1,400	350	51	--	--	6,500	190	<3.8	3.5	<13	<59	25	<.050	<.25	100
CCSL-43	9-26-89	14.6	2,000	1,200	400	88	--	--	8,300	170	<3.8	3.8	50	<59	19	<.050	<.25	<30
CCSL-44	9-26-89	17.9	480	1,200	360	77	--	--	11,000	81	<3.8	3.7	<13	<59	81	<.050	<.25	<30
CCSL-45	9-26-89	19.7	1,500	1,800	370	76	--	--	12,000	160	<3.8	3.0	<13	<59	62	<.050	<.25	<30
CCSL-45R	9-26-89	20.1	2,700	1,900	380	120	--	--	10,000	190	<3.8	2.5	<13	<59	53	<.050	<.25	<30
CCSL-46	9-11-89	4.6	470	2,200	340	81	700	95	11,000	110	<3.8	2.5	26	<59	16	<.050	<.25	<30

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland

[All units in micrograms per gram dry soil, unless otherwise noted. g/kg, grams per kilogram dry soil; R, replicate sample. See tables 9 and 10 for USATHAMA codes for volatile and semivolatile organics that were quantitatively analyzed. (V), quantitative analysis for volatile organics; (VL), unknown or TIOC's (tentatively identified organic compounds) with estimated concentrations detected by library search for volatile compounds; (S), quantitative analysis for semivolatile organics; (SL), unknown or TIOC's with estimated concentrations detected by library search for semivolatile compounds. Codes for TIOC's are: BENZAL, benzaldehyde; C14, tetradecane; C15, pentadecane; C16, hexadecane; C17, heptadecane; C16ABE, hexadecanoic acid,butyl ester; C18ABE, octadecanoic acid, butyl ester; 12EPCH, 1,2-epoxycyclohexene - cyclohexene oxide; 4MSBSA, 4-methylbenzene sulfonamide; 7MTRID, 7-methyltridecane; PPDDE, 2,2-bis-(para-chlorophenyl)-1,1-dichloroethene; TCLTFE, 1,1,2-trichloro-1,2,2-trifluoroethane]

Sample no.	Sampling date	Organic halides, total	Phenols, total	Organic carbon, total (g/kg)	CCL3F (V)	TCLTFE (VL)	ANAPYL (S)	ANTRC (S)	BAANTR (S)	BBFANT (S)	BKFANT (S)	BGHIPY (S)	BAPYR (S)	CHRY (S)
CCSL-1	9-26-89	200	0.56	--	<0.006	--	<0.03	<0.03	<0.17	<0.21	<0.07	<0.25	<0.25	<0.12
CCSL-2	9-26-89	<200	.74	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-3	9-26-89	<200	.54	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-4	9-25-89	--	--	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-5	9-25-89	<200	1.7	11	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-6	9-25-89	<200	4.8	6.9	<.006	--	<.03	<.03	<.17	<.21	.20	<.25	<.25	.26
CCSL-7	9-25-89	--	--	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-8	9-25-89	<200	5.6	5.6	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-9	9-25-89	<200	.82	6.8	<.006	--	<.03	<.03	<.17	<.21	.09	<.25	<.25	.19
CCSL-10	9-25-89	<200	.53	5.4	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-11	9-25-89	<200	1.5	1.0	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-12	9-25-89	<200	4.8	11	<.006	--	.22	.11	.55	.82	.45	.51	.89	.84
CCSL-13	9-25-89	--	--	--	<.006	--	<.03	<.03	<.17	<.21	.12	<.25	<.25	.21
CCSL-14	9-25-89	<200	.68	4.0	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-14R	9-25-89	--	--	2.5	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-15	9-11-89	<200	270	15	.03	0.02	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-16	9-11-89	<200	1,700	23	<.006	.03	<.17	<.17	<.85	<1.1	.38	<1.3	<1.3	<.60
CCSL-17	9-11-89	<200	170	17	<.006	.02	<.03	<.03	<.17	<.21	<.07	<.25	<.25	.21
CCSL-18	9-11-89	<200	440	48	<.006	.05	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-19	9-11-89	<200	280	13	<.006	.04	<.03	<.03	.17	<.21	.16	<.25	<.25	.27
CCSL-20	9-11-89	<200	1,100	15	<.006	.04	<.03	<.03	<.17	<.21	.09	<.25	<.25	.18
CCSL-21	9-11-89	<200	1,500	8.9	<.006	.04	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-21R	9-11-89	<200	<110	3.9	<.006	.03	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-22	9-11-89	<200	340	8.2	<.006	.05	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-23	9-11-89	<200	540	4.7	<.006	.04	<.03	<.03	.18	.37	.23	<.25	<.25	.34
CCSL-24	9-11-89	<200	3,200	9.6	<.006	.03	<.03	<.03	<.17	<.21	.09	<.25	<.25	.19
CCSL-25	9-11-89	<200	270	3.7	<.006	.04	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-26	9-11-89	<200	<100	11	<.006	.04	<.03	.09	.19	<.21	.10	<.25	<.25	.26
CCSL-27	9-25-89	--	--	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-28	9-25-89	<200	1.1	9.0	<.006	--	<.03	.26	.47	.38	.34	<.25	.51	.57
CCSL-29	9-25-89	<200	.46	1.9	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-30	9-25-89	<200	1.1	5.6	<.006	--	<.03	.11	.25	<.21	.20	<.25	<.25	.36
CCSL-30R	9-25-89	--	.43	--	<.006	--	<.03	<.03	<.17	<.21	.10	<.25	<.25	.20
CCSL-31	9-25-89	<200	1.6	20	<.006	--	<.03	<.03	.25	.41	.22	.27	<.25	.53
CCSL-32	9-25-89	<200	1.3	3.4	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-33	9-26-89	<200	1.3	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-34	9-26-89	<200	1.5	--	<.006	--	<.03	<.03	<.17	<.21	.09	<.25	<.25	.22
CCSL-35	9-26-89	<200	.39	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-36	9-26-89	<200	.36	--	<.006	--	<.03	<.03	<.17	<.21	.09	<.25	<.25	.19
CCSL-37	9-26-89	<200	.20	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-38	9-26-89	<200	.63	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-39	9-26-89	<200	2.1	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-40	9-26-89	<200	.30	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-41	9-26-89	--	.33	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-42	9-26-89	--	.45	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-43	9-26-89	--	.47	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-44	9-26-89	--	.46	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-45	9-26-89	--	1.0	--	<.006	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-45R	9-26-89	--	.39	--	.01	--	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12
CCSL-46	9-11-89	<200	570	5.4	<.006	.05	<.03	<.03	<.17	<.21	<.07	<.25	<.25	<.12

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued

Sample no.	Sampling date	DBZFUR (S)	DNBP (S)	FANT (S)	FLRENE (S)	ICDPYR (S)	2MNAP (S)	NAP (S)	PHANTR (S)	PYR (S)	PPDDE (S)	PCB260 (S)
CCSL-1	9-26-89	<0.04	<0.06	<0.07	<0.03	<0.29	<0.05	<0.04	<0.03	<0.03	<0.31	<2.6
CCSL-2	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-3	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-4	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-5	9-25-89	<.04	.22	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-6	9-25-89	<.04	<.06	.22	<.03	<.29	<.05	<.04	.17	.20	<.31	<2.6
CCSL-7	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-8	9-25-89	<.04	.21	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-9	9-25-89	<.04	<.06	.33	<.03	<.29	<.05	<.04	.21	.21	<.31	<2.6
CCSL-10	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	.05	<.03	<.31	<2.6
CCSL-11	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-12	9-25-89	<.04	<.06	.76	<.03	.50	<.05	<.04	.13	.72	<.31	<2.6
CCSL-13	9-25-89	<.04	<.06	.22	<.03	<.29	<.05	<.04	<.03	.17	<.31	<2.6
CCSL-14	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-14R	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-15	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-16	9-11-89	<.18	<.31	.61	<.17	<1.5	<.25	<.19	.22	.31	<1.6	330
CCSL-17	9-11-89	<.04	<.06	.11	<.03	<.29	<.05	.11	.12	.21	<.31	<2.6
CCSL-18	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-19	9-11-89	<.04	<.06	.39	<.03	<.29	<.05	<.04	.20	.27	<.31	<2.6
CCSL-20	9-11-89	<.04	<.06	.17	<.03	<.29	<.05	<.04	<.03	.15	<.31	<2.6
CCSL-21	9-11-89	<.04	<.06	.12	<.03	<.29	<.05	<.04	<.03	.10	<.31	<2.6
CCSL-21R	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-22	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-23	9-11-89	<.04	<.06	.28	<.03	<.29	<.05	<.04	.09	.21	<.31	<2.6
CCSL-24	9-11-89	<.04	<.06	.19	<.03	<.29	<.05	<.04	.10	.15	<.31	<2.6
CCSL-25	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-26	9-11-89	<.04	<.06	.38	<.03	<.29	<.05	<.04	.33	.33	<.31	<2.6
CCSL-27	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-28	9-25-89	.14	<.06	.96	.15	<.29	<.05	.19	1.0	.70	<.31	<2.6
CCSL-29	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-30	9-25-89	<.04	<.06	.61	<.03	<.29	<.05	<.04	.38	.45	<.31	<2.6
CCSL-30R	9-25-89	<.04	<.06	.36	<.03	<.29	<.05	<.04	.22	.29	<.31	<2.6
CCSL-31	9-25-89	<.04	<.06	.66	<.03	<.29	<.09	<.04	.44	.46	.60	<2.6
CCSL-32	9-25-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-33	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-34	9-26-89	<.04	<.06	.43	<.03	<.29	<.05	<.04	.33	.31	<.31	<2.6
CCSL-35	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-36	9-26-89	<.04	<.06	.15	<.03	<.29	<.05	<.04	<.03	.15	<.31	<2.6
CCSL-37	9-26-89	<.04	<.06	.13	<.03	<.29	<.05	<.04	<.03	.11	<.31	<2.6
CCSL-38	9-26-89	<.04	.10	<.07	<.03	<.29	<.05	<.04	<.03	<.03	.40	<2.6
CCSL-39	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	.49	<2.6
CCSL-40	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-41	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-42	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-43	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-44	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-45	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-45R	9-26-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6
CCSL-46	9-11-89	<.04	<.06	<.07	<.03	<.29	<.05	<.04	<.03	<.03	<.31	<2.6

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued

Sample no.	Sampling date	UNK514 (SL)	UNK681 (SL)	UNK682 (SL)	UNK641 (SL)	UNK652 (SL)	UNK661 (SL)	UNK624 (SL)	UNK648 (SL)	UNK691 (SL)	DIACAL (SL)	UNK614 (SL)	UNK688 (SL)	UNK650 (SL)	UNK608 (SL)
CCSL-1	9-26-89	0.8	0.4	0.5	--	--	--	--	--	--	--	--	--	--	--
CCSL-2	9-26-89	--	.5	--	0.6	1	0.4	--	--	--	--	--	--	--	--
CCSL-3	9-26-89	--	.7	--	.6	5	.8	0.2	2	0.6	--	--	--	--	--
CCSL-4	9-25-89	--	--	--	.4	.7	--	--	.6	--	0.2	--	--	--	--
CCSL-5	9-25-89	--	--	--	--	--	--	--	--	--	--	0.2	--	--	--
CCSL-6	9-25-89	--	--	--	--	--	--	--	--	--	--	.3	0.3	0.3	--
CCSL-7	9-25-89	--	--	--	.3	1	1	--	.8	--	--	.2	--	--	--
CCSL-8	9-25-89	--	--	--	--	--	--	--	.6	--	--	--	--	--	0.2
CCSL-9	9-25-89	--	--	--	--	--	--	--	--	.5	--	--	--	--	--
CCSL-10	9-25-89	--	.3	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-11	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	.1
CCSL-12	9-25-89	--	.5	--	--	--	--	--	2	.8	--	--	--	.8	--
CCSL-13	9-25-89	--	--	--	--	--	--	--	.3	--	--	--	--	--	--
CCSL-14	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14R	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-15	9-11-89	--	--	--	--	8	--	--	4	--	--	--	--	--	--
CCSL-16	9-11-89	--	--	--	--	--	--	--	3	--	--	--	--	--	--
CCSL-17	9-11-89	--	--	--	1	--	2	--	2	--	--	.3	--	--	--
CCSL-18	9-11-89	.3	--	6	--	1	--	.9	1	--	--	.6	--	--	--
CCSL-19	9-11-89	.3	1	--	.5	--	1	--	4	--	--	.3	--	--	--
CCSL-20	9-11-89	--	.6	1	.9	--	1	--	1	--	--	--	.3	--	--
CCSL-21	9-11-89	.7	--	--	.3	--	.3	--	--	--	--	--	--	--	--
CCSL-21R	9-11-89	.5	--	--	.3	--	--	--	.3	--	--	.1	--	--	--
CCSL-22	9-11-89	.4	--	--	.8	--	--	--	--	--	--	--	--	--	--
CCSL-23	9-11-89	--	.7	--	.6	--	.9	--	2	--	--	--	.3	.3	--
CCSL-24	9-11-89	.3	.5	--	.3	--	.5	--	1	--	--	--	--	--	--
CCSL-25	9-11-89	--	--	--	.3	--	--	--	.4	--	--	--	--	--	--
CCSL-26	9-11-89	.7	1	--	.7	--	1	--	3	--	--	--	.8	--	--
CCSL-27	9-25-89	--	.4	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-28	9-25-89	--	.8	.7	--	--	.7	--	.6	--	--	--	--	--	--
CCSL-29	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30	9-25-89	--	--	1	--	--	--	--	--	--	--	--	--	--	--
CCSL-30R	9-25-89	--	--	2	--	--	--	--	--	--	--	--	--	--	--
CCSL-31	9-25-89	--	--	--	--	--	--	--	--	1	--	.4	--	.3	--
CCSL-32	9-25-89	--	--	--	--	--	--	--	--	.2	--	--	--	--	--
CCSL-33	9-26-89	--	--	--	--	2	--	--	--	.8	--	--	--	--	--
CCSL-34	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-35	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-36	9-26-89	--	.5	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-37	9-26-89	--	--	.7	--	--	--	--	--	--	--	--	--	--	--
CCSL-38	9-26-89	--	--	--	--	--	--	--	--	1	--	--	--	--	--
CCSL-39	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-40	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-41	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-42	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-43	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-44	9-26-89	--	.9	--	2	1	.6	--	--	.7	--	--	--	--	--
CCSL-45	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45R	9-26-89	--	--	--	.6	--	--	--	--	--	--	--	--	--	--
CCSL-46	9-11-89	2	.4	--	.4	--	--	--	.4	--	--	--	--	--	--

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued

Sample no.	Sampling date	UNK577 (SL)	UNK579 (SL)	UNK565 (SL)	12EPCH (SL)	C16ABE (SL)	UNK625 (SL)	C18ABE (SL)	UNK637 (SL)	UNK687 (SL)	7MTRID (SL)	C14 (SL)	UNK580 (SL)	C15 (SL)	C16 (SL)	C17 (SL)
CCSL-1	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-2	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-3	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-4	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-5	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-6	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-7	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-8	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-9	9-25-89	0.7	0.7	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-10	9-25-89	.5	.6	0.2	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-11	9-25-89	--	--	--	0.2	--	--	--	--	--	--	--	--	--	--	--
CCSL-12	9-25-89	.2	.2	--	--	0.2	0.2	0.3	0.2	0.5	--	--	--	--	--	--
CCSL-13	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14	9-25-89	--	--	--	.2	--	--	--	--	--	--	--	--	--	--	--
CCSL-14R	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-15	9-11-89	--	--	--	--	--	--	--	--	--	0.6	0.3	10	0.6	0.5	1
CCSL-16	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-17	9-11-89	.2	.1	--	--	--	--	--	.5	--	--	--	--	--	--	--
CCSL-18	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-19	9-11-89	.4	.4	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-20	9-11-89	.2	.2	--	--	.2	--	--	--	--	--	--	--	--	--	--
CCSL-21	9-11-89	.2	.2	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-21R	9-11-89	.2	.2	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-22	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-23	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-24	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-25	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-26	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-27	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-28	9-25-89	--	--	--	--	--	--	--	--	.7	--	--	--	--	--	--
CCSL-29	9-25-89	--	--	--	.2	--	--	--	--	--	--	--	--	--	--	--
CCSL-30	9-25-89	.7	.9	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30R	9-25-89	6	6	.2	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-31	9-25-89	1	.9	--	--	--	--	.2	--	.4	--	--	--	--	--	--
CCSL-32	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-33	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-34	9-26-89	.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-35	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-36	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-37	9-26-89	--	--	--	--	.4	--	.2	--	--	--	--	--	--	--	--
CCSL-38	9-26-89	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-39	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-40	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-41	9-26-89	--	--	--	--	--	.5	--	--	--	--	--	--	--	--	--
CCSL-42	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-43	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-44	9-26-89	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45	9-26-89	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45R	9-26-89	3	3	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-46	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued

Sample no.	Sampling date	UNK670 (SL)	UNK692 (SL)	BENZAL (SL)	UNK576 (SL)	UNK603 (SL)	UNK613 (SL)	UNK626 (SL)	UNK627 (SL)	UNK628 (SL)	UNK629 (SL)	UNK630 (SL)	UNK680 (SL)	UNK634 (SL)	UNK638 (SL)	UNK646 (SL)
CCSL-1	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-2	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-3	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-4	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-5	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-6	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-7	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-8	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-9	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-10	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-11	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-12	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-13	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14R	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-15	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-16	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-17	9-11-89	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-18	9-11-89	--	--	0.6	0.2	1	0.3	2	0.5	0.5	0.8	0.5	--	--	--	--
CCSL-19	9-11-89	--	.7	--	--	--	--	--	--	--	--	--	0.3	--	--	--
CCSL-20	9-11-89	--	.4	--	--	--	--	--	--	--	--	.6	--	0.3	0.2	0.3
CCSL-21	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-21R	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-22	9-11-89	--	.3	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-23	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-24	9-11-89	--	.4	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-25	9-11-89	--	--	--	--	--	--	--	.2	--	--	.4	--	.2	--	--
CCSL-26	9-11-89	--	1	--	--	--	--	--	--	--	--	.3	--	--	--	--
CCSL-27	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-28	9-25-89	--	--	--	--	--	--	--	--	--	--	.2	--	--	--	--
CCSL-29	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30R	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-31	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-32	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	.3	--
CCSL-33	9-26-89	--	--	--	--	--	--	--	--	--	--	--	.3	--	--	--
CCSL-34	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-35	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-36	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-37	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-38	9-26-89	--	--	--	--	--	--	--	--	--	--	.6	--	--	--	--
CCSL-39	9-26-89	--	--	--	--	--	--	--	--	--	--	.2	--	--	--	--
CCSL-40	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-41	9-26-89	--	--	--	.4	--	--	--	--	--	--	--	--	--	--	--
CCSL-42	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-43	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-44	9-26-89	--	--	--	--	--	--	--	--	--	--	.4	--	--	--	--
CCSL-45	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45R	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-46	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix D2. Organic-chemical data for soil in the Canal Creek area, Aberdeen Proving Ground, Maryland--Continued

Sample no.	Sampling date	UNK683 (SL)	UNK685 (SL)	UNK686 (SL)	UNK651 (SL)	UNK515 (SL)	UNK693 (SL)	UNK667 (SL)	UNK570 (SL)	UNK572 (SL)	UNK591 (SL)	UNK592 (SL)	UNK631 (SL)	UNK684 (SL)	4MBSA (SL)	UNK620 (SL)	UNK610 (SL)
CCSL-1	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-2	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-3	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-4	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-5	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-6	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-7	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-8	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-9	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-10	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-11	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-12	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-13	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-14R	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-15	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-16	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-17	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-18	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-19	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-20	9-11-89	2	0.9	0.8	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-21	9-11-89	.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-21R	9-11-89	.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-22	9-11-89	2	--	.4	0.6	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-23	9-11-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-24	9-11-89	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-25	9-11-89	10	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--
CCSL-26	9-11-89	--	.5	--	--	--	0.3	--	--	--	--	--	--	--	--	--	--
CCSL-27	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-28	9-25-89	--	--	--	--	--	--	0.4	--	--	--	--	--	--	--	--	--
CCSL-29	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-30R	9-25-89	--	--	--	--	--	--	--	0.2	0.2	0.2	0.2	--	--	--	--	--
CCSL-31	9-25-89	--	.8	--	--	--	--	--	--	--	--	--	0.2	0.7	--	--	--
CCSL-32	9-25-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-33	9-26-89	--	--	--	--	--	--	--	--	--	.3	--	--	.3	0.8	--	--
CCSL-34	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-35	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-36	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-37	9-26-89	--	--	--	--	--	--	--	--	--	.2	--	--	--	--	--	--
CCSL-38	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3	--
CCSL-39	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.2	--
CCSL-40	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-41	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4
CCSL-42	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-43	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-44	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45	9-26-89	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-45R	9-26-89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CCSL-46	9-11-89	--	.3	--	.6	--	--	--	--	--	--	--	--	--	--	--	--