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Distribution and Mass Loss of Volatile Organic Compounds in the Surficial Aquifer at Sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November 2000 - February 2001

Water-Resources Investigations Report 02-4121

U.S. Department of the Interior
U.S. Geological Survey

Cover. Mini-piezometer installation in the bed of Pipe Elm Branch, Dover Air Force Base, Delaware.

[Photograph by Jeffrey R. Barbaro, U.S. Geological Survey.]

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by Jeffrey R. Barbaro and Pradumna P. Neupane

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2002

U.S. Department of the Interior
GALE A. NORTON, Secretary

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Acronyms and Abbreviations

A	area
AFRL	Air Force Research Laboratory
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, total xylenes
DAFB	Dover Air Force Base
cis-1,2-DCE	*cis*-1,2-dichloroethene
cm	centimeter
DO	dissolved oxygen
DNTS	Dover National Test Site
E	concentration below detection limit
EMU	East Management Unit
f_{oc}	weight fraction of organic carbon
ft	foot
ft/d	foot per day
ft/ft	foot per foot
ft sl	feet above or below sea level
FT03	Fire Training Area Three
g	gram
g/g	gram per gram
g/yr	gram per year
in.	inch
L	length
LF13	Rubble Area Landfill
LF15	Receiver Station Landfill
LTM	long-term monitoring
LT^{-1}	lenght per unit time
MCL	maximum contaminant level
M_{di}	mass flux across cell *i*
M_d	total mass flux across a transect
mg/L	milligrams per liter
mL	milliliter
ML^{-2}	mass per unit area
ML^{-3}	mass per unit volume
MT^{-1}	mass per unit time
MTBE	methyl *tert*-butyl ether

Acronyms and Abbreviations—Continued

NETTS	National Environmental Technology Test Site
ND	not detected
NWQL	National Water-Quality Laboratory
PCE	tetrachloroethene
QC	quality control
q	specific discharge
R	retardation factor
TCE	trichloroethene
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound
WP14	Liquid Waste Disposal Landfill
µg/L	micrograms per liter
µL	microliter
VC	vinyl chloride
yr	year

Conversion Factors and Vertical Datum

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per day (ft/d)	30.48	centimeter per day
acre	0.4047	hectare

Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$^\circ F = 9/5\,^\circ C + 32$$

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

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

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Distribution and Mass Loss of Volatile Organic Compounds in the Surficial Aquifer at Sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November 2000–February 2001

By Jeffrey R. Barbaro *and* Pradumna P. Neupane

Abstract

Ground-water and surface-water sampling was conducted in the natural attenuation study area in the East Management Unit of Dover Air Force Base, Delaware to determine the distributions of volatile organic compounds in the vicinity of four sites—Fire Training Area Three, the Rubble Area Landfill, the Receiver Station Landfill, and the Liquid Waste Disposal Landfill. This work was done by the U.S. Geological Survey, in cooperation with the U.S. Air Force, as part of an ongoing assessment of the effectiveness of natural attenuation at these sites. The specific objectives of the study were to (1) determine the areal and vertical extent of the contaminant plumes and source areas, (2) measure volatile organic compound concentrations in ground-water discharge areas and in surface water under base-flow conditions, (3) evaluate the potential for off-site migration of the mapped plumes, and (4) estimate the amount of mass loss downgradient of the Liquid Waste Disposal and Receiver Station Landfills. A direct-push drill rig and previously installed multi-level piezometers were used to determine the three-dimensional distributions of volatile organic compounds in the 30–60-foot-thick surficial aquifer underlying the natural attenuation study area. A hand-driven mini-piezometer was used to collect ground-water samples in ground-water discharge areas. A total of 319 ground-water and 4 surface-water samples were collected from November 2000 to February 2001 and analyzed for chlorinated solvents and fuel hydrocarbons.

The contaminant plumes migrating from Fire Training Area Three and the Rubble Area Landfill are approximately 500 feet and 800 feet, respectively, in length. These plumes consist predominantly of *cis*-1,2-dichloroethene, a daughter product, indicating that extensive dechlorination of tetrachloroethene and trichloroethene has occurred at these sites. With an approximate length of 2,200 feet, the plume migrating from the Receiver Station and Liquid Waste Disposal Landfills is the largest of the three plumes in the East Management Unit. In this plume, the parent compounds, tetrachloroethene and trichloroethene, as well as *cis*-1,2-dichloroethene, are present downgradient of the source. Vinyl chloride was not detected in the natural attenuation study area. Vertical water-quality profiles indicate that volatile organic compounds are present mainly in the upper part of the surficial aquifer. Plumes of fuel hydrocarbon constituents were not detected in the natural attenuation study area.

Volatile organic compounds were present at concentrations above detection limits in 6 of 14 samples collected from the aquifer underlying the bed of Pipe Elm Branch and the drainage ditch adjacent to Fire Training Area Three, indicating that the plumes migrating from Fire Training Area Three and the Receiver Station and Liquid Waste Disposal Landfills are reaching these ground-water discharge areas. In contrast, sampling results indicated that the plume from the Rubble Area Landfill does not reach these ground-water discharge areas. Trichloroethene was present above detection limits in one of four surface-water samples collected from Pipe Elm Branch and the drainage ditch adjacent to Fire Training Area Three. The trichloroethene concentration is below applicable Delaware Department of Natural

Resources and Environmental Control surface-water-quality standards for human health.

An assessment of chlorinated-solvent mass loss in the plume migrating from the Receiver Station and Liquid Waste Disposal Landfills indicates that tetrachloroethene and trichloroethene mass loss downgradient of the source is negligible. *Cis*-1,2-dichloroethene, however, appears to biodegrade by an unidentified reaction in the plume. Plan-view maps of the plume migrating from the Receiver Station and Liquid Waste Disposal Landfills indicate that tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene may migrate off Dover Air Force Base property approximately 1,500 feet downgradient of the source areas. In this downgradient area, the direction of plume migration is roughly parallel to the Dover Air Force Base boundary, which probably restricts the extent of off-site migration. Sampling results indicate that off-site migration of the other two plumes in the East Management Unit is unlikely. The ground- and surface-water samples collected in this study led to an improved understanding of the areal and vertical extent of the volatile organic compound plumes, the occurrence and fate of volatile organic compounds in the ground-water discharge areas, and the amount of intrinsic biodegradation downgradient of the Receiver Station and Liquid Waste Disposal Landfills.

Introduction

Fire training and waste-disposal activities that have taken place during the past 50 years in the East Management Unit (EMU) of Dover Air Force Base (DAFB), Delaware have resulted in contamination of shallow ground water with chlorinated solvents and fuel hydrocarbons (U.S. Army Corps of Engineers and Dames and Moore, Inc., 1997a; Bachman and others, 1998). Monitored natural attenuation is being used to remediate four sites in the EMU: Fire Training Area Three (FT03), the Rubble Area Landfill (LF13), the Receiver Station Landfill (LF15), and the Liquid Waste Disposal Landfill (WP14). The U.S. Geological Survey (USGS), in cooperation with the U.S. Air Force, is conducting long-term monitoring (LTM) and an ongoing assessment of the effectiveness of natural attenuation at these sites (Bachman and others, 1998; Barbaro, 2002).

In a recent report on the effectiveness of natural attenuation at these sites, four issues that needed further study were identified (Barbaro, 2002). These issues are delineating the areal and vertical extent of the contaminant plumes in greater detail, determining the fate of volatile organic compounds (VOCs) in the nearby ground-water discharge areas, determining the amount of intrinsic biodegradation downgradient of sites WP14 and LF15, and evaluating the occurrence and effect of temporal variability in source concentrations on the plume migrating from sites WP14 and LF15. A comprehensive round of ground-water sampling (53 wells and piezometers) showed that the current monitor well network in the natural attenuation study area is not adequate for determining the distribution of VOCs in ground water, or for determining the fate of these compounds in the ground-water discharge areas (Barbaro, 2002). The network contains many long-screened (defined in this report as screens greater than 3 ft, or feet, in length) monitor wells that mix water from geochemically distinct vertical intervals, and in most areas the network is too sparse to determine the location of the plume boundaries and the distribution of concentrations within the plumes. To address the need for better plume delineation as well as the other issues identified by Barbaro (2002), additional ground-water and surface-water sampling was conducted from November 2000 through February 2001 with a Geoprobe direct-push drill rig, a mini-piezometer, and previously installed multilevel piezometers.

Purpose and Scope

The purpose of this report is to present and interpret the results of ground-water and surface-water sampling conducted in the vicinity of sites FT03, LF13, WP14, and LF15 from November 2000 to February 2001. Sampling results were used to (1) determine the areal and vertical extent of the contaminant plumes and source areas, (2) determine VOC concentrations in ground-water discharge areas and in surface water under base-flow conditions, (3) evaluate the potential for off-site migration of the mapped plumes, and (4) estimate the amount of mass loss (intrinsic biodegradation) downgradient of sites WP14 and LF15. The interpretations in this report are based on 319 ground-water samples, 4 surface-water samples, and 50 quality-control (QC) samples.

At most of the drilling locations, vertical profiles of water quality were obtained across the surficial aquifer to determine the three-dimensional distribution of VOCs. Environmental samples were analyzed for VOCs such as tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), vinyl chloride (VC), methyl *tert*-butyl ether (MTBE), the aromatic hydrocarbons benzene, toluene, ethylbenzene, *p,m*-xylene, and *o*-xylene (BTEX), and field-measured constituents (pH, specific conductance, dissolved oxygen, and temperature). QC samples were analyzed for VOCs only. The field-measured constituents were used mainly during ground-water sampling to determine if samples were representative of aquifer conditions; therefore, these results are not discussed in detail in this report.

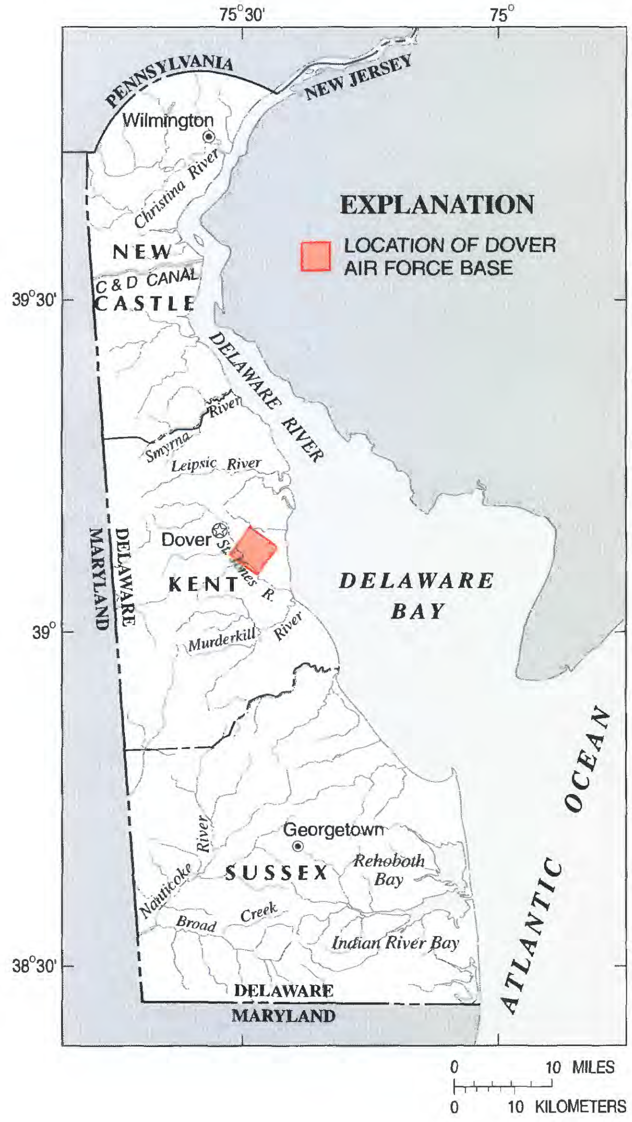


Figure 1a. Location of Dover Air Force Base, Dover, Delaware.

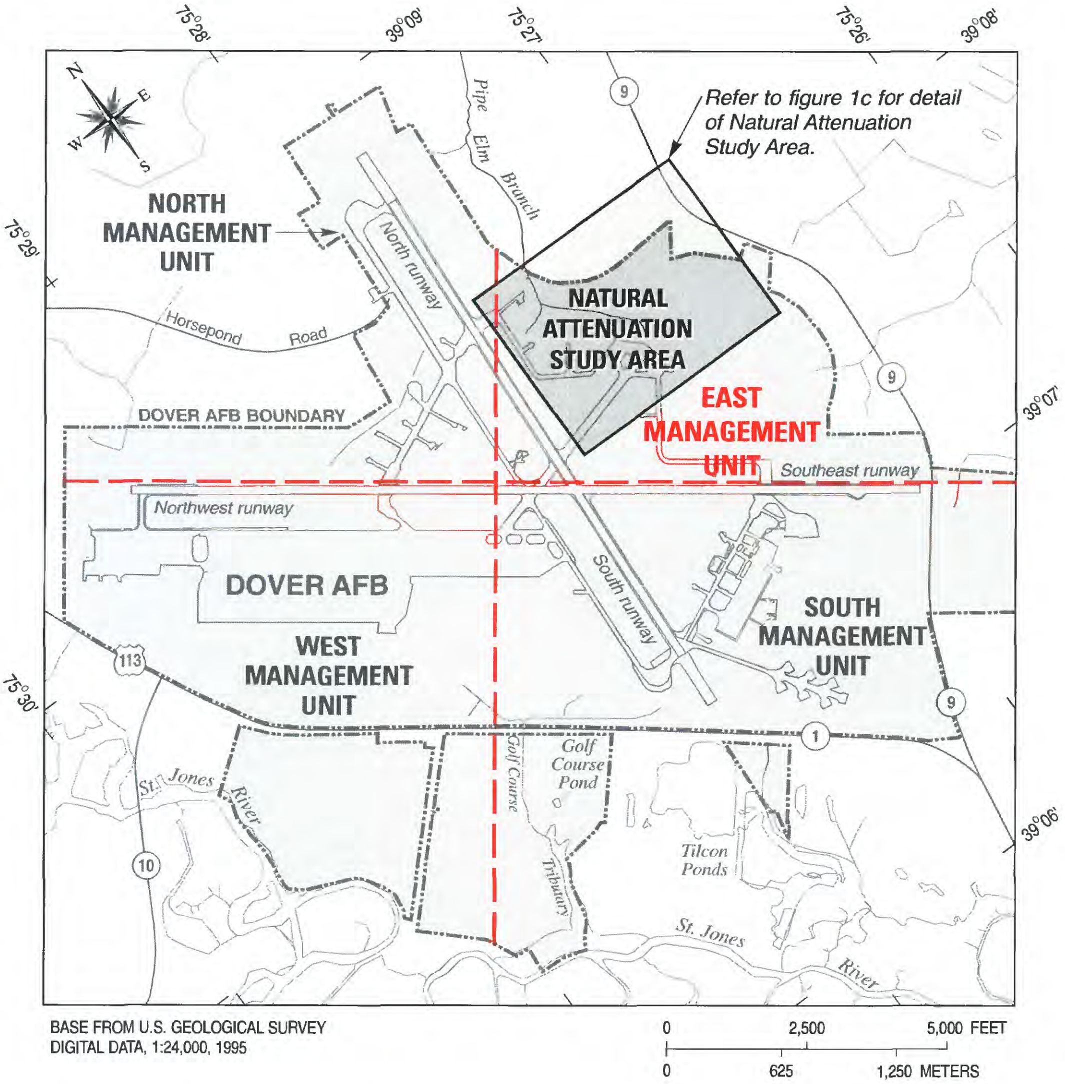
Description of Study Area

DAFB is approximately 3.5 mi (miles) southeast of the center of Dover, Delaware (fig. 1a). The natural attenuation study area is in the EMU of DAFB (fig. 1b). Ground-water contamination is present in the unconfined, surficial aquifer that underlies the natural attenuation study area. The surficial aquifer is 30–60 ft thick in the natural attenuation study area, and consists of interbedded layers of sand and gravel with discontinuous layers of silt and clay (Bachman and others, 1998, p. 14). The aquifer is underlain by the upper confining unit of the Calvert Formation. Pipe Elm Branch and shallow drainage ditches drain the natural attenuation study area (fig. 1c). Strong upward hydraulic gradients and perennial flow indicate that Pipe Elm Branch and the drainage ditch adjacent to FT03 (a tributary to Pipe Elm Branch) are ground-water discharge boundaries. Hinaman and Tenbus (2000, p. 7) and Barbaro (2002, p. 13) provide detailed descriptions of the hydrogeologic framework of the area.

Hydraulic-head distributions in the upper and lower parts of the surficial aquifer in March 2000 are shown in figures 2 and 3. The general ground-water flow direction is to the northwest, but flow varies both spatially and temporally. The presence of ground-water discharge boundaries and a local ground-water divide (recharge boundary) near LF13 create complex spatial flow patterns in the upper part of the surficial aquifer (fig. 2). With the exception of vertical flow in the vicinity of these hydrologic boundaries, ground-water flow is predominantly horizontal. Ground-water flow in the lower part of the surficial aquifer is more uniform spatially than in the upper part of the aquifer (fig. 3). Synoptic measurements of hydraulic head taken during previous investigations have shown a seasonal effect on the ground-water flow field, with a shallower water table and steeper hydraulic gradients during wetter conditions (Bachman and others, 1998, p. 14; Hinaman and Tenbus, 2000, p. 16).

Based on a geometric mean hydraulic conductivity of 43 ft/d (feet per day) from 15 slug tests and a representative hydraulic gradient of 0.003, the specific discharge in the surficial aquifer is 0.1 ft/d (Barbaro, 2002, p. 13). Dividing the specific discharge by an assumed effective porosity of 0.25 for sand and gravel (Wiedemeier and others, 1999, p. 129) yields an average ground-water velocity of 0.4 ft/d. The aquifer consists mainly of clean sand and gravel with a relatively low mean weight fraction of organic carbon (f_{oc}) of 0.00029 g/g (grams of naturally occurring carbon per gram of dry sediment) (Barbaro, 2002, p. 7). Consequently, adsorption of VOCs to aquifer sediment is not a strong attenuation mechanism in the surficial aquifer. Retardation factors (R) for VOCs present in the natural attenuation study area range from 1.35 for PCE to 1.00 for VC (Barbaro, 2002, p. 17).

Four source areas are present in the natural attenuation study area (fig. 4). Site FT03 is a 2- to 3-acre grassy area that was used until 1989 for fire training. Waste oils and fuels were stored and periodically burned at the site. Site LF13 is an 8-acre landfill that has received construction rubble and small amounts of other refuse since the 1960s. Site WP14 is a former liquid-waste disposal area that received liquid waste during the 1950s and early 1960s. Site LF15 is a former landfill site 200 ft east of WP14. During the 1960s, LF15 received general refuse and small quantities of shop wastes. In this report, sites WP14 and LF15 are combined and referred to as site WP14/LF15. Some of the source material (contaminated soil) at FT03 was excavated during the early 1990s (U.S. Army Corps of Engineers and Dames and Moore, Inc., 1997b). Sites FT03 and WP14/LF15 have received clean fill, and a part of site FT03 is covered with a clay cap. Based on the longevity of the plumes (it has been more than 10 years since these sites were used for waste disposal), source materials such as hydro-



BASE FROM U.S. GEOLOGICAL SURVEY
DIGITAL DATA, 1:24,000, 1995

Figure 1b. Location of the East Management Unit and the natural attenuation study area at Dover Air Force Base, Delaware.

carbons and chlorinated solvents probably are present in all four source areas in the EMU.

Intended Use for Data

The sampling methods used in this investigation are designed for the rapid collection of large numbers of samples with the expectation that the accuracy and precision of the data would be lower than that of data collected from monitor wells and piezometers with customary sampling procedures. The intended use for the data was to locate the boundaries of the contaminant plumes, and to determine relative VOC concentrations in the plumes and ground-water discharge areas; however, a comparison of VOC concentrations from the direct-push boreholes with concentrations from nearby monitor wells indicated that the direct-push data are representative of actual concentrations in the aquifer. Therefore, rapid sample collection with the direct-push drill rig was determined to be an adequate sampling technique, and VOC concentrations in ground water were compared to U.S. Environmental Protection Agency (USEPA) maximum contaminant levels (MCLs) where applicable.

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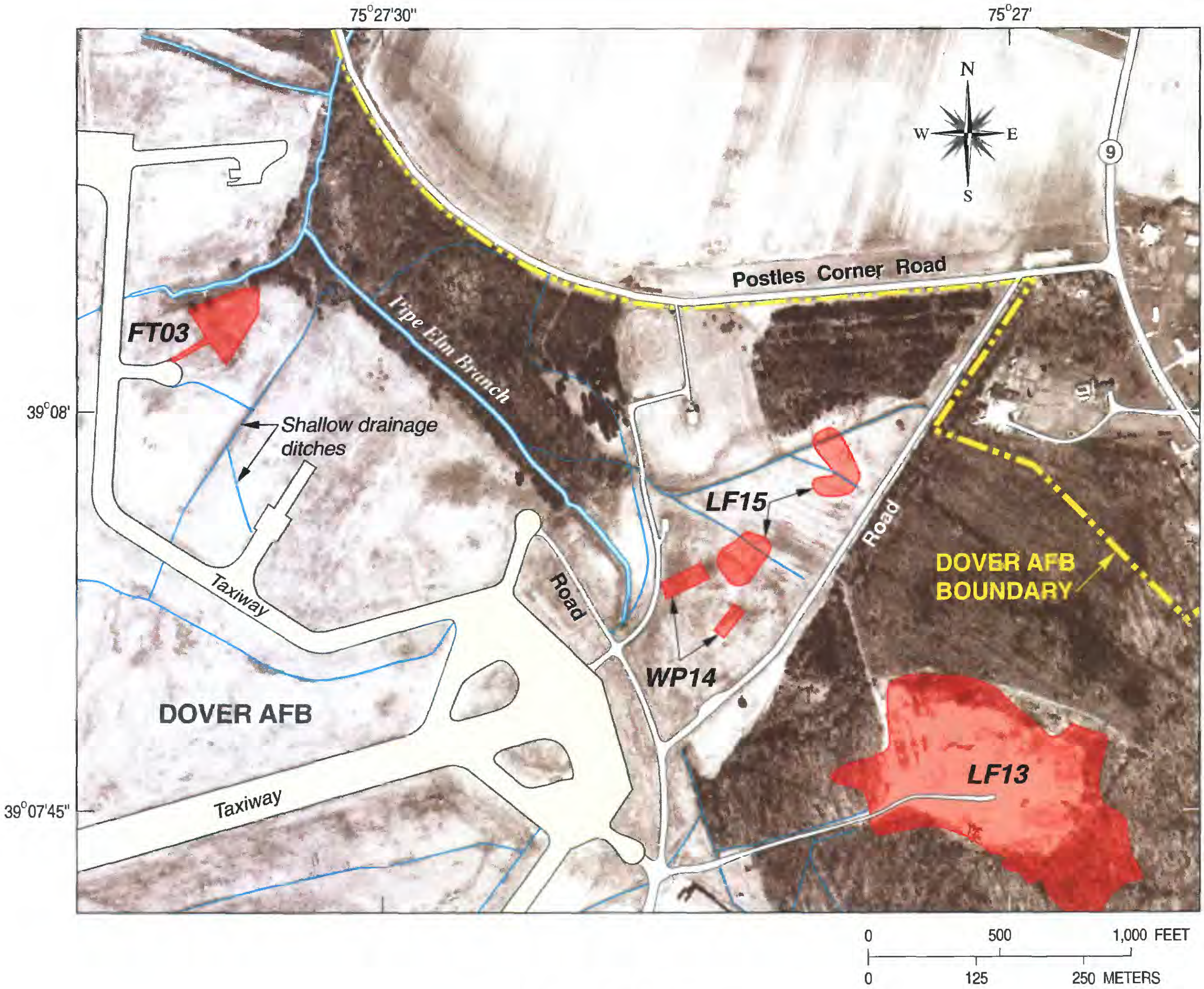

EXPLANATION

🟥 **CONTAMINANT SOURCE AREAS:**

LF13, Rubble Area Landfill
WP14, Liquid Waste Disposal Landfill
LF15, Receiver Station Landfill
FT03, Fire Training Area Three

— SHALLOW DRAINAGE DITCH

Figure 1c. Location of contaminant source areas within the natural attenuation study area, East Management Unit, Dover Air Force Base, Delaware.

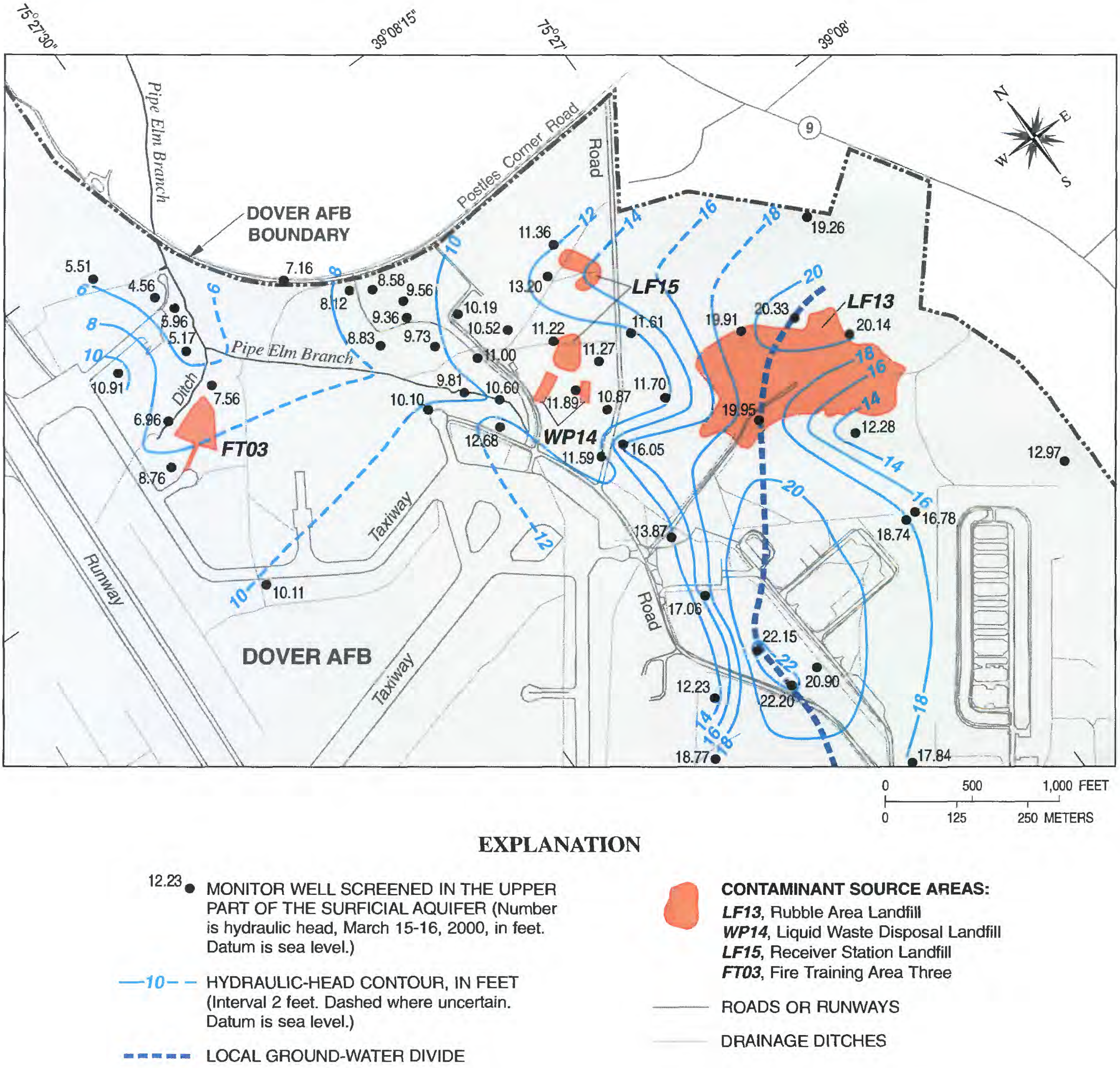

Figure 2. Hydraulic-head distribution in the upper part of the surficial aquifer in the East Management Unit, Dover Air Force Base, Delaware, March 15-16, 2000 (modified from Barbaro, 2002).

- Louis Trujillo and Frederick Gebhardt of the USGS New Mexico District for the operation of the direct-push drill rig;
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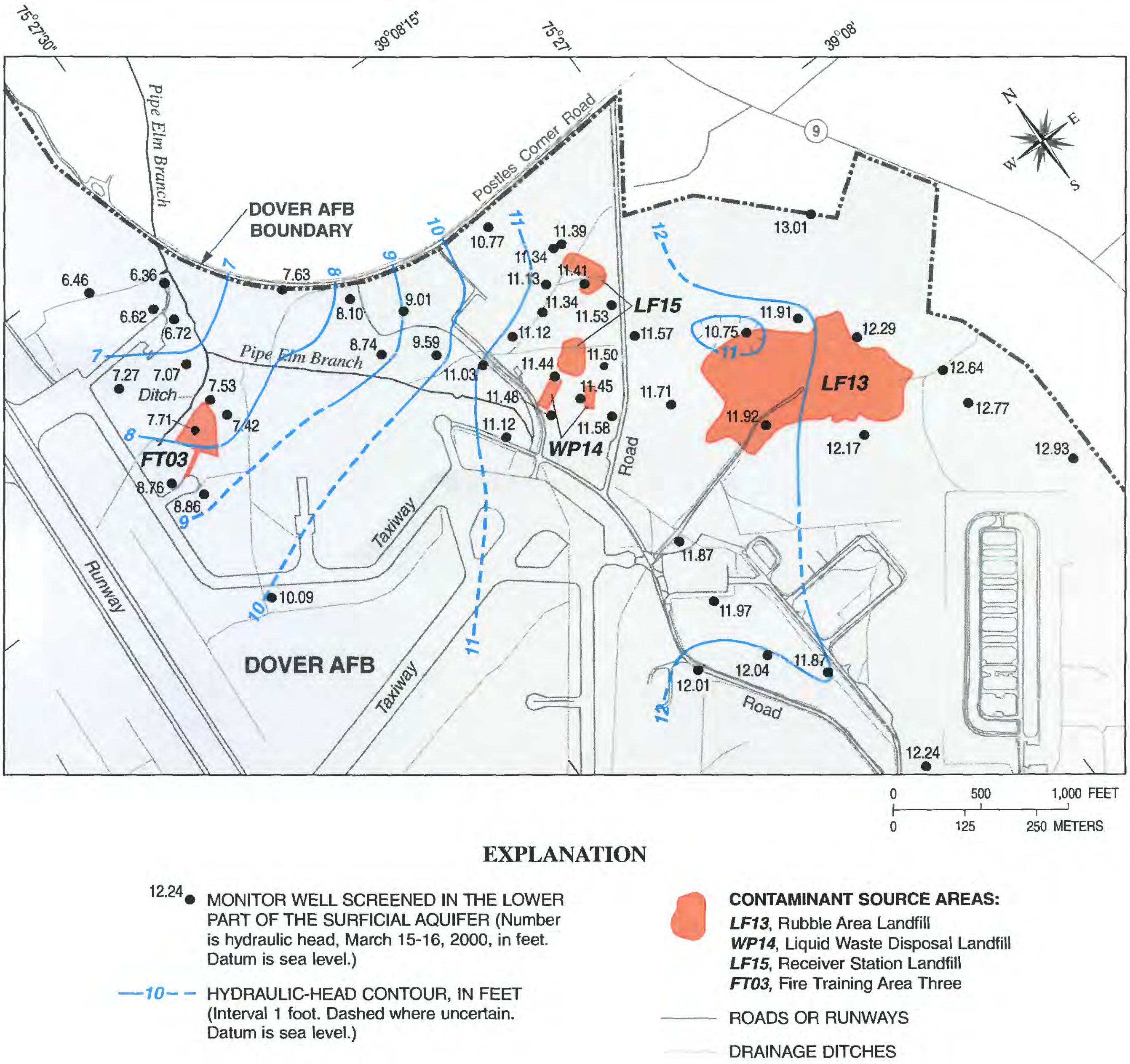


Figure 3. Hydraulic-head distribution in the lower part of the surficial aquifer in the East Management Unit, Dover Air Force Base, Delaware, March 15-16, 2000 (modified from Barbaro, 2002).

Methods of Investigation

The methods used to collect and analyze the ground-water, surface-water, and QC samples are described in the following sections. The sample-collection methods used in this study were primarily "profiling" methods that do not include the installation of permanent monitoring instrumentation. A Geoprobe direct-push drill rig was used to determine three-dimensional VOC distributions in the surficial aquifer. Ground-water samples were collected from 10 boreholes in the vicinity of site FT03, 56 boreholes in the vicinity of site WP14/LF15, and 11 boreholes in the vicinity of LF13 (fig. 4). To assist in plume delineation, two previously installed multilevel piezometers near site WP14/LF15 also were sampled. To collect samples in ground-water discharge areas, a hand-driven mini-piezometer was

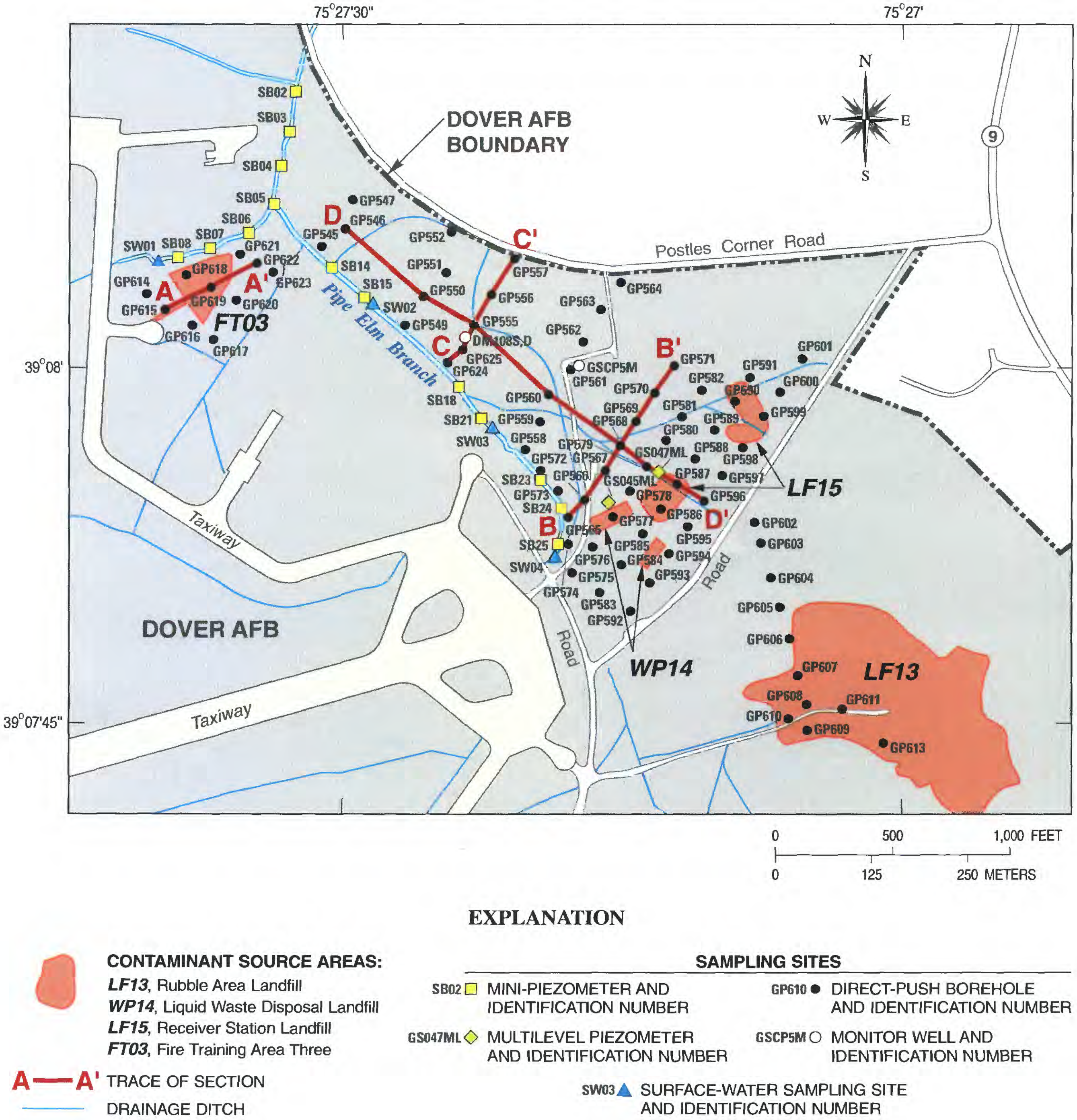


Figure 4. Location of ground-water and surface-water sampling sites and traces of sections A-A', B-B', C-C', and D-D' in the natural attenuation study area, Dover Air Force Base, Delaware.

used; 14 ground-water samples were collected from the aquifer underlying Pipe Elm Branch and the drainage ditch adjacent to FT03 (fig. 4). Surface-water samples also were collected from 4 locations along Pipe Elm Branch and the drainage ditch (fig. 4).

Ground-Water Sample Collection

Ground-water samples were collected from the direct-push boreholes, the mini-piezometers, and the multilevel piezometers with a peristaltic pump. When the ground-water yield was adequate (continuous flow), temperature, pH, specific conductance, and dissolved oxygen (DO) were measured with a Hydrolab meter. After the field-measured constituent levels stabilized, samples were collected in 40-mL (milliliter) VOC vials and preserved with concentrated hydrochloric acid. Re-usable ¼-in. (inch) outer-diameter Teflon tubing was used to collect the samples from the direct-push boreholes and mini-piezometers. The multilevel piezometers contain dedicated Teflon tubing.

Equipment was decontaminated to prevent cross-contamination. All re-usable Teflon tubing was decontaminated between sampling events. The direct-push well screen, drill rods, and mini-piezometer were decontaminated between sampling locations. Equipment was decontaminated with a soapy wash followed by a thorough rinse with deionized water. Following decontamination, field blanks were collected periodically from the Teflon tubing, direct-push well screen, and mini-piezometer to determine the effectiveness of the cleaning procedure.

Direct-Push Drill Rig Vertical profiles of VOC concentrations were obtained from ground-water samples collected from the direct-push boreholes. To obtain samples, drill rods (2.1-in. outer-diameter by 1.5-in. inner-diameter) were pushed or vibrated to the deepest sampling depth (typically 40–50 ft below ground surface). A 4-ft-long stainless-steel well screen then was exposed to the aquifer for ground-water sample collection. After a ground-water sample was collected with a peristaltic pump, the drill rod with the exposed screen was pulled up to the next sampling depth. The vertical interval between samples typically was 8 ft. The last sample from each borehole was obtained near the water table.

After reaching a given sampling interval, the drill string generally did not need to be clamped in place, indicating that the borehole below the drill string collapsed quickly. Fluid behavior of the saturated sand that makes up the surficial aquifer has been observed previously (K. Hinaman, U.S. Geological Survey, oral commun., 2001). The direct-push boreholes were used only to collect ground-water samples; permanent wells were not installed. The top part of the boreholes (above the water table) remained open and was backfilled to ground surface with bentonite grout.

A total of 292 ground-water samples were collected from various depths at 77 locations from November 6 through December 8, 2000 (fig. 4). The direct-push drilling and sampling data and the concentrations of the field-measured constituents are presented in Appendix 1. Each sample identifier consists of the borehole number plus an alphabetical extension indicating the depth of the sample, where "A" represents the deepest sample collected from a given borehole.

Mini-Piezometer Measurements of VOC concentrations in the ground-water discharge areas were made with a 5-ft-long, small diameter (¼-in.) stainless-steel mini-piezometer. Fourteen ground-water samples were collected during January 2001 from the surficial aquifer underlying the bed of Pipe Elm Branch and the drainage ditch adjacent to FT03 (fig. 4). The piezometer was driven manually into the streambed until a relatively permeable layer below the fine-grained streambed sediment was reached. A 2-in. screen then was exposed to collect ground-water samples (fig. 5). Depths below the streambed ranged from 2.5 ft to 4.5 ft. In three locations, between SB05 and SB14, SB15 and SB18, and SB21 and SB23 (fig. 4), samples were not collected because the streambed sediment consisted of a relatively thick soft mud deposit that did not produce sufficient water for sample collection. This lack of water probably indicates that the ground-water flux to the stream channel is variable spatially along this reach.

Measurements of DO, pH, specific conductance, and temperature on surface-water and ground-water samples were compared at each location to verify that the samples obtained from the mini-piezometer were not affected by surface-water infiltration. These measurements are listed in table 1. At most of the sampling locations, a manometer was used to compare ground-water levels (hydraulic head) to surface-water levels, and to calculate the magnitude and direction of the hydraulic gradient. Upward gradients indicating ground-water discharge conditions were present at all locations where the gradient was checked (table 1).

Multilevel Piezometers To supplement the direct-push data, two multilevel piezometers (GS045ML and GS047ML) near site WP14/LF15 were sampled for VOCs on February 21, 2001 (fig. 4). The piezometers are constructed of a series of 1/8-in.-diameter Teflon tubes attached to a ¾-in.-diameter polyvinylchloride center tube. The ends of the Teflon tubes (the sample ports) are covered with nylon screen. Piezometer GS045ML contains eight sample ports spaced 5 ft apart, with the lowest port at –34.55 ft sl (feet above or below sea level). Piezometer GS047ML contains 5 sample ports spaced 2 ft apart with the lowest port at –3.99 ft sl. A total of 13 VOC samples were collected from the multilevel piezometers. Because yields from the piezometers were low, field constituents were not measured.

Surface-Water Sample Collection

Four surface-water samples were collected along Pipe Elm Branch (3 samples) and the drainage ditch adjacent to FT03 (1 sample) by lowering 40-mL VOC vials to the base of the water column and filling them. The samples then were analyzed for VOCs.

Quality-Control Sample Collection

The QC samples included 1 source-water blank and 44 field blanks from the direct-push drilling, 4 field blanks from the mini-piezometer sampling, and 1 field blank from the

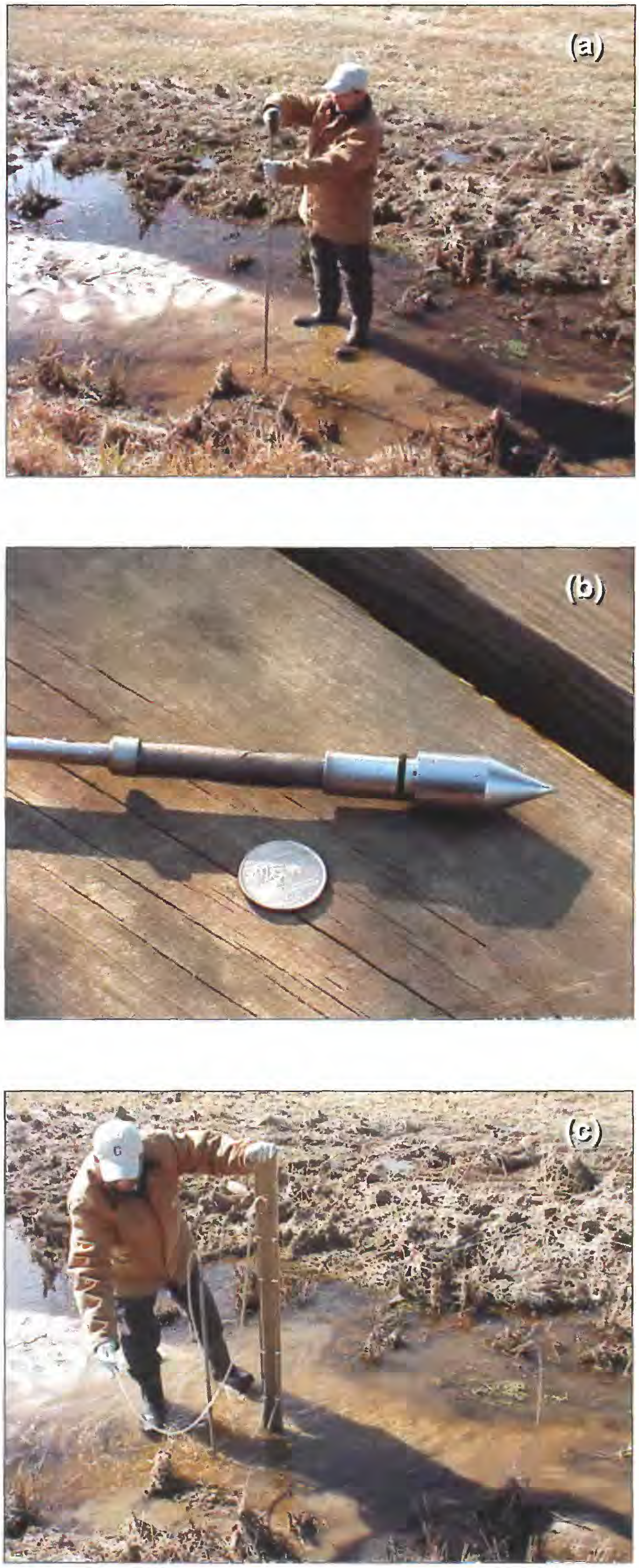


Figure 5. **(a)** Mini-piezometer installation in the bed of Pipe Elm Branch, **(b)** mini-piezometer screen, and **(c)** manometer used to measure relative ground-water and surface-water levels, Dover Air Force Base, Delaware. *(Photographs by Jeffrey R. Barbaro, USGS.)*

Table 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected from the aquifer underlying Pipe Elm Branch and the drainage ditch adjacent to site FT03, Dover Air Force Base, Delaware, January 2001*

[ft bgs, feet below ground surface; ft, feet; ft/ft, feet per feet; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; –, no data; U, upward gradient]

Sample identification number	Sampling date	Depth (ft bgs)	Head difference between ground water and surface water (ft)	Hydraulic gradient (ft/ft)	pH (standard units)	Temperature (°C)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
SB02	01/10/2001	3.5	–	–	5.5	–	1.2	102
SB03	01/10/2001	3.4	–	–	5.7	–	.70	114
SB04	01/10/2001	3.4	–	–	5.4	8.9	1.4	124
SB05	01/10/2001	3.3	–	–	5.6	10.6	1.6	117
SB06	01/10/2001	3.2	0.08	0.03 U	5.4	10.2	.99	103
SB07	01/10/2001	3.5	1.00	.29 U	5.7	12.0	2.4	137
SB08	01/25/2001	3.7	1.00	.27 U	5.7	8.3	1.5	141
SB14	01/12/2001	4.5	.55	.12 U	5.1	9.3	.95	102
SB15	01/12/2001	4.5	.80	.18 U	–	7.0	–	–
SB18	01/24/2001	4.3	1.25	.29 U	5.5	7.7	1.0	73
SB21	01/24/2001	4.2	1.20	.29 U	5.1	8.6	2.4	72
SB23	01/24/2001	3.2	1.10	.34 U	5.0	8.3	8.5	53
SB24	01/24/2001	3.4	1.05	.31 U	5.4	9.0	1.8	104
SB25	01/24/2001	2.5	.42	.17 U	6.4	8.3	.82	405

multilevel piezometer sampling. The source-water blank was collected to determine if VOCs were present in the Delaware Subdistrict Laboratory deionized water used for field blanks. To verify the effectiveness of the cleaning procedures, field blanks were collected from the Teflon tubing, Geoprobe well screen, and mini-piezometer. Most of the field blanks were taken with the Delaware Subdistrict Laboratory deionized water. Eight field blanks also were collected with certified organic-free blank water from the U.S. Geological Survey's National Water-Quality Laboratory (NWQL) in Denver, Colorado.

Analytical Methods

VOCs were analyzed at the Dover National Test Site (DNTS) Laboratory at Dover Air Force Base. DNTS is part of the National Environmental Technology Test Site (NETTS) program, administered by the U.S. Air Force Research Laboratory (AFRL). Samples were analyzed following the USEPA Method 8021B procedure (U.S. Environmental Protection Agency, 1996). Samples were run on a Hewlett Packard 6890A gas chromatograph equipped with flame ionization and electron capture detectors, a Hewlett Packard 7694 automatic headspace sampler, and a Supelco SPB-624 capillary column. To prepare samples and standards for analysis, 5 mL of water were transferred to 20-mL headspace vials and sealed. Vials were then injected with 5 microliters (µL) of a 10-µg/L internal standard mixture (1-chloro-2-fluorobenzene). For quality control, 10 µg/L check standards (Supelco custom VOC mixture) were run approximately every 10 samples during each sample run, and laboratory blanks prepared with reagent-grade deionized water were run periodically, as needed. A five-point calibration curve was used to determine VOC concentrations. Environmental samples and field blanks were analyzed for PCE, TCE, *cis*-1,2-DCE, VC, MTBE, and BTEX. Method detection limits for the VOCs are shown in table 2.

In this report, positively identified compounds that fall below the method detection limits are flagged with an "E," denoting estimated results. These concentrations are considered to be estimates because a result reported below the detection limit has an increased risk (greater than 1 percent) of being a false positive (Oblinger Childress and others, 1999). A false positive occurs when a compound is reported to be present in a sample when it is not present. Because of the increased false-positive risk, users should carefully consider the low-concentration (approximately 0.01 to 1.0 µg/L) estimated results in comparison to the field-blank results when interpreting the data. It also should be noted that a result reported as "ND" by the laboratory runs a small risk of being a false negative (a report that a compound is not present in a sample that contains the compound) (Oblinger Childress and others, 1999).

Temperature, pH, specific conductance, and DO were analyzed in the field using a Hydrolab Model H20 meter. The Hydrolab was calibrated daily using standard pH and specific conductance solutions.

Table 2. *Method detection limits for volatile organic compounds, Dover Air Force Base, Delaware*

[µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; –, not available]

Compound	Detection limit (µg/L)
PCE	1.3
TCE	0.80
cis-1,2-DCE	.60
VC	–
Benzene	.60
Toluene	1.4
Ethylbenzene	1.3
p,m-xylene	2.6
o-xylene	1.2
MTBE	–

Distribution of Volatile Organic Compounds

PCE, TCE, and *cis*-1,2-DCE are the most prevalent compounds in ground water underlying the natural attenuation study area. Accordingly, although all VOC results obtained during the sampling program are described in this section, only PCE, TCE and *cis*-1,2-DCE are discussed in detail. Concentrations of VOCs are listed in Appendix 2 and tables 3, 4, and 5. Concentrations above the USEPA MCLs are listed in bold.

Ground Water

The distributions of PCE, TCE, and *cis*-1,2-DCE in the surficial aquifer at sites FT03, LF13, and WP14/LF15 are shown in plan view (figs. 6 a–c) and in cross section (figs. 7 a–c, 8 a–c, 9 a–c, and 10 a–c). The traces of the sections are shown in figure 4. To display the three-dimensional data in two dimensions (plan view), vertically averaged concentrations were calculated at each direct-push borehole location with the approach described by Schirmer and Barker (1998). To calculate the average, a depth-integrated concentration first was calculated using linear interpolation between sampling points (Bevington, 1969, p. 268). The "sampling point" is defined as the midpoint of the 4-ft direct-push screened interval. When the sampling

Table 3. *Concentrations of volatile organic compounds in ground-water samples collected from multilevel piezometers at site WP14/LF15, Dover Air Force Base, Delaware, February 21, 2001*

[ft bgs, feet below ground surface; sl, sea level; µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; MCL, maximum contaminant level; concentrations in **bold** are above MCLs; –, MCL not available; ND, not detected]

Piezometer number	Sample identification number	Depth (ft bgs)	Depth (ft sl)		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
				MCL	**5**		**5**		**70**		**2**	**–**	**5**	**1,000**	**700**	**10,000**	**10,000**
GS045ML	GS045ML.H	19.5	0.45		**252**	68.1	332	60.1	**591**	106	ND	ND	ND	ND	ND	ND	ND
	GS045ML.G	24.5	-4.55		**45.6**		**48.3**		**80.6**		ND	ND	ND	ND	ND	ND	ND
	GS045ML.F	29.5	-9.55		**12.7**		3.4		1.1		ND	ND	ND	ND	ND	ND	ND
	GS045ML.E	34.5	-14.55		**11.4**		3.9		1.3		ND	ND	ND	ND	ND	ND	ND
	GS045ML.D	39.5	-19.55		**17.6**		4.7		1.4		ND	ND	ND	ND	ND	ND	ND
	GS045ML.C	44.5	-24.55		**42.3**		**13.7**		17.8		ND	ND	ND	ND	ND	ND	ND
	GS045ML.B	49.5	-29.55		**280**		**243**		**448**		ND	ND	ND	ND	ND	ND	ND
	GS045ML.A	54.5	-34.55		**18.1**		**6.9**		3.2		ND	ND	ND	ND	ND	ND	ND
GS047ML	GS047ML.E	13	4.01		**46.9**	128	**23.2**	80.4	14.0	41.2	ND	ND	ND	ND	ND	ND	ND
	GS047ML.D	15	2.01		**54.4**		**57.3**		32.9		ND	ND	ND	ND	ND	ND	ND
	GS047ML.C	17	.01		**262**		**166**		**90.3**		ND	ND	ND	ND	ND	ND	ND
	GS047ML.B	19	-1.99		**270**		**136**		63.4		ND	ND	ND	ND	ND	ND	ND
	GS047ML.A	21	-3.99		**58.8**		**61.8**		25.1		ND	ND	ND	ND	ND	ND	ND

Table 4. *Concentrations of volatile organic compounds in ground-water samples collected from the aquifer underlying Pipe Elm Branch and the drainage ditch adjacent to site FT03, Dover Air Force Base, Delaware, January 2001*

[µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; MCL, maximum contaminant level; concentrations in **bold** are above MCLs; –, MCL not available; **E**, estimated result below detection limit; ND, not detected]

Sample identification number	Sampling date		PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	**5**	**5**	**70**	**2**	**-**	**5**	**1,000**	**700**	**10,000**	**10,000**
SB02	01/10/2001		0.46 E	0.40 E	ND	ND	ND	ND	ND	ND	ND	ND
SB03	01/10/2001		.31 E	.57 E	ND	ND	ND	ND	ND	ND	ND	ND
SB04	01/10/2001		.01 E	.38 E	ND	ND	ND	ND	ND	ND	ND	ND
SB05	01/10/2001		.10 E	.66 E	ND	ND	ND	ND	ND	ND	ND	ND
SB06	01/10/2001		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB07	01/10/0201		.01 E	.40 E	6.7	ND	ND	1.6	ND	ND	ND	ND
SB08	01/25/2001		.01 E	1.2	7.0	ND	ND	ND	ND	ND	ND	ND
SB14	01/12/2001		.03 E	**5.1**	ND	ND	ND	ND	ND	ND	ND	ND
SB15	01/12/2001		.01 E	1.2	ND	ND	ND	ND	ND	ND	ND	ND
SB18	01/24/2001		2.4	**7.6**	4.6	ND	ND	ND	ND	ND	ND	ND
SB21	01/24/2001		ND	.13 E	ND	ND	ND	ND	ND	ND	ND	ND
SB23	01/24/2001		**28.6**	**31.9**	15.9	ND	ND	ND	ND	ND	ND	ND
SB24	01/24/2001		.01 E	.04 E	ND	ND	ND	ND	ND	ND	ND	ND
SB25	01/24/2001		ND	.03 E	ND	ND	ND	ND	ND	ND	ND	ND

Table 5. *Concentrations of volatile organic compounds in surface-water samples collected from Pipe Elm Branch and the drainage ditch adjacent to site FT03, Dover Air Force Base, Delaware, January 2001*

[µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; E, estimated result below detection limit; ND, not detected]

Sample identification number	Sampling date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p.m*-xylene (µg/L)	*o*-xylene (µg/L)
SW01	01/11/2001	ND	0.16 E	ND	ND	ND	ND	ND	ND	ND	ND
SW02	01/12/2001	ND	.50 E	0.08 E	ND	ND	ND	ND	ND	ND	ND
SW03	01/24/2001	ND	1.0	.32 E	ND	ND	ND	ND	ND	ND	ND
SW04	01/24/2001	ND	.76 E	ND	ND	ND	ND	ND	ND	ND	ND

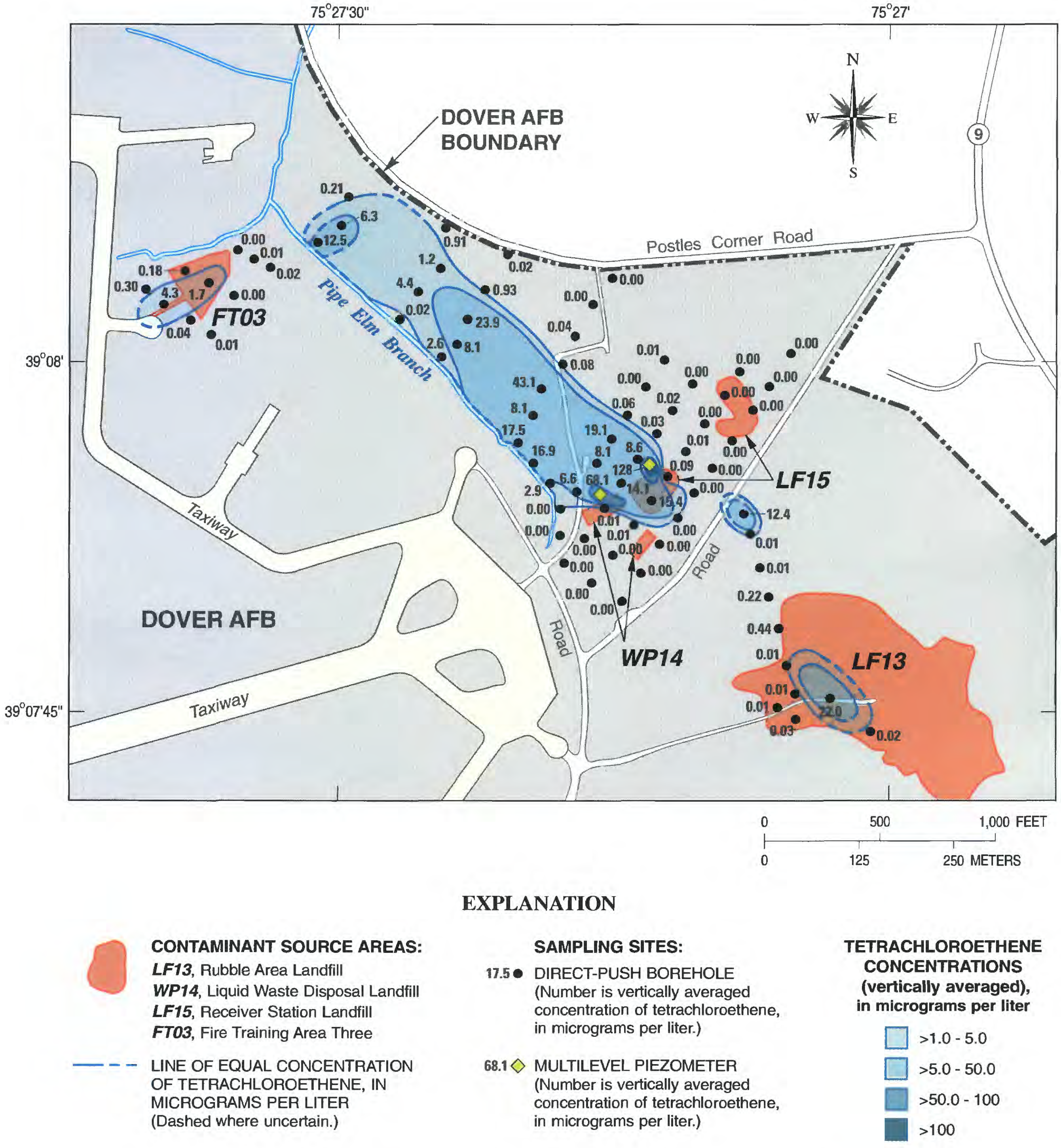
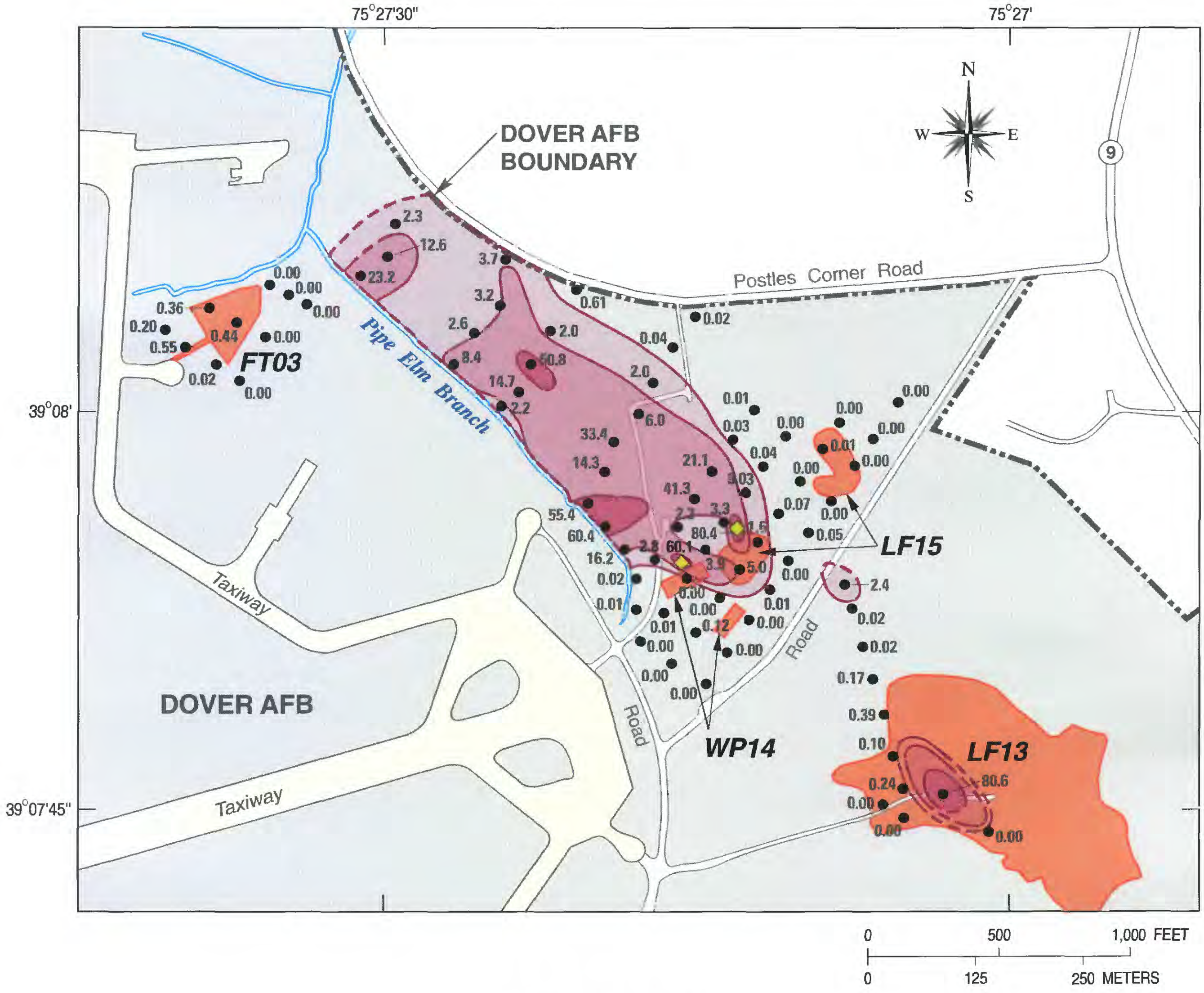


Figure 6a. Distribution of tetrachloroethene in the surficial aquifer at sites FT03, LF13, and WP14/LF15 in the natural attenuation study area, Dover Air Force Base, Delaware, November 2000 - February 2001.



EXPLANATION

CONTAMINANT SOURCE AREAS:

LF13, Rubble Area Landfill
WP14, Liquid Waste Disposal Landfill
LF15, Receiver Station Landfill
FT03, Fire Training Area Three

LINE OF EQUAL CONCENTRATION OF TRICHLOROETHENE, IN MICROGRAMS PER LITER (Dashed where uncertain.)

SAMPLING SITES:

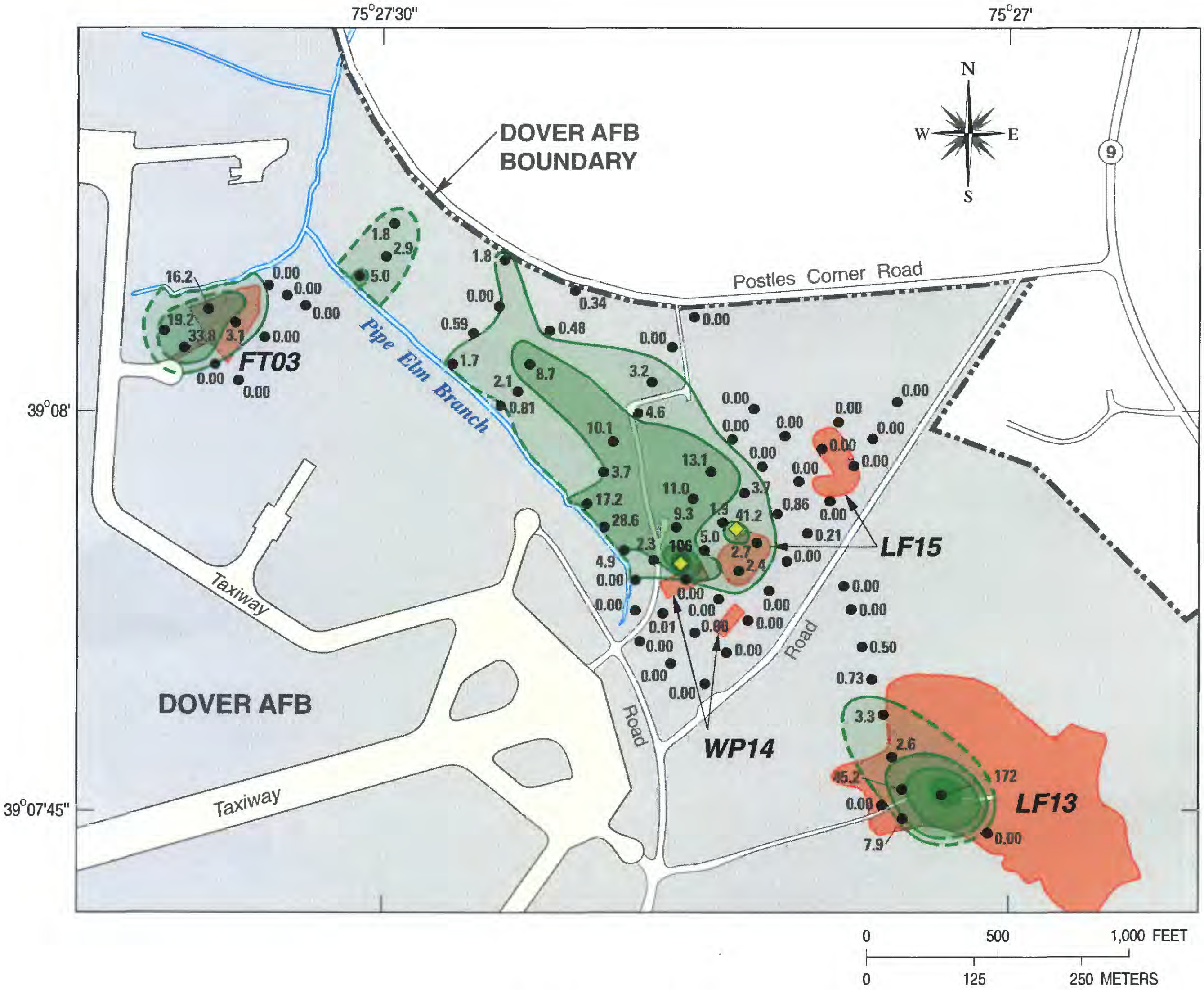
23.2 ● DIRECT-PUSH BOREHOLE (Number is vertically averaged concentration of trichloroethene, in micrograms per liter.)

80.4 ◇ MULTILEVEL PIEZOMETER (Number is vertically averaged concentration of trichloroethene, in micrograms per liter.)

TRICHLOROETHENE CONCENTRATIONS (vertically averaged), *in micrograms per liter*

▨ >1.0 - 5.0
▨ >5.0 - 50.0
▨ >50.0

Figure 6b. Distribution of trichloroethene in the surficial aquifer at sites FT03, LF13, and WP14/LF15 in the natural attenuation study area, Dover Air Force Base, Delaware, November 2000 - February 2001.



EXPLANATION

CONTAMINANT SOURCE AREAS:
LF13, Rubble Area Landfill
WP14, Liquid Waste Disposal Landfill
LF15, Receiver Station Landfill
FT03, Fire Training Area Three

— – – LINE OF EQUAL CONCENTRATION OF *cis*-1,2-DICHLOROETHENE, IN MICROGRAMS PER LITER (Dashed where uncertain.)

SAMPLING SITES:

28.6 ● DIRECT-PUSH BOREHOLE (Number is vertically averaged concentration of *cis*-1,2-dichloroethene, in micrograms per liter.)

41.2 ◇ MULTILEVEL PIEZOMETER (Number is vertically averaged concentration of *cis*-1,2-dichloroethene, in micrograms per liter.)

***cis*-1,2-DICHLOROETHENE CONCENTRATIONS (vertically averaged), in micrograms per liter**

- 🟩 >1.0 - 5.0
- 🟩 >5.0 - 50.0
- 🟩 >50.0 - 100
- 🟩 >100

Figure 6c. Distribution of *cis*-1,2-dichloroethene in the surficial aquifer at sites FT03, LF13, and WP14/LF15 in the natural attenuation study area, Dover Air Force Base, Delaware, November 2000 - February 2001.

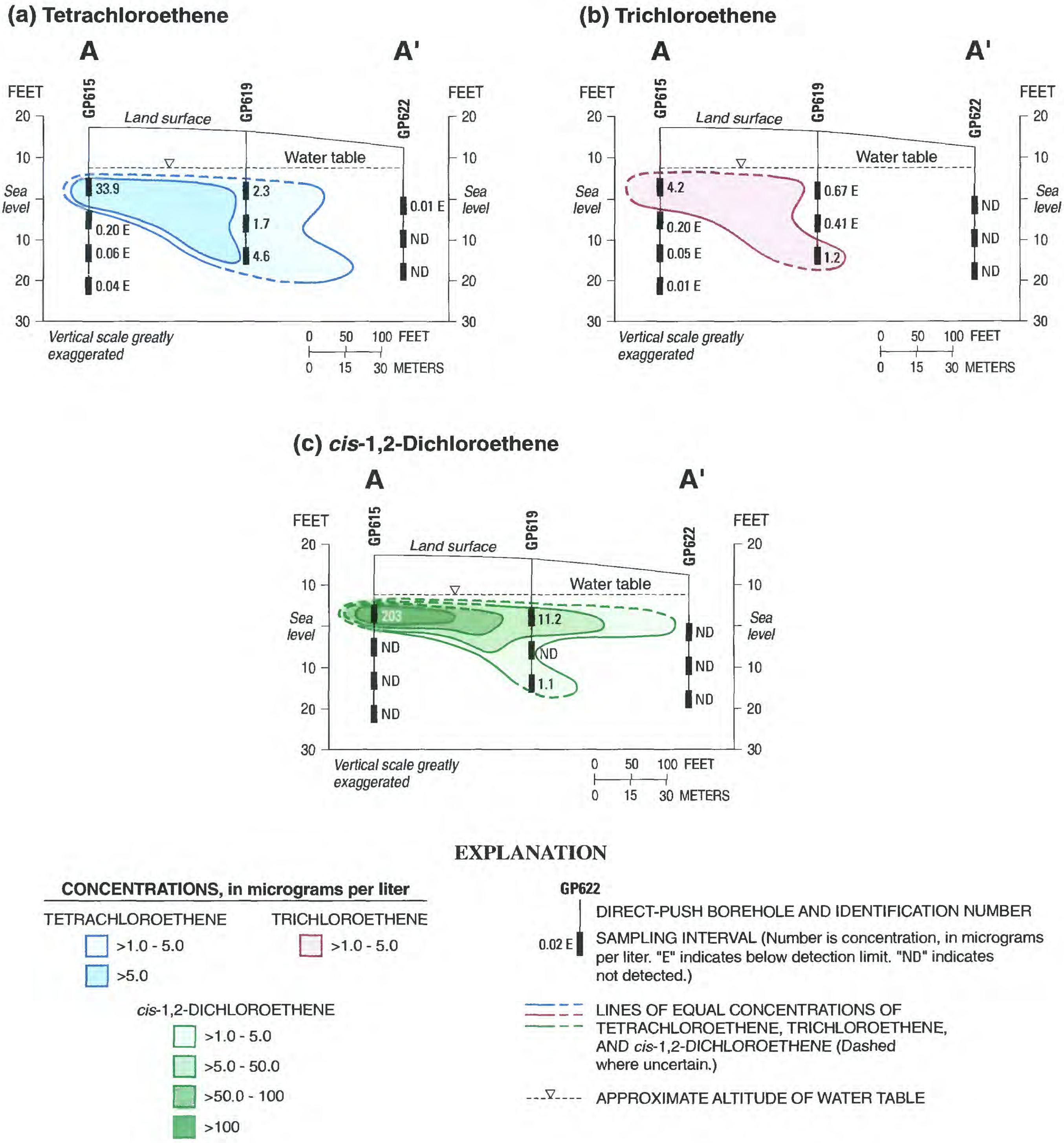
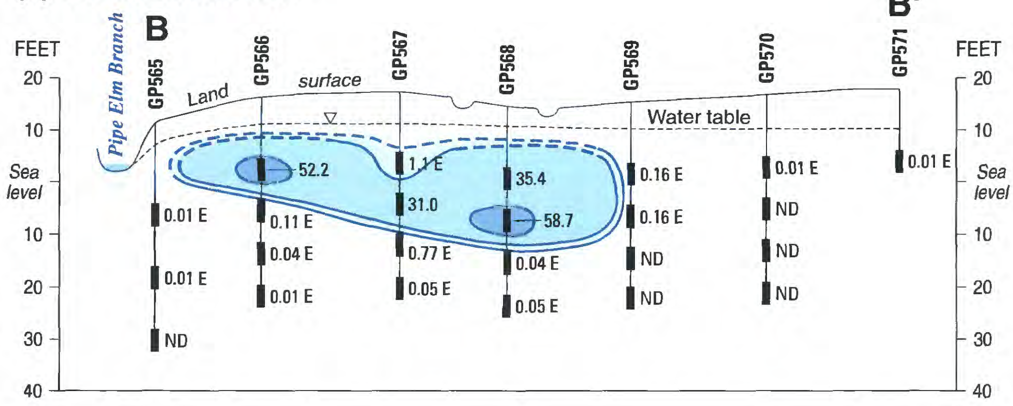
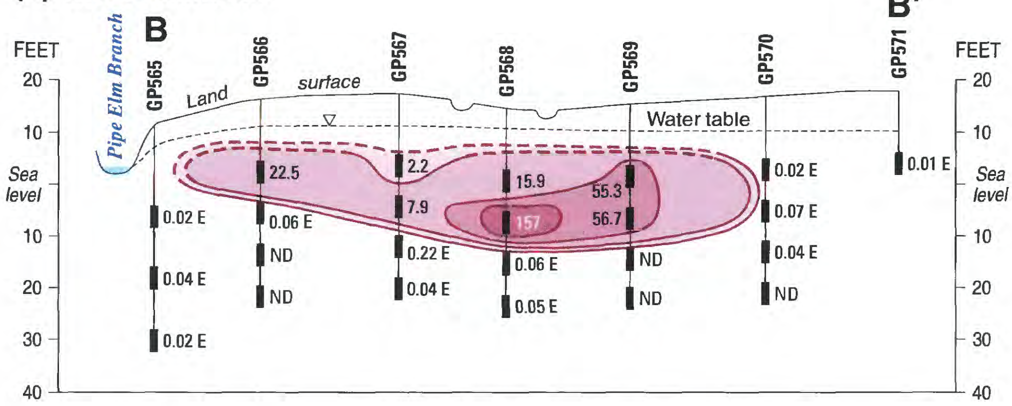


Figure 7. Vertical distribution of **(a)** tetrachloroethene, **(b)** trichloroethene, and **(c)** *cis*-1,2-dichloroethene on section A-A' at site FT03, Dover Air Force Base, Delaware, November-December 2000. *(Trace of section shown in figure 4.)*

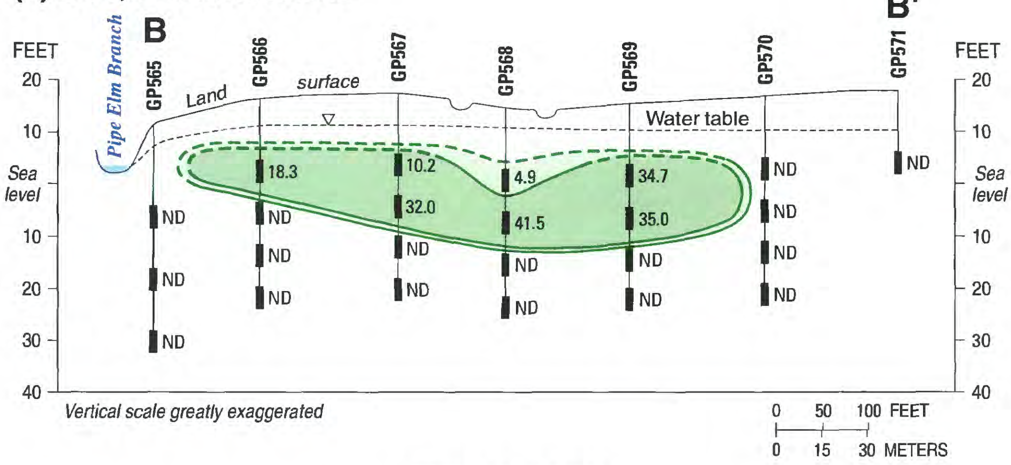
(a) Tetrachloroethene



(b) Trichloroethene



(c) *cis*-1,2-Dichloroethene



EXPLANATION

CONCENTRATIONS, in micrograms per liter

TETRACHLOROETHENE

- ☐ >1.0 - 5.0
- ☐ >5.0 - 50.0
- ■ >50.0

TRICHLOROETHENE

- ☐ >1.0 - 5.0
- ☐ >5.0 - 50.0
- ■ >50.0 - 100
- ■ >100

cis-1,2-DICHLOROETHENE

- ☐ >1.0 - 5.0
- ☐ >5.0 - 50.0

GP570 | DIRECT-PUSH BOREHOLE AND IDENTIFICATION NUMBER

0.02 E ▌ SAMPLING INTERVAL (Number is concentration, in micrograms per liter. "E" indicates below detection limit. "ND" indicates not detected.)

— — — LINES OF EQUAL CONCENTRATIONS OF TETRACHLOROETHENE, TRICHLOROETHENE, AND *cis*-1,2-DICHLOROETHENE (Dashed where uncertain.)

---▽--- APPROXIMATE ALTITUDE OF WATER TABLE

Figure 8. Vertical distribution of **(a)** tetrachloroethene, **(b)** trichloroethene, and **(c)** *cis*-1,2-dichloroethene on section B-B' at site WP14/LF15, Dover Air Force Base, Delaware, November-December 2000. *(Trace of section shown in figure 4.)*

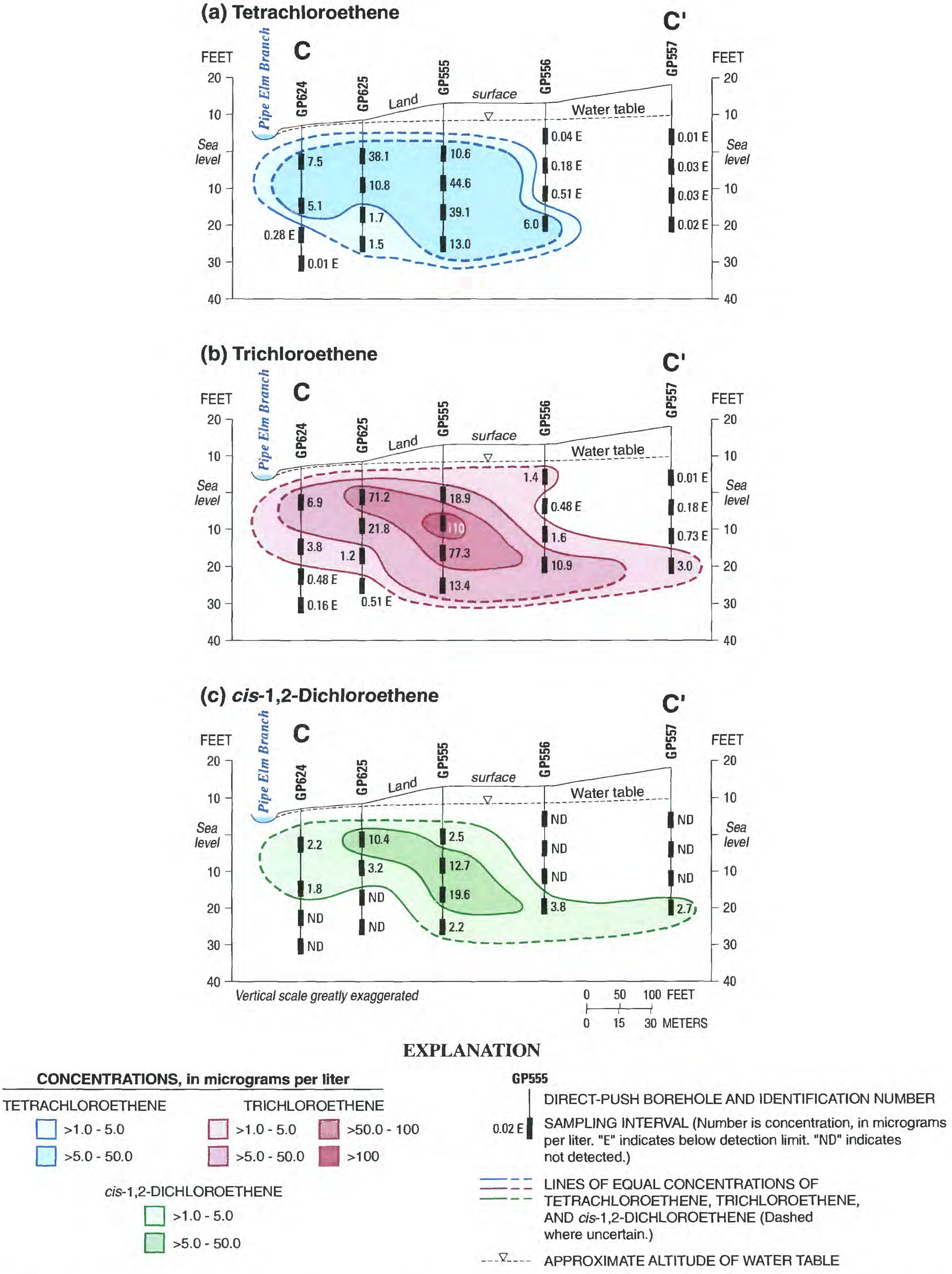


Figure 9. Vertical distribution of **(a)** tetrachloroethene, **(b)** trichloroethene, and **(c)** *cis*-1,2-dichloroethene on section C-C' at site WP14/LF15, Dover Air Force Base, Delaware, November-December 2000. *(Trace of section shown in figure 4.)*

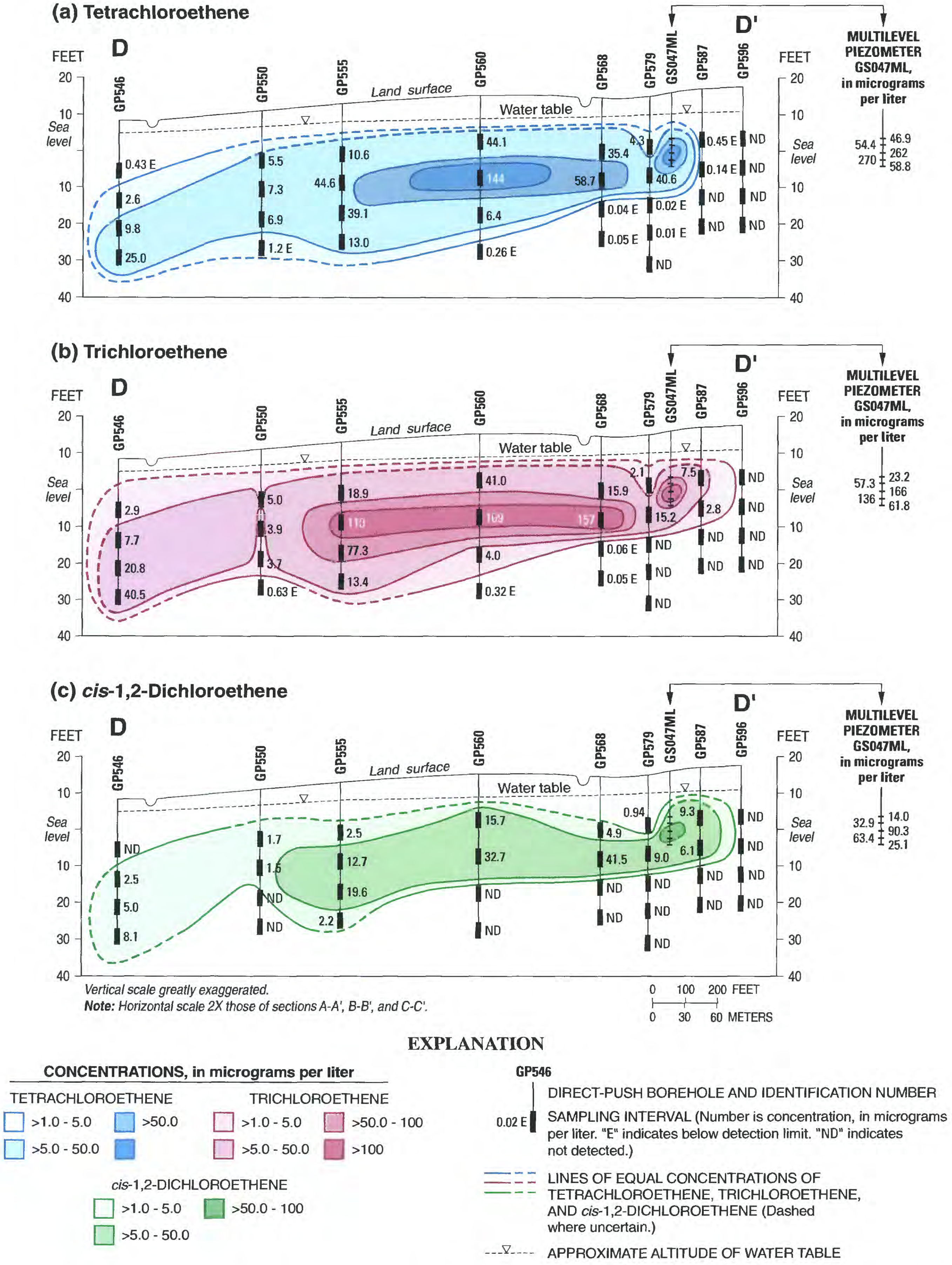


Figure 10. Vertical distribution of **(a)** tetrachloroethene, **(b)** trichloroethene, and **(c)** *cis*-1,2-dichloroethene on section D-D' at site WP14/LF15, Dover Air Force Base, Delaware, November 2000 - February 2001. *(Trace of section shown in figure 4.)*

points were equally spaced, the depth-integrated concentration was obtained from

$$C_{\mathrm{int}} = \Delta z\left(c_1/2 + \sum_{i=2}^{n-1} c_i + c_n/2\right),$$

where

C_{int} = the depth-integrated concentration [ML^{-2}],

c_1 = the concentration at the top sampling point [ML^{-3}],

c_i = the concentration at the intermediary sampling points [ML^{-3}],

c_n = the concentration at the bottom sampling point [ML^{-3}], and

Δz = the vertical distance between sampling points [L].

n = total number of sampling points.

When the sampling points were not equally spaced, the depth-integrated concentration was obtained from

$$C_{\mathrm{int}} = 0.5\left(\sum_{i=1}^{n-1} \Delta z_i(c_i + c_{i+1})\right),$$

where

c_i = the concentration at the ith sampling point [ML^{-3}], and

Δz_i = the vertical distance between sampling points c_i and c_{i+1} [L].

The vertically averaged concentration at a given direct-push borehole location then was calculated by dividing the depth-integrated concentration by the total vertical distance over which direct-push samples were collected, and is given as

$$C_{\mathrm{ave}} = C_{\mathrm{int}}/z ,$$

where

C_{ave} = the vertically averaged concentration [ML^{-3}], and

z = the total vertical distance over which direct-push samples were collected [L].

To determine the total vertical distance, z, vertical intervals that straddled the sampling points were assigned to each sample in the profile. The upper and lower boundaries of each interval corresponded to the midpoints between adjacent sampling points. Symmetrical distances were used to locate the upper and lower boundaries of the top and bottom intervals, respectively, in a vertical profile. The total vertical distance for a given borehole then was obtained as the sum of the vertical intervals straddling the sampling points. For example, for four direct-push sampling points spaced 8 ft apart (the most common profile), each vertical interval was 8 ft, and the total vertical distance was 32 ft. At most boreholes, the total vertical distance over which direct-push samples were collected was greater than 50 percent of the saturated thickness of the surficial aquifer. A value of zero was assigned to samples that did not contain detectable concentrations of VOCs (results reported as "ND" by the laboratory). Concentrations below the method detection limits (MDLs) (values flagged with an "E," denoting estimated results) were used at face value in these calculations.

FT03 Thirty-four samples were collected from 10 direct-push boreholes located in the vicinity of FT03 (fig. 4). Concentrations ranged from zero (results reported as "ND" by the laboratory) to maximum values of 33.9 µg/L for PCE, 4.2 µg/L for TCE, 203 µg/L for *cis*-1,2-DCE, 8.1 µg/L for MTBE, 34.2 µg/L for benzene, 3.5 µg/L for toluene, and 1.6 µg/L for *o*-xylene (Appendix 2). Vinyl chloride and *p,m*-xylene were not detected in any sample. Concentrations of PCE and *cis*-1,2-DCE were above their respective MCLs in sample GP615.D (Appendix 2).

The approximate length of the contaminant plume at site FT03 is 500 ft. Vertically averaged concentrations of PCE, TCE, and *cis*-1,2-DCE are shown in plan view in figs. 6 a–c. Vertical concentration distributions are shown on section A–A′ (figs. 7a–c). As shown in figs. 6a–c, the downgradient edges and the southeastern lateral boundaries of the plume are well defined; however, the locations of the upgradient and northwestern boundaries remain uncertain. The vertical boundary of the plume also is well defined. The contaminant source appears to be in the upper part of the surficial aquifer.

To determine the position of the northwestern lateral boundary, an assumption was made that the plume does not migrate under the drainage ditch adjacent to FT03 (fig. 6c). This assumption implies that the contaminant plume discharges to the drainage ditch along the northern edge of FT03. The discharge of shallow, contaminated ground water to the ditch is consistent with the upward hydraulic-head gradients beneath the streambed (table 1), but drilling on the northwest side of the ditch to confirm the assumption of complete plume discharge was not done during this investigation. Off-site migration of this plume appears unlikely, however.

The plume consists predominantly of a chlorinated-solvent daughter product (*cis*-1,2-DCE), indicating that the reductive dechlorination of PCE and TCE is extensive. Although the site has a history of fuel disposal (U.S. Army Corps of Engineers and Dames and Moore, Inc., 1997a), a plume of soluble fuel hydrocarbon constituents (BTEX) was not present. This lack of a plume probably reflects rapid intrinsic biodegradation of these compounds.

LF13 Forty-four samples were collected from 11 direct-push boreholes located in the vicinity of LF13 (fig. 4). Concentrations ranged from zero (results reported as "ND" by the laboratory) to maximum values of 65.4 µg/L for PCE, 285 µg/L for TCE, 505 µg/L for *cis*-1,2-DCE, 39.9 µg/L for benzene, 12.7 µg/L for toluene, 3.4 µg/L for ethylbenzene, 6.6 µg/L for *p,m*-xylene, and 1.6 µg/L for *o*-xylene (Appendix 2). VC and MTBE were not detected in any sample. The concentrations of PCE, TCE, *cis*-1,2-DCE, and benzene were above their respective MCLs in 4, 3, 3, and 4 samples, respectively (Appendix 2).

Based on the available data, the approximate length of the contaminant plume at this site is 800 ft. Vertically averaged concentrations of PCE, TCE, and *cis*-1,2-DCE are shown in plan view in figs. 6a–c. Because much of the area surrounding LF13 was inaccessible to the drill rig, drilling on lines perpendicular to the presumed direction of ground-water flow was not conducted. As a result, the lateral boundaries of the plume were not located. In addition, because LF13 is located in an area with complex ground-water flow patterns (figs. 2 and 3), the direction of plume migration is uncertain. Consequently, although the direct-push sampling improved the understanding of VOC distributions, there still is uncertainty about the boundaries and migration direction of the LF13 plume.

The plume migrating from LF13 consists mainly of chlorinated solvents. Fuel hydrocarbon compounds were not detected beyond the source area. The plume contains high concentrations (up to 500 µg/L) of *cis*-1,2-DCE relative to the other sites and lacks parent compounds, indicating that extensive reductive dechlorination has occurred at this site. PCE and TCE were present in concentrations above detection limits at only one sampling location near the source area (GP611, fig. 4). Intrinsic biodegradation may limit the size of the *cis*-1,2-DCE plume; however, the occurrence of biodegradation in this plume cannot be determined from the available information. Regardless of the precise size and migration direction of the plume, LF13 is not near ground-water discharge areas or the DAFB boundary; therefore, discharge of VOCs to surface water and off-site migration of the plume are unlikely.

WP14/LF15 Two hundred twenty-seven samples were collected from 56 direct-push boreholes and 2 multilevel piezometers located in the vicinity of WP14/LF15 (fig. 4). Concentrations ranged from zero (results reported as "ND" by the laboratory) to maximum values of 280 µg/L for PCE, 332 µg/L for TCE, 591 µg/L for *cis*-1,2-DCE, 429 µg/L for MTBE, 5.7 µg/L for benzene, 38.4 µg/L for toluene, 226 µg/L for ethylbenzene, 280 µg/L for *p,m*-xylene, and 66.7 µg/L for *o*-xylene (Appendix 2 and table 3). VC was not detected in any sample. The concentrations of PCE, TCE, *cis*-1,2-DCE, and benzene were above MCLs in 51, 58, 5, and 2 samples, respectively (Appendix 2 and table 3). The vertically averaged concentrations obtained near the DAFB boundary were less than 10 µg/L (figs. 6 a–c). The highest concentration of TCE in an individual sample near the DAFB boundary was 10.3 µg/L (sample GP552.B), above the MCL of 5.0 µg/L (Appendix 2).

With an approximate length of 2,200 ft, the VOC plume migrating from WP14/LF15 is the largest of the three plumes in the EMU. Vertically averaged concentrations of PCE, TCE, and *cis*-1,2-DCE are shown in plan view in figs. 6 a–c. Vertical concentration distributions are shown on sections B–B′, C–C′, and D–D′ in figs. 8 a–c, 9 a–c, and 10 a–c, respectively. The plume consists mainly of chlorinated solvents. Fuel hydrocarbon constituents (BTEX and MTBE) were present in concentrations above detection limits only in discrete areas (for example, direct-push borehole GP562). Results from the ground-water samples collected in the vicinity of the WP14/LF15 source area indicate that the source is confined to two discrete areas (figs. 6 a–c). The plume, which is in the upper part of the surficial aquifer near the source, moves deeper with distance from the source (figs. 10 a–c).

In contrast to the other two sites in the EMU, parent compounds are present at an appreciable distance (at least 2,200 ft) downgradient of the source at this site. The length of the plume and the similarity of the spatial distributions of PCE, TCE, and *cis*-1,2-DCE indicate that these compounds are either recalcitrant or reacting slowly downgradient of the WP14/LF15 source area. The plume also has a heterogeneous concentration distribution (figs. 8 a–c, 9 a–c, and 10 a–c), possibly resulting from temporal variability in source concentrations (Barbaro, 2002, p. 35), or from the heterogeneity of the aquifer sediment. Relatively high PCE and TCE concentrations (greater than 100 µg/L) are evident in the core of the plume (figs. 10 a–b). The downgradient edge of the high concentration core currently (2001) is about 1,000 ft from the DAFB boundary, and at a ground-water migration velocity of 0.4 ft/d, will reach the boundary in roughly 7 years. Additional information on geochemical conditions (concentrations of electron acceptors such as DO, iron, sulfate, and methane) and potential reaction mechanisms would be useful in determining if the high-concentration ground water in the core of this plume will reach the boundary.

The vertical boundary of the plume is well defined in most areas, and a deep chlorinated-solvent source area is not evident. The northern lateral boundary of the plume also is well defined. The position of the northern boundary was determined from drilling on transects perpendicular to the direction of ground-water flow. To determine the position of the southern lateral boundary, an assumption was made that the plume does not migrate under Pipe Elm Branch (that is, the stream channel and southern plume boundary are coincident). Ground-water discharge is consistent with the upward hydraulic-head gradients beneath the streambed (table 1). The effectiveness of Pipe Elm Branch in completely intercepting the plume could not be confirmed by drilling on the opposite side of Pipe Elm Branch, however, because access to this area is restricted.

Although low concentrations (less than 10 µg/L) of chlorinated solvents were present in the samples collected from the farthest downgradient boreholes, the locations of the downgradient boundaries of the PCE, TCE, and *cis*-1,2-DCE plumes were not determined during this investigation (figs. 6 a–c). The plan-view distributions indicate that these compounds possibly migrate off the DAFB property approximately 1,500 ft downgradient of the source area (figs. 6 a–c). In this area, the direction of plume migration is roughly parallel to the DAFB boundary, which probably restricts the extent of off-site migration.

Ground-Water Discharge Areas

Fourteen ground-water samples were collected from the surficial aquifer underlying the bed of Pipe Elm Branch and the drainage ditch adjacent to FT03 (fig. 4). Concentrations ranged from zero (results reported as "ND" by the laboratory) to maximum values of 28.6 µg/L for PCE, 31.9 µg/L for TCE, 15.9 µg/L for *cis*-1,2-DCE, and 1.6 µg/L for benzene (table 4). The concentration of TCE was above the MCL in samples SB14 and SB18. The concentrations of both PCE and TCE were above MCLs in sample SB23. VC, MTBE, toluene, ethylbenzene, *p,m*-xylene, and *o*-xylene were not detected in any sample (table 4).

Two of three samples collected from the aquifer underlying the drainage ditch adjacent to FT03 contained chlorinated solvents at concentrations above detection limits (fig. 11). Sample SB08 contained TCE (1.2 µg/L) and *cis*-1,2-DCE (7.0 µg/L), and sample SB07 contained *cis*-1,2-DCE (6.7 µg/L) and benzene (1.6 µg/L). These compounds are likely from the plume migrating from FT03.

Four of 11 samples collected from the aquifer underlying Pipe Elm Branch contained VOCs at concentrations above detection limits (fig. 11). Samples SB18 and SB23 contained PCE (2.4 µg/L and 28.6 µg/L), TCE (7.6 µg/L and 31.9 µg/L) and *cis*-1,2-DCE (4.6 µg/L and 15.9 µg/L). Samples SB14 and SB15 contained TCE (5.1 µg/L and 1.2 µg/L) only. VOCs were either not detected or present at very low concentrations (values flagged with an "E", denoting estimated results) in samples collected from the farthest downgradient locations (SB02 through SB05), where the downgradient edge of the plume from WP14/LF15 would be expected to discharge to Pipe Elm Branch (fig. 11). These low concentrations could indicate that the plume does not reach Pipe Elm Branch or encounters a reducing environment and biodegrades before reaching this boundary.

The VOC distributions in the ground-water discharge areas generally are consistent with the VOC distributions at FT03 and WP14/LF15 shown in figs. 8 a–c. It should be noted that the fate of the VOCs between the mini-piezometer sampling points and the streambed was not determined. Biodegradation could occur in this vertical interval, reducing the mass flux to surface water. Further study would be needed to determine the position of the downgradient boundary of the WP14/LF15 plume, and the location and amount of contaminant discharge to Pipe Elm Branch and the drainage ditch adjacent to FT03.

Surface Water

Four surface-water samples were collected along Pipe Elm Branch and the drainage ditch adjacent to FT03 (fig. 4) during January 2001. Because the preceding 3–4 weeks were dry, the streams were under base-flow conditions when sampled. In this report, base flow is defined as streamflow derived entirely from ground-water discharge. One sample, SW03, contained TCE above the detection limit at a concentration of 1.0 µg/L (table 5). The other three samples, SW01, SW02, and SW04 contained TCE below the detection limit at estimated concentrations of 0.16 E µg/L, 0.50 E µg/L, and 0.76 E µg/L, respectively. Samples SW02 and SW03 also contained *cis*-1,2-DCE at estimated concentrations of 0.08 E µg/L and 0.32 E µg/L, respectively. PCE, VC, MTBE, benzene, toluene, ethylbenzene, *p,m*-xylene and *o*-xylene were not detected in surface water during this investigation.

Samples SW01 and SW04 were collected from the mouths of the culverts where Pipe Elm Branch and the drainage ditch adjacent to FT03 enter the natural attenuation study area (fig. 4). These sampling locations are upstream of the areas where the plumes from the sources in the natural attenuation study area discharge to the streams. Thus, the low levels (values flagged with an "E," denoting estimated results) of TCE in these samples indicate that the surface water contains TCE from unknown sources farther upstream.

Sample SW03 was collected near the WP14/LF15 source area. The TCE in this sample may be from the WP14/LF15 plume, or from the unknown upstream source. The farthest downstream sample collected during this investigation, sample SW02, contained concentrations of TCE and *cis*-1,2,-DCE that were lower than the concentrations in sample SW03 (table 5). This result is consistent with the mini-piezometer results along this reach of Pipe Elm Branch.

Because the discharge of contaminated ground water to surface water typically is small in relation to the discharge of uncontaminated ground water, dilution from in-stream mixing reduces contaminant concentrations substantially, even under low-flow conditions. As a consequence of dilution, it is possible that plume discharge occurs without an appreciable increase in surface-water VOC concentrations. Volatilization across the stream-atmosphere interface also may remove VOCs from surface water. The rate of volatilization depends on properties of both the compound and the stream (Rathbun, 1998), and cannot be determined with the available information. The TCE concentration in the sample collected in January 2001 (SW03) is below the applicable Delaware Department of Natural Resources and Environmental Control surface-water quality standards for human health. Pipe Elm Branch lies within the Little River Basin, and the fresh water in this basin has designated uses of primary and secondary contact recreation and industrial water supply (Delaware Department of Natural Resources

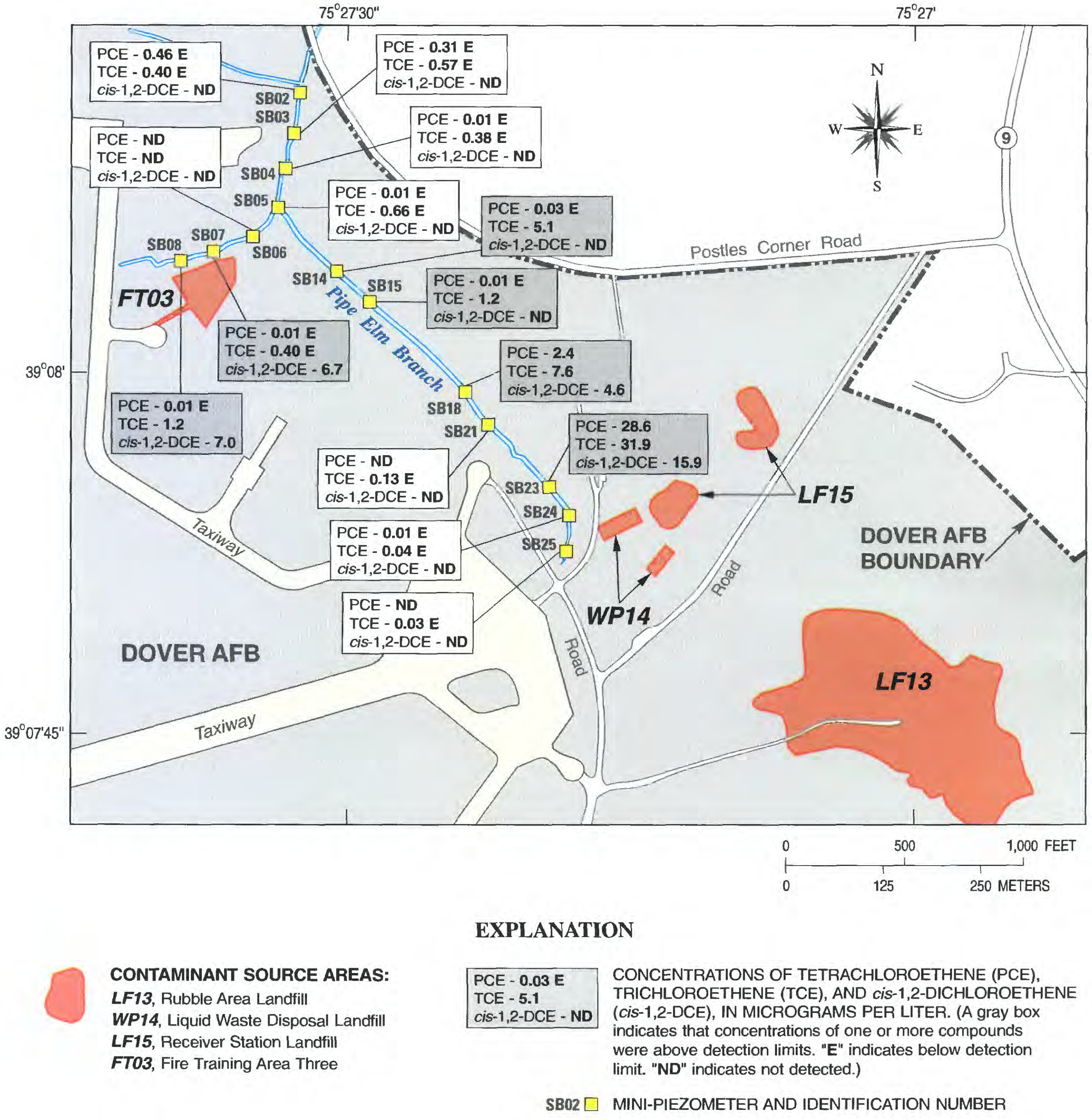


Figure 11. Distribution of tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene in ground-water samples collected from the surficial aquifer underlying Pipe Elm Branch and the drainage ditch adjacent to site FT03 in the natural attenuation study area, Dover Air Force Base, Delaware, January 2001.

and Environmental Control, 1999). The current (2002) standard for TCE in fresh water with these designated uses is 115 µg/L (Delaware Department of Natural Resources and Environmental Control, 1999).

Quality-Control Samples

VOCs were not present above detection limits in any field or source-water blank collected during this investigation (table 6). A majority of blanks did contain PCE and TCE at concentrations from 10 to 100 times lower than the MDLs (concentrations flagged with an "E," denoting

Table 6. *Concentrations of volatile organic compounds in quality-control samples, Dover Air Force Base, Delaware, November 2000–February 2001*

[µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; FDB, field bank. The 2-digit number that follows FDB represents the direct-push depth interval sampled before the tubing was cleaned; **E**, estimated result below detection limit; ND, not detected]

Sample identification number	Sampling date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
Deionized Water Blank	11/30/2000	0.03 **E**	0.02 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP546.FDB16	11/07/2000	.01 **E**	.11 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP547.FDB40	11/07/2000	.03 **E**	.15 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP549.FDB12	11/08/2000	.02 **E**	.15 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP551.FDB24	11/08/2000	.02 **E**	.08 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP552.FDB40	11/14/2000	ND	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP556.FDB40	11/09/2000	.03 **E**	.03 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP558.FDB24	11/13/2000	.05 **E**	.06 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP559.FDB12	11/10/2000	.01 **E**	.05 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP560.FDB45	11/06/2000	.01 **E**	.03 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP560.FDB25	11/06/2000	.12 **E**	.11 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP563.FDB16	11/10/2000	.02 **E**	.07 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP565.FDB44	11/13/2000	.01 **E**	.03 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP569.FDB40	11/28/2000	ND	.02 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP570.FDB32	11/28/2000	ND	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP571.FDB44	11/15/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP572.FDB12	11/13/2000	.04 **E**	.11 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP575.FDB24	11/16/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP578.FDB32*	12/01/2000	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP579.FDB48*	12/01/2000	.02 **E**	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP581.FDB32	11/29/2000	.07 **E**	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP585.FDB32	11/30/2000	.02 **E**	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP586.FDB16	11/30/2000	.01 **E**	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP588.FDB40	11/29/2000	ND	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP589.FDB40	11/27/2000	ND	.01 **E**	ND	ND	ND	ND	ND	ND	ND	ND
GP591.FDB32	11/15/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP592.FDB44	11/16/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 6. *Concentrations of volatile organic compounds in quality-control samples, Dover Air Force Base, Delaware, November 2000–February 2001—Continued*

Sample identification number	Sampling date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
GP593.FDB20	11/16/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP596.FDB44	11/17/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP597.FDB32	11/17/2000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP599.FDB20	11/27/2000	ND	0.01 E	ND	ND	ND	ND	ND	ND	ND	ND
GP600.FDB32	11/27/2000	ND	.01 E	ND	ND	ND	ND	ND	ND	ND	ND
GP602.FDB56*	12/05/2000	0.02 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP603.FDB40	12/08/2000	.05 E	.02 E	ND	ND	ND	ND	ND	ND	ND	ND
GP604.FDB32	12/08/2000	.05 E	.04 E	ND	ND	ND	ND	ND	ND	ND	ND
GP604.FDB16	12/08/2000	.06 E	.04 E	ND	ND	ND	ND	ND	ND	ND	ND
GP605.FDB40*	12/07/2000	.07 E	.11 E	ND	ND	ND	ND	ND	ND	ND	ND
GP608.FDB40	12/06/2000	.02 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP610.FDB16*	12/06/2000	.05 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP611.FDB32*	12/07/2000	.01 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP614.FDB16	12/04/2000	.10 E	.03 E	ND	ND	ND	ND	ND	ND	ND	ND
GP619.FDB32*	12/04/2000	.05 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP622.FDB36*	12/05/2000	.01 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GP624.FDB32	11/09/2000	.27 E	.44 E	ND	ND	ND	ND	ND	ND	ND	ND
GP625.FDB20	11/09/2000	.02 E	.03 E	ND	ND	ND	ND	ND	ND	ND	ND
SB03.FDB	01/11/2001	.02 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB07.FDB	01/11/2001	.01 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB14.FDB	01/12/2001	.02 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB22.FDB	01/24/2001	.02 E	ND	ND	ND	ND	ND	ND	ND	ND	ND
GS045ML.FDB	02/21/2001	.93 E	.41 E	ND	ND	ND	ND	ND	ND	ND	ND

* Field blanks collected with certified organic-free blank water from the U.S. Geological Survey's National Water-Quality Laboratory.

estimated results). These low concentrations may be the result of internal laboratory contamination or the tubing cleaning procedure. Although the source of the contamination is unknown, concentrations in blanks were not high enough to bias the VOC distributions described in this report, and, therefore, do not affect the conclusions drawn from those distributions. Estimated concentrations of PCE and TCE in the range of 0.01 E µg/L to 0.10 E µg/L in ground-water samples should be interpreted with caution, however.

To determine if vertical profiling with an exposed well screen caused cross-contamination between sampling intervals, two locations, GP579 and GP585 (fig. 4), were selected for additional sampling. At these locations, an additional direct-push borehole was drilled within 2 ft of the profiled borehole and sampled. The drill rods were advanced directly from ground surface to the desired sampling intervals (16 ft bgs, or below ground surface, at GP579, and 32 ft bgs at GP585), rather than pulling the exposed screen up from the bottom of the aquifer. Samples GP579.F and GP585.E were collected from these boreholes. In one location, VOCs were not present in the sampled interval (samples GP585.B and GP585.E); in the other location, the concentrations were similar (samples GP579.E and GP579.F) (Appendix 2). The relative percent difference, defined as 100 times the ratio of the difference between values over the average, between concentrations in samples GP579.E and GP579.F is 15 percent for PCE, 4.6 percent for TCE, and 56 percent for *cis*-1,2-DCE. These results, and the spatially consistent concentration distributions within the plumes, indicate that this profiling method did not cause appreciable cross-contamination between sampling intervals.

Rapid sample-collection methodologies appropriate for plume mapping were used in this investigation. Consequently, a majority of the samples collected with the direct-push drill rig contained substantial turbidity and were collected under high suction, which potentially could bias the results through adsorption to particulates and degassing, respectively. To determine if there was observable bias in the data collected with the direct-push drill rig, VOC concentrations from ground-water samples collected with the direct-push drill rig were compared to VOC concentrations from nearby monitor wells that had been sampled within the previous year (2000). Samples from direct-push boreholes GP555 and GP625 (Appendix 1) were compared with September 2000 samples from monitor well cluster DM108. This cluster consists of monitor wells DM108S and DM108D, with 10-ft well screens (screened intervals are from 4.7 ft sl to –5.2 ft sl and from –11.3 ft sl to –21.3 ft sl for wells DM108S and DM108D, respectively). Boreholes GP555 and GP625 are 69 ft and 47 ft, respectively, from monitor well cluster DM108, but all of these locations are about the same distance (1,000 ft) from the source (fig. 4). Vertically averaged concentrations of the chlorinated solvents varied by a factor of approximately ten or less at these three locations (table 7). Direct-push sample GP561.B also was compared with the March 2000 sample from monitor well GSCP5M. Borehole GP561 is 40 ft from monitor well GSCP5M (fig. 4). The altitudes and lengths of the screened intervals used in this comparison are similar; the screened intervals for GP561.B and GSCP5M are from –6 ft sl to –10 ft sl and from –8.3 ft sl to –11.3 ft sl, respectively. Concentrations of the chlorinated solvents varied by a factor of approximately two at these two locations (table 7). Although

Table 7. *Comparison of tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene concentrations in samples from monitor wells and direct-push boreholes, Dover Air Force Base, Delaware, March–November 2000*

[µg/L, micrograms per liter; PCE, tetrachloroethane; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; E, estimated result below detection limit; ND, not detected. Values for GP555, GP625, and DM108 are vertically averaged concentrations from multiple samples. Values for GP561.B and GSCP5M are concentrations from individual samples.]

Well or direct-push borehole identification number	Sampling date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	VC (µg/L)
GP625	11/09/2000	8.1	14.7	2.1	0.00
GP555	11/08/2000	23.9	50.8	8.7	.00
DM108	10/02/2000–10/03/2000	37.5	118	19.0	.88
GP561.B	11/06/2000	0.12 E	15.6	10.7	ND
GSCP5M	03/06/2000	ND	7.2	4.5	.85 E

the comparisons shown in table 7 are not exact because screen lengths differ, and the samples are separated both spatially and temporally, the reasonable agreement between the direct-push and conventional monitor well-sample results indicates that the direct-push samples are representative of VOC concentrations in the aquifer.

Assessment of Volatile Organic Compound Mass Loss at WP14/LF15

An assessment of VOC mass loss in the plume migrating from site WP14/LF15 was made by calculating the mass flux across two plume transects, and by comparing concentration ratios and mole fractions of selected chlorinated solvents on the plume centerline. Because the plume from WP14/LF15 is relatively large (as compared to the plumes from the other sites) and migrating toward the DAFB boundary, determining the amount of mass loss is particularly important at this site. Intrinsic biodegradation probably is the most important mass-loss reaction in the natural attenuation study area (Barbaro, 2002, p. 12).

Mass Flux

The amount of mass lost (or gained) between sections B–B′ and C–C′ (fig. 4) was determined by comparing the calculated mass flux across each section. Sections B–B′ and C–C′ are approximately 300 ft and 1,100 ft downgradient of the source, respectively. Mass flux is defined in this report as the amount of contaminant mass migrating through a cross section of the aquifer perpendicular to the ground-water flow direction (Feenstra and others, 1996). The mass-loss calculation is most accurate when the plume has been mapped in three dimensions, and the concentrations in the source area do not vary over time.

Calculations of mass flux (M_d) for PCE, TCE, and *cis*-1,2-DCE were made at sections B–B′ and C–C′ using the method described by Einarson and Mackay (2001). To calculate the mass flux, the concentrations in direct-push samples were assigned to rectangular cells constructed around the direct-push screened intervals. This approach is shown in figure 12 with TCE concentrations on section B–B′. The lateral cell boundaries were positioned at the midpoints between the direct-push boreholes. The upper and lower cell boundaries were positioned at the midpoints between the direct-push screened intervals. For the peripheral direct-push sampling intervals in a given section, cell boundaries were located by assuming that the cells were centered on the screened interval (that is, symmetrical distances were used to locate the outer boundaries of the cells) (fig. 12). The mass flux (M_{di}) across an individual cell i was calculated by multiplying the concentration and the area of the cell by the specific discharge, and is given as

$$M_{di} = 0.0103qC_iA_i \ ,$$

where

M_{di} = the mass flux across cell i [MT^{-1}],
q = the specific discharge [LT^{-1}],
C_i = the concentration in cell i [ML^{-3}],
A_i = area of cell i [L^2], and
0.0103 = a conversion factor to convert the specific discharge and concentrations to obtain mass flux values in g/yr.

The ground-water flow rate was assumed to be uniform spatially in the vicinity of the WP14/LF15 plume. Thus, the average specific discharge of 0.1 ft/d calculated by Barbaro (2002, p. 13) was used for all cells on sections B–B′ and C–C′. The total mass flux (M_d) in g/yr (grams per year) was obtained by summing the individual M_{di} flux values for all n cells on a transect, and is given as

$$M_d = \sum_{i=1}^{n} M_{di} \ ,$$

where

M_d = the total mass flux across a transect [MT^{-1}].

The mass fluxes of PCE and TCE did not change substantially between sections B–B′ and C–C′ (table 8). In contrast, the mass flux of *cis*-1,2-DCE decreased between sections (table 8). Based on the average ground-water velocity of 0.4 ft/d, the traveltime between the sections is approximately 5 years. If the plume is depleted in electron acceptors and sufficient fermentative organic carbon is present, reductive dechlorination likely will continue downgradient of the source (Wiedemeier and others, 1999, p. 270), and substantial mass loss from intrinsic biodegradation could occur in a 5-year period. The similarity in mass-flux values indicates that PCE and TCE mass loss in the plume between sections B–B′ and C–C′ was negligible, however. Although concentrations of DO generally were low (less than 1 mg/L) throughout the surficial aquifer (Appendix 1), geochemical conditions may not have been suitable for reductive dechlorination downgradient of the source in this plume. In contrast, the mass-flux results indicate that the *cis*-1,2-DCE mass declined by 65 percent between these sections. The removal mechanism cannot be determined from the available information; however, because there are no common abiotic reactions that affect *cis*-1,2-DCE (Barbaro, 2002, p. 20), the most likely reaction is biodegradation. Studies have shown that *cis*-1,2-DCE biodegrades under both aerobic and iron-reducing conditions (Bradley, 1997; Bradley and Chapelle, 1998).

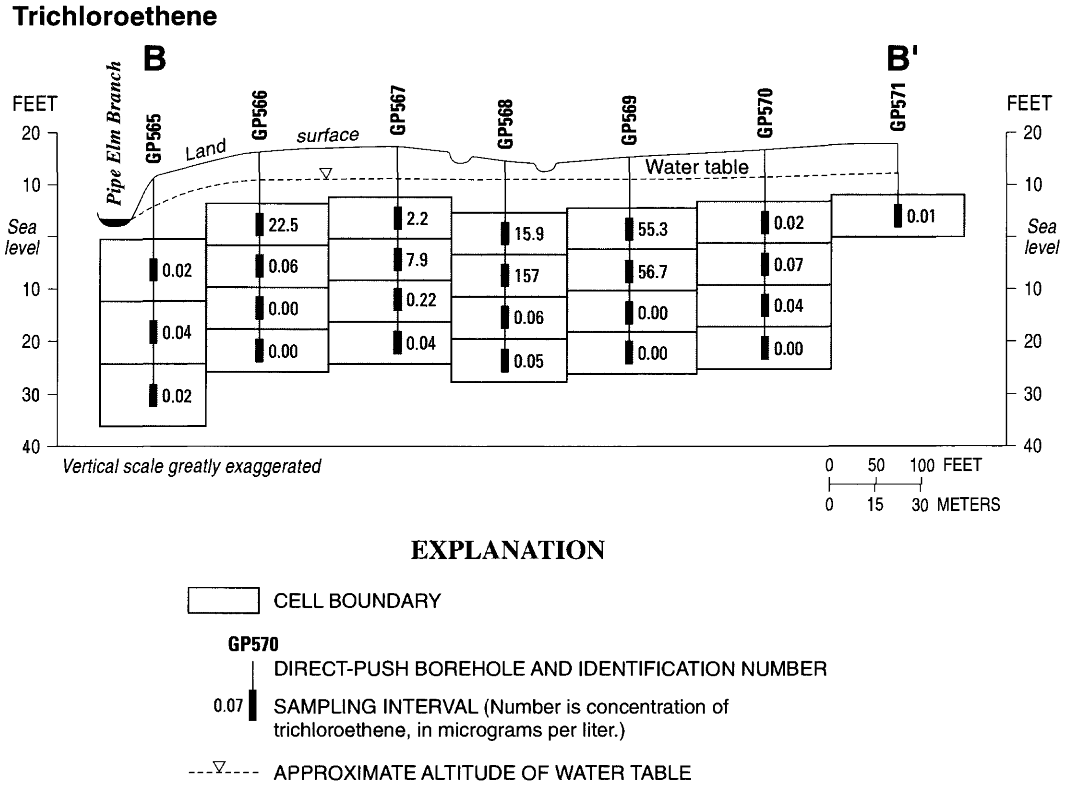


Figure 12. Cell boundaries and concentrations used to calculate the mass flux of trichloroethene across section B-B', Dover Air Force Base, Delaware.

Table 8. *Mass fluxes of tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene across sections B–B′ and C–C′, Dover Air Force Base, Delaware, November–December 2000*

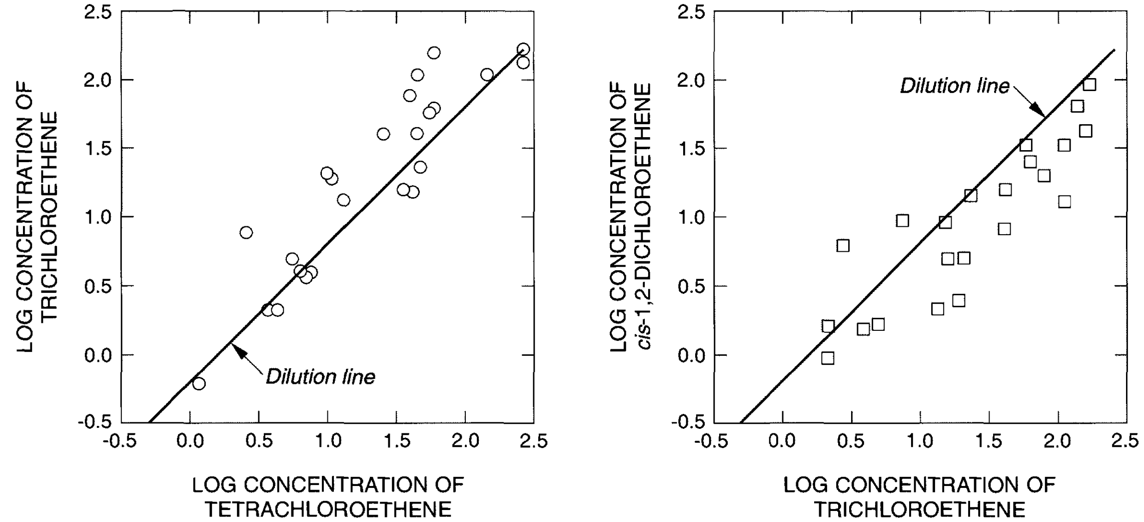
[g/yr, grams per year; PCE, tetrachloroethane; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; traces of sections shown in figure 4]

Compound	Upgradient section B–B′ (g/yr)	Downgradient section C–C′ (g/yr)
PCE	193	196
TCE	350	379
cis-1,2-DCE	195	69

Concentration Ratios

Concentration ratios of selected pairs of VOCs from wells along section D–D′ (fig. 4) were used to determine whether the decreasing concentrations of VOCs downgradient of the source were due solely to dilution from dispersive mixing, or to both dilution and reaction. If the concentration ratio of solute A to solute B is constant, then $\log A = 1.0 \log B + \log \text{constant}$. When the logarithms of the concentrations of A and B plot on the dilution line (slope of 1.0 relative to the concentration ratio in the source area), the decrease in solute concentrations is from dilution only. If the concentrations deviate from a slope of 1.0, transformation reactions are affecting VOC concentrations downgradient of the source.

Concentration ratios of PCE and TCE, and TCE and *cis*-1,2-DCE from samples collected along section D–D′ are shown in figure 13. Samples with concentrations below detection limits (values flagged with an "E", denoting estimated results) and non-detections are not shown in the figure. The dilution line in each graph has a slope of 1.0 relative to concentration ratios in the source area. Most of the values in the graphs of log PCE–log TCE and



NOTE: Dilution lines have slopes of 1.0 relative to the concentration ratios in the source area.

Figure 13. Logarithms of concentrations of selected pairs of volatile organic compounds in ground-water samples collected along section D-D' at site WP14/LF15, Dover Air Force Base, Delaware, November 2000 - February 2001. *(Trace of section shown in figure 4.)*

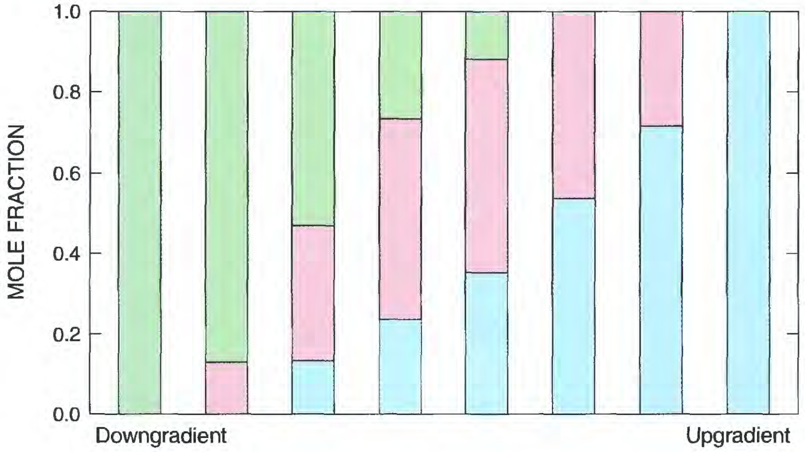
log TCE–log *cis*-1,2-DCE are on or near the dilution line. There may be minor PCE loss relative to TCE (possibly TCE production) shown in the first graph, and more pronounced *cis*-1,2-DCE loss relative to TCE shown in the second graph. Based on the relations shown in these graphs, PCE and TCE are not undergoing substantial chemical or biological transformation downgradient of the source. Some *cis*-1,2-DCE removal appears to be occurring, however. These results are qualitatively consistent with the mass-flux calculations.

Mole Fractions

When reductive dechlorination occurs continuously along a flow path, the proportion of parent compounds (PCE and TCE) progressively decreases and the proportion of daughter compounds (*cis*-1,2-DCE and VC) progressively increases with distance from the source (fig. 14a) (Wiedemeier and others, 1999, p. 271). Because reductive dechlorination produces one mole of product for every mole of reactant, the total number of moles remains constant; consequently, the change in mole fractions along a plume centerline can be a useful indicator of the occurrence of reductive dechlorination reactions. Because proportions are used, this approach is not greatly affected by concentration fluctuations in the source area. Preferential removal of a given compound by a different reaction mechanism, such as oxidation, will affect the mole fractions, however. As indicated by the mass flux calculations, the biodegradation of *cis*-1,2-DCE is one such reaction that appears to occur in the WP14/LF15 plume. In the absence of continuous reductive dechlorination of PCE and TCE, the occurrence of *cis*-1,2-DCE biodegradation should cause the mole fractions of PCE and TCE to increase along the flow path.

To determine whether reductive dechlorination continues to occur downgradient of the source area, mole fractions of PCE, TCE, and *cis*-1,2-DCE were calculated from samples along section D–D′ (fig. 4). Samples from the core of the plume (samples with the highest concentrations in the vertical profile) were assumed to be representative of water quality along a single flow path, and, therefore, form a representative mole-fraction trend. To calculate the mole fractions, concentrations of PCE, TCE, and *cis*-1,2-DCE in µg/L were first converted to molar concentrations. Mole fractions in each sample then were calculated as a percentage of the total moles of PCE, TCE and *cis*-1,2-DCE. The mole fractions of these compounds in samples from wells along section D–D′ are shown in figure 14b. Variability in mole fractions is evident, which may reflect temporal variability in source proportions that propagated downgradient. In contrast to the hypothetical case of continuous reductive dechlorination of the parent compounds accompanied by an accumulation of *cis*-1,2-DCE (fig. 14a), a clear indication of decreasing mole fractions of parent compounds is not evident along section D–D′ (fig. 14b). The mole-fraction results indicate, therefore, that substantial PCE and TCE removal does not occur downgradient of the source area in this plume. This conclusion is consistent with the findings from the concentration-ratio and mass-flux analyses.

(a) Hypothetical Continuous Reductive Dechlorination



(b) Observed Data On Section D-D'

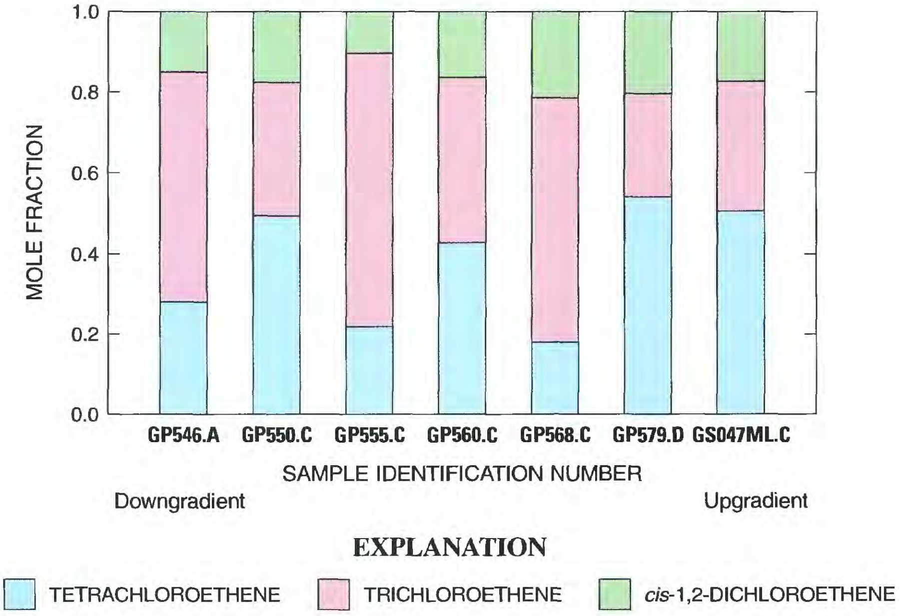


Figure 14. Mole fractions of tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene for **(a)** a hypothetical case where reductive dechlorination of tetrachloroethene occurs continuously along a flow path, and **(b)** the observed case on section D-D' at site WP14/LF15, Dover Air Force Base, Delaware, November 2000 - February 2001. *(Trace of section shown in figure 4.)*

Summary and Conclusions

Ground-water and surface-water sampling was conducted in the natural attenuation study area in the East Management Unit of Dover Air Force Base, Delaware in the vicinity of four sites contaminated with chlorinated solvents and fuel hydrocarbons—Fire Training Area Three, the Rubble Area Landfill, the Receiver Station Landfill, and the Liquid Waste Disposal Landfill. The investigation was conducted by the U.S. Geological Survey, in cooperation with the U.S. Air Force, to address issues that were identified as needing further study in a previous U.S. Geological Survey report on the effectiveness of natural attenuation. The specific objectives of this study were to (1) determine the areal and vertical extent of the contaminant plumes and source areas, (2) determine volatile organic compound concentrations in the ground-water discharge areas and in surface water under base-flow conditions, (3) evaluate the potential for off-site migration of the mapped plumes, and (4) estimate the amount of mass loss downgradient of the Liquid Waste Disposal and Receiver Station Landfills.

The sample-collection methods used in this study primarily were "profiling" methods that do not include the installation of permanent monitoring instrumentation. A Geoprobe direct-push drill rig was used to determine the three-dimensional distribution of volatile organic compounds in the surficial aquifer. To supplement the direct-push data, two previously installed multilevel piezometers near the Liquid Waste Disposal and Receiver Station Landfills also were sampled. To collect samples in ground-water discharge areas, a hand-driven mini-piezometer was used. Surface-water samples were collected from four locations along Pipe Elm Branch and the drainage ditch adjacent to Fire Training Area Three. The interpretations in this report are based on a total of 319 ground-water samples and four surface-water samples collected from November 2000 through February 2001. Tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene are the most prevalent volatile organic compounds in the surficial aquifer underlying the natural attenuation study area. Concentrations above U.S. Environmental Protection Agency maximum contaminant levels were found most frequently in samples collected near the source areas. Methyl *tert*-butyl ether, benzene, toluene, ethylbenzene, *m,p*-xylene, and *o*-xylene were detected in a smaller number of samples, and vinyl chloride was not detected in any sample.

The contaminant plume migrating from Fire Training Area Three has an approximate length of 500 feet. The plume consists predominantly of *cis*-1,2-dichloroethene, a daughter product, indicating that extensive reductive dechlorination of tetrachloroethene and trichloroethene has occurred. The plume migrating from the Rubble Area Landfill has an approximate length of 800 feet, and also is composed predominantly of *cis*-1,2-dichloroethene. With an approximate length of 2,200 feet, the plume migrating from the Receiver Station and Liquid Waste Disposal Landfills is the largest of the three plumes in the East Management Unit. The parent compounds tetrachloroethene and trichloroethene as well as *cis*-1,2-dichloroethene are present downgradient of the source at this site. Vertical water-quality profiles indicate that volatile organic compounds are present mainly in the upper part of the surficial aquifer, which is 30–60 feet thick in the natural attenuation study area. Plumes of fuel hydrocarbon compounds were not detected in the natural attenuation study area.

Volatile organic compounds were present at concentrations above detection limits in 6 of 14 samples collected from the aquifer underlying the streambed of Pipe Elm Branch and the drainage ditch adjacent to Fire Training Area Three. These detections indicate that the plumes migrating from Fire Training Area Three and the Receiver Station and Liquid Waste Disposal Landfills are reaching these ground-water discharge areas. The fate of the volatile organic compounds between the mini-piezometer sampling points and the streambed was not determined, however. In contrast, sampling results indicate that the plume from the Rubble Area Landfill does not reach these discharge areas. Trichloroethene was present above detection limits in one of four surface-water samples collected from Pipe Elm Branch and the drainage ditch adjacent to Fire Training Area Three. The trichloroethene concentration was below applicable Delaware Department of Natural Resources and Environmental Control surface-water quality standards for human health.

The plan-view maps of the plume migrating from the Receiver Station and Liquid Waste Disposal Landfills indicate that tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene possibly migrate off Dover Air Force Base property approximately 1,500 feet downgradient of the source area. In this area, the direction of plume migration is roughly parallel to the Dover Air Force Base boundary, which probably restricts the extent of off-site migration. Sampling results indicate that off-site migration of the other two plumes in the East Management Unit is unlikely.

Because the plume migrating from the Receiver Station and Liquid Waste Disposal Landfill sites is migrating toward the Dover Air Force Base boundary, an assessment of the occurrence and amount of chlorinated-solvent mass loss downgradient of the source areas was made. The assessment consisted of calculating mass fluxes across two transects perpendicular to the ground-water flow direction, and comparing the concentration ratios and mole fractions of selected volatile organic compounds in samples from boreholes on the plume centerline. The results of these analyses indicated that tetrachloroethene and trichloroethene mass loss downgradient of the source is negligible. *Cis*-1,2-dichloroethene, however, appears to biodegrade by an unidentified reaction in the plume. Additional information on geochemical conditions and potential reaction mechanisms would be useful in determining the extent of intrinsic biodegradation of these compounds.

The ground- and surface-water samples collected in this study led to an improved understanding of the areal and vertical extent of the volatile organic compound plumes, the fate of volatile organic compounds in the ground-water discharge areas, and the amount of intrinsic biodegradation downgradient of the Receiver Station and Liquid Waste Disposal Landfills. The information presented in this report will be useful in determining the locations of permanent monitoring instrumentation, and improving the Long-Term Monitoring program in the East Management Unit of Dover Air Force Base. Further data collection to (1) determine the boundaries of the plumes in localized areas, (2) determine the effectiveness of the surface-water bodies as ground-water and contaminant discharge boundaries, (3) monitor the effect of contaminant discharge on surface-water quality, and (4) better understand the geochemical conditions and reaction mechanisms in streambed sediments and in the surficial aquifer downgradient of the Receiver Station and Liquid Waste Disposal Landfills still may be needed to conduct future evaluations of the effectiveness of natural attenuation at these sites.

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Appendixes 1 and 2 Follow

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*

[ft, feet; bgs, below ground surface; sl, sea level; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; –, no data]

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP545			4.8						
	GP545.D	11/07/2000		12	-3	-7	13.9	139	0.10
	GP545.C	11/07/2000		20	-11	-15	13.8	145	0.10
	GP545.B	11/07/2000		32	-23	-27	13.7	126	0.10
	GP545.A	11/07/2000		40	-31	-35	14.0	130	0.16
GP546			8.9						
	GP546.D	11/07/2000		16	-3	-7	14.5	225	0.08
	GP546.C	11/07/2000		24	-11	-15	13.9	156	2.1
	GP546.B	11/07/2000		32	-19	-23	13.5	133	0.50
	GP546.A	11/07/2000		40	-27	-31	13.5	112	0.34
GP547			16.1						
	GP 547.D	11/07/2000		16	4	0	13.8	307	0.33
	GP 547.C	11/07/2000		24	-4	-8	13.4	226	0.14
	GP 547.B	11/07/2000		32	-12	-16	13.1	115	0.31
	GP 547.A	11/07/2000		40	-20	-24	12.9	94	0.73
GP549			7.1						
	GP 549.D	11/08/2000		12	-1	-5	14.6	78	2.9
	GP 549.C	11/08/2000		20	-9	-13	14.1	118	0.21
	GP 549.B	11/08/2000		28	-17	-21	13.9	121	0.37
	GP 549.A	11/08/2000		36	-25	-29	14.0	95	0.16
GP550			11.4						
	GP550.D	11/08/2000		16	-1	-5	14.5	82	0.20
	GP550.C	11/08/2000		24	-9	-13	14.3	71	0.15
	GP550.B	11/08/2000		32	-17	-21	15.3	117	3.1
	GP550.A	11/08/2000		40	-25	-29	15.3	114	0.40

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP551			17.7						
	GP551.D	11/08/2000		16	6	2	14.8	200	1.0
	GP551.C	11/08/2000		24	-2	-6	13.9	199	0.56
	GP551.B	11/08/2000		32	-10	-14	13.6	172	0.83
	GP551.A	11/08/2000		40	-18	-22	13.3	162	1.6
GP552			15.1						
	GP552.D	11/14/2000		16	3	-1	13.6	168	0.22
	GP552.C	11/14/2000		24	-5	-9	13.3	125	0.19
	GP552.B	11/14/2000		32	-13	-17	13.0	92	1.4
	GP552.A	11/14/2000		40	-21	-25	12.6	97	0.92
GP555			13.5						
	GP555.D	11/08/2000		16	2	-2	14.7	91	2.7
	GP555.C	11/08/2000		24	-6	-10	13.8	97	0.71
	GP555.B	11/08/2000		32	-14	-18	13.6	86	0.54
	GP555.A	11/08/2000		40	-22	-26	14.6	103	0.33
GP556			18.2						
	GP556.D	11/09/2000		16	6	2	15.2	189	–
	GP556.C	11/09/2000		24	-2	-6	14.5	162	0.25
	GP556.B	11/09/2000		32	-10	-14	13.9	85	1.0
	GP556.A	11/09/2000		40	-18	-22	14.3	89	0.38
GP557			18.0						
	GP557.D	11/14/2000		16	6	2	14.4	369	2.6
	GP557.C	11/14/2000		24	-2	-6	13.7	149	1.3
	GP557.B	11/14/2000		32	-10	-14	13.6	96	0.69
	GP557.A	11/14/2000		40	-18	-22	12.9	118	0.58

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP558			13.1						
	GP558.D	11/13/2000		12	5	1	16.1	122	0.11
	GP558.C	11/13/2000		24	-7	-11	14.8	116	0.20
	GP558.B	11/13/2000		32	-15	-19	14.7	121	0.63
	GP558.A	11/13/2000		40	-23	-27	13.6	115	–
GP559			6.5						
	GP559.D	11/10/2000		12	-2	-6	15.2	109	0.10
	GP559.C	11/10/2000		24	-14	-18	14.8	95	0.15
	GP559.B	11/10/2000		32	-22	-26	14.9	119	0.76
	GP559.A	11/10/2000		40	-30	-34	15.7	92	1.5
GP560			15.7						
	GP560.D	11/06/2000		15	5	1	15.0	117	0.38
	GP560.C	11/06/2000		25	-5	-9	14.8	117	0.33
	GP560.B	11/06/2000		35	-15	-19	15.4	84	0.60
	GP560.A	11/06/2000		45	-25	-29	20.4	127	–
GP561			18.1						
	GP561.D	11/06/2000		12	10	6	13.4	79	1.8
	GP561.C	11/06/2000		20	2	-2	14.2	109	1.0
	GP561.B	11/06/2000		28	-6	-10	13.8	142	0.10
	GP561.A	11/06/2000		36	-14	-18	14.3	186	0.06
GP562			19.9						
	GP562.D	11/09/2000		16	8	4	15.8	135	0.08
	GP562.C	11/09/2000		24	0	-4	15.2	183	0.09
	GP562.B	11/09/2000		32	-8	-12	14.9	170	0.12
	GP562.A	11/09/2000		44	-20	-24	15.2	135	1.3

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP563			16.0						
	GP563.C	11/10/2000		16	4	0	16.6	61	1.3
	GP563.B	11/10/2000		24	-4	-8	16.1	90	0.11
	GP563.A	11/10/2000		36	-16	-20	–	–	–
GP564			14.5						
	GP564.C	11/15/2000		16	2	-2	13.5	106	2.2
	GP564.B	11/15/2000		24	-6	-10	13.4	81	0.27
	GP564.A	11/15/2000		36	-18	-22	13.3	120	0.18
GP565			11.9						
	GP565.C	11/13/2000		20	-4	-8	15.1	166	–
	GP565.B	11/13/2000		32	-16	-20	15.1	200	0.11
	GP565.A	11/13/2000		44	-28	-32	15.3	206	0.11
GP566			16.2						
	GP566.D	11/29/2000		16	4	0	15.9	115	0.96
	GP566.C	11/29/2000		24	-4	-8	15.0	91	0.36
	GP566.B	11/29/2000		32	-12	-16	14.1	111	0.45
	GP566.A	11/29/2000		40	-20	-24	12.8	110	1.2
GP567			17.8						
	GP567.D	11/28/2000		16	6	2	14.4	105	0.64
	GP567.C	11/28/2000		24	-2	-6	14.7	134	0.28
	GP567.B	11/28/2000		32	-10	-14	14.8	122	0.62
	GP567.A	11/28/2000		40	-18	-22	–	–	–
GP568			14.4						
	GP568.D	11/28/2000		16	2	-2	15.7	130	1.8
	GP568.C	11/28/2000		24	- 6	-10	15.3	145	0.29
	GP568.B	11/28/2000		32	-14	-18	14.9	85	0.18
	GP568.A	11/28/2000		40	-22	-26	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP569			15.1						
	GP569.D	11/28/2000		16	3	-1	15.6	132	0.41
	GP569.C	11/28/2000		24	-5	-9	15.0	140	0.35
	GP569.B	11/28/2000		32	-13	-17	14.8	154	0.24
	GP569.A	11/28/2000		40	-21	-25	14.9	138	1.5
GP570			16.8						
	GP570.D	11/28/2000		16	5	1	15.5	134	0.74
	GP570.C	11/28/2000		24	-3	-7	14.7	129	0.37
	GP570.B	11/28/2000		32	-11	-15	14.6	133	0.53
	GP570.A	11/28/2000		40	-19	-23	–	–	–
GP571			17.9						
	GP571.A	11/15/2000		16	6	2	15.0	148	1.2
GP572			13.1						
	GP572.D	11/13/2000		12	5	1	16.0	67	1.1
	GP572.C	11/13/2000		20	-3	-7	17.2	108	0.24
	GP572.B	11/13/2000		32	-15	-19	15.5	110	0.38
	GP572.A	11/13/2000		40	-23	-27	15.6	116	1.3
GP573			13.3						
	GP573.D	11/13/2000		12	5	1	16.2	87	0.40
	GP573.C	11/13/2000		20	-3	-7	16.0	114	0.58
	GP573.B	11/13/2000		32	-15	-19	15.2	135	0.20
	GP573.A	11/13/2000		40	-23	-27	14.9	172	0.30
GP574			14.7						
	GP574.D	11/13/2000		12	7	3	15.2	170	0.17
	GP574.C	11/13/2000		20	-1	-5	15.2	145	0.21
	GP574.B	11/13/2000		32	-13	-17	14.6	136	0.13
	GP574.A	11/13/2000		44	-25	-29	14.3	144	0.31

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP575			19.5						
	GP575.D	11/16/2000		16	8	4	13.5	214	–
	GP575.C	11/16/2000		24	0	-4	13.9	143	0.63
	GP575.B	11/16/2000		32	-8	-12	13.9	116	0.33
	GP575.A	11/16/2000		40	-16	-20	12.4	125	0.31
GP576			19.0						
	GP576.D	11/30/2000		16	7	3	14.3	190	0.27
	GP576.C	11/30/2000		24	-1	-5	13.1	126	0.40
	GP576.B	11/30/2000		32	-9	-13	12.8	143	0.50
	GP576.A	11/30/2000		40	-17	-21	11.3	117	1.1
GP577			20.1						
	GP577.E	12/01/2000		16	8	4	–	–	–
	GP577.D	12/01/2000		24	0	-4	11.9	103	1.2
	GP577.C	12/01/2000		32	-8	-12	11.5	118	1.2
	GP577.B	12/01/2000		40	-16	-20	11.7	103	0.80
	GP577.A	12/01/2000		48	-24	-28	10.9	107	3.7
GP578			18.1						
	GP578.E	12/01/2000		16	6	2	13.5	142	–
	GP578.D	12/01/2000		24	-2	-6	13.2	126	0.35
	GP578.C	12/01/2000		32	-10	-14	12.6	153	1.4
	GP578.B	12/01/2000		40	-18	-22	12.5	132	1.8
	GP578.A	12/01/2000		48	-26	-30	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP579			15.8						
	GP579.E	12/01/2000		16	4	0	14.1	133	2.4
	GP579.D	12/01/2000		24	-4	-8	12.9	110	0.62
	GP579.C	12/01/2000		32	-12	-16	13.2	99	0.25
	GP579.B	12/01/2000		40	-20	-24	12.3	95	1.4
	GP579.A	12/01/2000		48	-28	-32	12.5	93	2.6
	GP579.F	12/01/2000		16	4	0	12.5	140	3.6
GP580			17.3						
	GP580.D	11/29/2000		16	5	1	15.7	153	2.0
	GP580.C	11/29/2000		24	-3	-7	16.8	169	0.16
	GP580.B	11/29/2000		32	-11	-15	15.1	191	0.18
	GP580.A	11/29/2000		40	-19	-23	15.2	167	0.60
GP581			14.8						
	GP581.D	11/29/2000		16	3	-1	16.2	171	0.29
	GP581.C	11/29/2000		24	-5	-9	–	–	–
	GP581.B	11/29/2000		32	-13	-17	14.7	150	0.94
	GP581.A	11/29/2000		40	-21	-25	–	–	–
GP582			16.6						
	GP582.A	11/15/2000		16	5	1	17.0	100	0.23
GP583			20.2						
	GP583.D	11/16/2000		16	8	4	15.0	326	0.38
	GP583.C	11/16/2000		24	0	-4	13.9	192	–
	GP583.B	11/16/2000		32	-8	-12	13.7	139	0.20
	GP583.A	11/16/2000		44	-20	-24	13.6	113	0.28

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP584			20.7						
	GP584.D	11/30/2000		24	1	-3	12.4	168	1.1
	GP584.C	11/30/2000		32	-7	-11	12.5	180	0.57
	GP584.B	11/30/2000		40	-15	-19	13.3	139	0.32
	GP584.A	11/30/2000		48	-23	-27	–	–	–
GP585			20.4						
	GP585.D	11/30/2000		16	8	4	–	–	–
	GP585.C	11/30/2000		24	0	-4	–	–	–
	GP585.B	11/30/2000		32	-8	-12	12.8	116	0.92
	GP585.A	11/30/2000		40	-16	-20	–	–	–
	GP585.E	11/30/2000		32	-8	-12	–	–	–
GP586			19.0						
	GP586.C	11/30/2000		16	7	3	–	–	–
	GP586.B	11/30/2000		24	-1	-5	–	–	–
	GP586.A	11/30/2000		32	-9	-13	11.2	139	–
GP587			17.8						
	GP587.D	11/29/2000		16	6	2	13.8	141	–
	GP587.C	11/29/2000		24	-2	-6	13.6	89	0.56
	GP587.B	11/29/2000		32	-10	-14	13.3	107	0.27
	GP587.A	11/29/2000		40	-18	-22	12.8	116	0.72
GP588			17.8						
	GP588.D	11/29/2000		16	6	2	15.4	160	0.32
	GP588.C	11/29/2000		24	-2	-6	14.7	182	–
	GP588.B	11/29/2000		32	-10	-14	13.5	218	–
	GP588.A	11/29/2000		40	-18	-22	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP589			17.3						
	GP589.D	11/27/2000		16	5	1	14.9	146	0.20
	GP589.C	11/27/2000		24	-3	-7	14.6	189	0.21
	GP589.B	11/27/2000		32	-11	-15	14.2	137	0.21
	GP589.A	11/27/2000		40	-19	-23	–	–	–
GP590			17.4						
	GP590.D	11/27/2000		16	5	1	16.3	89	2.1
	GP590.C	11/27/2000		24	-3	-7	15.5	153	0.60
	GP590.B	11/27/2000		32	-11	-15	15.5	141	0.29
	GP590.A	11/27/2000		40	-19	-23	15.8	172	0.51
GP591			16.4						
	GP591.B	11/15/2000		32	-12	-16	15.3	193	0.20
	GP591.A	11/15/2000		40	-20	-24	–	–	–
GP592			22.1						
	GP592.D	11/16/2000		16	10	6	14.7	317	0.24
	GP592.C	11/16/2000		24	2	-2	14.2	127	0.75
	GP592.B	11/16/2000		32	-6	-10	14.1	140	1.1
	GP592.A	11/16/2000		44	-18	-22	11.7	138	–
GP593			22.0						
	GP593.D	11/16/2000		16	10	6	13.7	103	–
	GP593.C	11/16/2000		24	2	-2	13.7	78	3.8
	GP593.B	11/16/2000		32	-6	-10	12.8	134	0.33
	GP593.A	11/16/2000		40	-14	-18	10.7	105	--
GP594			20.4						
	GP594.D	11/16/2000		16	8	4	14.0	126	–
	GP594.C	11/16/2000		24	0	-4	13.6	155	0.30
	GP594.B	11/16/2000		32	-8	-12	13.5	82	0.43
	GP594.A	11/16/2000		44	-20	-24	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP595			18.1						
	GP595.D	11/17/2000		16	6	2	15.2	93	0.40
	GP595.C	11/17/2000		24	-2	-6	13.8	125	0.19
	GP595.B	11/17/2000		32	-10	-14	13.7	93	0.17
	GP595.A	11/17/2000		44	-22	-26	13.2	93	0.37
GP596			18.1						
	GP596.D	11/17/2000		16	6	2	16.4	175	–
	GP596.C	11/17/2000		24	-2	-6	15.5	155	0.19
	GP596.B	11/17/2000		32	-10	-14	14.9	122	0.30
	GP596.A	11/17/2000		40	-18	-22	14.6	126	0.46
GP597			19.1						
	GP597.D	11/17/2000		16	7	3	16.7	198	0.16
	GP597.C	11/17/2000		24	-1	-5	15.9	135	0.17
	GP597.B	11/17/2000		32	-9	-13	15.5	127	0.24
	GP597.A	11/17/2000		40	-17	-21	15.1	118	0.18
GP598			18.7						
	GP598.B	11/17/2000		32	-9	-13	14.6	145	0.35
	GP598.A	11/17/2000		40	-17	-21	16.0	137	0.18
GP599			18.0						
	GP599.D	11/27/2000		16	6	2	16.2	116	0.20
	GP599.C	11/27/2000		24	-2	-6	15.4	129	0.34
	GP599.B	11/27/2000		32	-10	-14	15.2	174	0.64
	GP599.A	11/27/2000		40	-18	-22	–	–	–
GP600			16.3						
	GP600.D	11/27/2000		14	6	2	16.0	123	0.18
	GP600.C	11/27/2000		20	0	-4	17.2	122	0.23
	GP600.B	11/27/2000		32	-12	-16	16.2	205	0.61
	GP600.A	11/27/2000		40	-20	-24	15.6	189	1.8

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP601			16.3						
	GP601.C	11/15/2000		16	4	0	–	–	–
	GP601.B	11/15/2000		24	-4	-8	–	–	–
	GP601.A	11/15/2000		32	-12	-16	13.9	240	0.30
GP602			21.4						
	GP602.F	12/05/2000		16	9	5	12.6	239	0.50
	GP602.E	12/05/2000		24	1	-3	12.4	208	0.24
	GP602.D	12/05/2000		32	-7	-11	12.2	194	0.40
	GP602.C	12/05/2000		40	-15	-19	11.5	233	0.33
	GP602.B	12/05/2000		48	-23	-27	10.7	150	–
	GP602.A	12/05/2000		56	-31	-35	–	–	–
GP603			21.2						
	GP603.D	12/08/2000		16	9	5	13.4	194	0.35
	GP603.C	12/08/2000		24	1	-3	12.6	230	0.41
	GP603.B	12/08/2000		32	-7	-11	11.9	197	0.40
	GP603.A	12/08/2000		40	-15	-19	–	–	–
GP604			21.6						
	GP604.D	12/08/2000		16	10	6	13.0	262	0.29
	GP604.C	12/08/2000		24	2	-2	11.9	288	0.42
	GP604.B	12/08/2000		32	-6	-10	11.3	217	0.50
	GP604.A	12/08/2000		40	-14	-18	–	–	–
GP605			21.8						
	GP605.C	12/07/2000		24	2	-2	–	–	–
	GP605.B	12/07/2000		32	-6	-10	2.3	201	1.9
	GP605.A	12/07/2000		40	-14	-18	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP606			22.2						
	GP606.D	12/07/2000		16	10	-6	–	–	–
	GP606.C	12/07/2000		24	2	-2	10.0	425	0.39
	GP606.B	12/07/2000		32	-6	-10	11.6	265	1.2
	GP606.A	12/07/2000		40	-14	-18	–	–	–
GP607			21.5						
	GP607.E	12/06/2000		24	2	-2	10.3	419	0.40
	GP607.D	12/06/2000		32	-7	-11	10.5	329	1.5
	GP607.C	12/06/2000		40	-15	-19	9.5	261	2.4
	GP607.B	12/06/2000		48	-23	-27	10.0	288	4.6
	GP607.A	12/06/2000		56	-31	-35	11.0	272	5.5
GP608			22.2						
	GP608.D	12/06/2000		16	10	6	14.3	1,448	0.37
	GP608.C	12/06/2000		24	2	-2	12.4	834	0.36
	GP608.B	12/06/2000		32	-6	-10	12.9	204	0.45
	GP608.A	12/06/2000		40	-14	-18	–	–	–
GP609			20.2						
	GP609.D	12/06/2000		16	8	4	–	–	–
	GP609.C	12/06/2000		24	0	-4	9.7	195	0.31
	GP609.B	12/06/2000		32	-8	-12	9.9	181	0.38
	GP609.A	12/06/2000		40	-16	-20	–	–	–
GP610			21.3						
	GP610.C	12/06/2000		24	1	-3	12.6	217	0.45
	GP610.B	12/06/2000		32	-7	-11	11.0	192	–
	GP610.A	12/06/2000		40	-15	-19	–	–	–

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP611			25.4						
	GP611.D	12/07/2000		16	13	9	14.4	1,145	0.34
	GP611.C	12/07/2000		24	5	1	13.0	399	0.32
	GP611.B	12/07/2000		32	-3	-7	13.0	228	0.33
	GP611.A	12/07/2000		40	-11	-15	11.2	203	0.54
GP613			40.9						
	GP613.C	12/07/2000		32	13	9	–	–	–
	GP613.B	12/07/2000		40	5	1	–	–	–
	GP613.A	12/07/2000		52	-7	-11	–	–	–
GP614			17.2						
	GP614.D	12/04/2000		16	5	1	13.7	332	0.26
	GP614.C	12/04/2000		24	-3	-7	14.9	228	0.22
	GP614.B	12/04/2000		32	-11	-15	15.0	178	0.18
	GP614.A	12/04/2000		40	-19	-23	14.3	125	0.22
GP615			17.4						
	GP615.D	12/04/2000		16	5	1	15.0	158	0.19
	GP615.C	12/04/2000		24	-3	-7	15.1	125	0.23
	GP615.B	12/04/2000		32	-11	-15	15.3	155	0.19
	GP615.A	12/04/2000		40	-19	-23	13.9	145	0.26
GP616			17.5						
	GP616.C	12/04/2000		16	5	1	13.2	93	0.24
	GP616.B	12/04/2000		24	-3	-7	12.7	110	1.1
	GP616.A	12/04/2000		36	-15	-19	10.5	120	3.4
GP617			16.0						
	GP617.C	12/01/2000		16	4	0	14.3	70	0.20
	GP617.B	12/01/2000		24	-4	-8	13.7	99	1.9
	GP617.A	12/01/2000		36	-16	-20	11.3	139	0.29

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP618			14.0						
	GP618.C	12/04/2000		16	2	-2	14.8	474	0.22
	GP618.B	12/04/2000		24	-6	-10	14.1	498	0.20
	GP618.A	12/04/2000		33	-15	-19	15.3	118	0.21
GP619			16.2						
	GP619.C	12/04/2000		16	4	0	15.1	154	0.17
	GP619.B	12/04/2000		24	-4	-8	14.7	121	0.38
	GP619.A	12/04/2000		32	-12	-16	14.6	116	1.2
GP620			16.1						
	GP620.D	12/05/2000		16	4	0	15.3	133	0.18
	GP620.C	12/05/2000		24	-4	-8	14.4	131	0.27
	GP620.B	12/05/2000		32	-12	-16	15.1	117	0.20
	GP620.A	12/05/2000		40	-20	-24	14.2	92	0.40
GP621			12.1						
	GP621.C	12/05/2000		16	0	-4	15.9	128	0.18
	GP621.B	12/05/2000		24	-8	-12	17.2	153	0.19
	GP621.A	12/05/2000		32	-16	-20	15.8	140	0.30
GP622			13.0						
	GP622.C	12/05/2000		16	1	-3	15.2	143	0.24
	GP622.B	12/05/2000		24	-7	-11	14.6	108	0.29
	GP622.A	12/05/2000		36	-19	-23	14.5	110	0.40
GP623			9.6						
	GP623.D	12/05/2000		16	-2	-6	14.9	88	0.37
	GP623.C	12/05/2000		24	-10	-14	14.4	96	1.1
	GP623.B	12/05/2000		32	-18	-22	14.0	92	1.2
	GP623.A	12/05/2000		40	-26	-30	12.2	87	0.36

Appendix 1. *Drilling and sampling data and field-constituent concentrations in ground-water samples collected with a direct-push drilling rig at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000—Continued*

Borehole number	Sample identification number	Sampling date	Ground surface (ft sl)	Total depth (ft bgs)	Altitude of top of sampling interval (ft sl)	Altitude of bottom of sampling interval (ft sl)	Temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen concentration (mg/L)
GP624			7.1						
	GP624.D	11/09/2000		12	-1	-5	15.1	97	0.13
	GP624.C	11/09/2000		24	-13	-17	14.4	98	0.10
	GP624.B	11/09/2000		32	-21	-25	14.2	147	0.14
	GP624.A	11/09/2000		40	-29	-33	15.4	150	2.4
GP625			8.9						
	GP625.D	11/09/2000		12	1	-3	15.3	95	0.27
	GP625.C	11/09/2000		20	-7	-11	14.6	116	0.13
	GP625.B	11/09/2000		28	-15	-19	14.3	109	0.10
	GP625.A	11/09/2000		36	-23	-27	13.9	89	0.36

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*

[µg/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; *cis*-1,2-DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; MTBE, methyl *tert*-butyl ether; MCL, maximum contaminant level; concentrations in **bold** are above MCLs; –, MCL not available; E, estimated result below detection limit; ND, not detected]

Borehole number	Sample identification number		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	5		5		70		2	–	5	1,000	700	10,000	10,000
GP545	GP545.D		**15.3**	12.5	**35.5**	23.2	8.4	5.0	ND	ND	ND	ND	ND	ND	ND
	GP545.C		**20.6**		**31.4**		6.2		ND	ND	ND	ND	ND	ND	ND
	GP545.B		**14.5**		**29.0**		6.2		ND	ND	ND	ND	ND	ND	ND
	GP545.A		**9.8**		**22.7**		6.2		ND	ND	ND	ND	ND	ND	ND
GP546	GP546.D		0.43 E	6.3	2.9	12.6	ND	2.9	ND	ND	ND	ND	ND	ND	ND
	GP546.C		2.6		**7.7**		2.5		ND	ND	ND	ND	ND	ND	ND
	GP546.B		**9.8**		**20.8**		5.0		ND	ND	ND	ND	ND	ND	ND
	GP546.A		**25.0**		**40.5**		8.1		ND	ND	ND	ND	ND	ND	ND
GP 547	GP 547.D		ND	0.21	0.20 E	2.3	ND	1.8	ND	ND	ND	ND	ND	ND	ND
	GP 547.C		0.07 E		1.0		ND		ND	ND	ND	ND	ND	ND	ND
	GP 547.B		0.39 E		**5.2**		4.8		ND	ND	ND	ND	ND	ND	ND
	GP 547.A		0.76 E		**5.8**		4.9		ND	ND	ND	ND	ND	ND	ND
GP549	GP 549.D		ND	0.02	0.77 E	8.4	ND	1.7	ND	ND	ND	ND	ND	ND	ND
	GP 549.C		0.04 E		**15.4**		2.8		ND	ND	ND	ND	ND	ND	ND
	GP 549.B		0.02 E		**10.0**		1.7		ND	ND	ND	ND	ND	ND	ND
	GP 549.A		0.02 E		**15.3**		4.4		ND	ND	ND	ND	ND	ND	ND
GP550	GP550.D		**5.5**	4.4	5.0	2.6	1.7	0.59	ND	ND	ND	ND	ND	ND	ND
	GP550.C		**7.3**		3.9		1.5		ND	ND	ND	ND	ND	ND	ND
	GP550.B		**6.9**		3.7		ND		ND	ND	ND	ND	ND	ND	ND
	GP550.A		1.2 E		0.63 E		ND		ND	ND	ND	ND	ND	ND	ND
GP551	GP551.D		0.07 E	1.2	0.65 E	3.2	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP551.C		0.66 E		2.4		ND		ND	ND	ND	ND	ND	ND	ND
	GP551.B		2.4		**6.8**		ND		ND	ND	ND	ND	ND	ND	ND
	GP551.A		3.3		**6.8**		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	**Sample identification number**		**PCE (µg/L)**	**Vertically averaged PCE (µg/L)**	**TCE (µg/L)**	**Vertically averaged TCE (µg/L)**	***cis*-1,2-DCE (µg/L)**	**Vertically averaged *cis*-1,2-DCE (µg/L)**	**VC (µg/L)**	**MTBE (µg/L)**	**Benzene (µg/L)**	**Toluene (µg/L)**	**Ethylbenzene (µg/L)**	***p,m*-xylene (µg/L)**	***o*-xylene (µg/L)**
		MCL	**5**		**5**		**70**		**2**	**–**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP552	GP552.D		0.16 E	0.91	1.0	3.7	ND	1.8	ND	ND	1.8	ND	ND	ND	ND
	GP552.C		0.77 E		2.6		1.3		ND	ND	1.1	ND	ND	ND	ND
	GP552.B		2.7		**10.3**		4.6		ND	ND	ND	ND	ND	ND	ND
	GP552.A		0.16 E		3.1		2.3		ND	ND	ND	ND	ND	ND	ND
GP555	GP555.D		**10.6**	23.9	**18.9**	50.8	2.5	8.7	ND	ND	ND	ND	ND	ND	ND
	GP555.C		**44.6**		**110**		12.7		ND	ND	ND	ND	ND	ND	ND
	GP555.B		**39.1**		**77.3**		19.6		ND	ND	ND	ND	ND	ND	ND
	GP555.A		**13.0**		**13.4**		2.2		ND	ND	ND	ND	ND	ND	ND
GP556	GP556.D		0.04 E	0.93	1.4	2.0	ND	0.48	ND	ND	ND	ND	ND	ND	ND
	GP556.C		0.18 E		0.48 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP556.B		0.51 E		1.6		ND		ND	ND	ND	ND	ND	ND	ND
	GP556.A		**6.0**		**10.9**		3.8		ND	ND	ND	ND	ND	ND	ND
GP557	GP557.D		0.01 E	0.02	0.01 E	0.61	ND	0.34	ND	ND	ND	ND	ND	ND	ND
	GP557.C		0.03 E		0.18 E		ND		ND	ND	0.77	ND	ND	ND	ND
	GP557.B		0.03 E		0.73 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP557.A		0.02 E		3.0		2.7		ND	30.2	ND	ND	ND	ND	ND
GP558	GP558.D		**15.9**	17.5	**47.1**	55.4	16.4	17.2	ND	ND	ND	ND	ND	ND	ND
	GP558.C		**34.8**		**148**		45.3		ND	ND	ND	ND	ND	ND	ND
	GP558.B		**27.1**		**42.3**		12.9		ND	ND	ND	ND	ND	ND	ND
	GP558.A		0.76 E		0.40 E		ND		ND	ND	ND	ND	ND	ND	ND
GP559	GP559.D		**42.9**	8.1	**74.0**	14.3	19.5	3.7	ND	ND	ND	ND	ND	ND	ND
	GP559.C		0.45 E		0.66 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP559.B		**5.5**		**11.1**		3.1		ND	ND	ND	ND	ND	ND	ND
	GP559.A		0.83 E		0.51 E		ND		ND	ND	ND	ND	ND	ND	ND
GP560	GP560.D		**44.1**	43.1	**41.0**	33.4	15.6	10.1	ND	ND	ND	ND	ND	ND	ND
	GP560.C		**144**		**109**		32.7		ND	ND	ND	ND	ND	ND	ND
	GP560.B		**6.4**		4.0		ND		ND	ND	ND	ND	ND	ND	ND
	GP560.A		0.26 E		0.32 E		ND		ND	ND	ND	0.54 E	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	**5**		**5**		**70**		**2**	**–**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP561	GP561.D		0.07 E	0.08	0.42 E	6.0	ND	4.6	ND	ND	ND	ND	ND	ND	ND
	GP561.C		0.08 E		4.8		4.5		ND	ND	ND	ND	ND	ND	ND
	GP561.B		0.12 E		**15.6**		10.7		ND	ND	ND	ND	ND	ND	ND
	GP561.A		0.18 E		**6.5**		6.5		ND	ND	ND	ND	ND	ND	ND
GP562	GP562.D		0.22 E	0.04	0.27 E	2.0	ND	3.2	ND	178	ND	4.7	124	106	28.7
	GP562.C		0.03 E		0.13 E		1.5		ND	429	ND	9.1	226	280	66.7
	GP562.B		ND		4.0		7.0		ND	ND	ND	ND	ND	ND	ND
	GP562.A		0.04 E		**5.7**		6.4		ND	ND	ND	ND	ND	ND	ND
GP563	GP563.C		ND	0.00	0.01 E	0.04	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP563.B		ND		0.02 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP563.A		ND		0.14 E		ND		ND	ND	ND	0.43 E	ND	ND	ND
GP564	GP564.C		ND	0.00	0.01 E	0.02	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP564.B		ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP564.A		ND		0.08 E		ND		ND	ND	ND	ND	ND	ND	ND
GP565	GP565.C		0.01 E	0.00	0.02 E	0.02	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP565.B		0.01 E		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP565.A		ND		0.02 E		ND		ND	ND	ND	ND	ND	ND	ND
GP566	GP566.D		**52.2**	6.6	**22.5**	2.8	18.3	2.3	ND	ND	ND	ND	ND	ND	ND
	GP566.C		0.11 E		0.06 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP566.B		0.04 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP566.A		0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP567	GP567.D		1.1 E	8.1	2.2	2.3	10.2	9.3	ND	ND	ND	ND	ND	ND	ND
	GP567.C		**31.0**		**7.9**		32.0		ND	ND	ND	ND	ND	ND	ND
	GP567.B		0.77 E		0.22 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP567.A		0.05 E		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	**Sample identification number**	**PCE (µg/L)**	**Vertically averaged PCE (µg/L)**	**TCE (µg/L)**	**Vertically averaged TCE (µg/L)**	***cis*-1,2-DCE (µg/L)**	**Vertically averaged *cis*-1,2-DCE (µg/L)**	**VC (µg/L)**	**MTBE (µg/L)**	**Benzene (µg/L)**	**Toluene (µg/L)**	**Ethylbenzene (µg/L)**	***p,m*-xylene (µg/L)**	***o*-xylene (µg/L)**
	MCL	**5**		**5**		**70**		**2**	**–**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP568	GP568.D	**35.4**	19.1	**15.9**	41.3	4.9	11.0	ND	ND	ND	ND	ND	ND	ND
	GP568.C	**58.7**		**157**		41.5		ND	ND	ND	ND	ND	ND	ND
	GP568.B	0.04 E		0.06 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP568.A	0.05 E		0.05 E		ND		ND	ND	ND	ND	ND	ND	ND
GP569	GP569.D	0.16 E	0.06	**55.3**	21.1	34.7	13.1	ND	10.3	**5.6**	ND	ND	ND	ND
	GP569.C	0.16 E		**56.7**		35.0		ND	9.7	**5.7**	ND	ND	ND	ND
	GP569.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP569.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP570	GP570.D	0.01 E	0.00	0.02 E	0.03	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP570.C	ND		0.07 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP570.B	ND		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP570.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP571	GP571.A	0.01 E	0.01	0.01 E	0.01	ND	0.00	ND	ND	ND	ND	ND	ND	ND
GP572	GP572.D	**28.3**	16.9	**36.2**	60.4	15.3	28.6	ND	ND	ND	ND	ND	ND	ND
	GP572.C	**48.3**		**202**		**96.8**		ND	ND	ND	ND	ND	ND	ND
	GP572.B	1.0 E		1.2		ND		ND	ND	ND	ND	ND	ND	ND
	GP572.A	0.50 E		0.23 E		ND		ND	ND	ND	ND	ND	ND	ND
GP573	GP573.D	**16.3**	2.9	**139**	16.2	44.2	4.9	ND	ND	ND	ND	ND	ND	ND
	GP573.C	3.8		2.5		ND		ND	ND	ND	ND	ND	ND	ND
	GP573.B	ND		0.06 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP573.A	0.02 E		0.09 E		ND		ND	ND	ND	ND	ND	ND	ND
GP574	GP574.D	ND	0.00	0.01 E	0.01	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP574.C	ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP574.B	ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP574.A	ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	**5**		**5**		**70**		**2**	**-**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP575	GP575.D		ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP575.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP575.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP575.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP576	GP576.D		ND	0.00	ND	0.01	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP576.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP576.B		ND		0.02 **E**		ND		ND	ND	ND	ND	ND	ND	ND
	GP576.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP577	GP577.E		0.13 **E**	0.01	0.04 **E**	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP577.D		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP577.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP577.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP577.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP578	GP578.E		**43.9**	14.1	**9.8**	3.9	22.6	5.0	ND	ND	ND	ND	ND	1.9 **E**	1.4
	GP578.D		**48.6**		**14.8**		14.0		ND	42.6	ND	ND	ND	ND	ND
	GP578.C		0.06 **E**		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP578.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP578.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP579	GP579.E		4.3	8.6	2.1	3.3	0.94	1.9	ND	ND	ND	ND	ND	ND	ND
	GP579.D		**40.6**		**15.2**		9.0		ND	18.3	ND	ND	ND	ND	ND
	GP579.C		0.02 **E**		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP579.B		0.01 **E**		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP579.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP579.F		3.7		2.2		1.6		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number	PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
	MCL	**5**		**5**		**70**		**2**	**-**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP580	GP580.D	0.11 E	0.03	**18.1**	3.2	20.0	3.7	ND	7.3	4.7	ND	ND	ND	ND
	GP580.C	0.05 E		3.6		4.6		ND	ND	ND	ND	ND	ND	ND
	GP580.B	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP580.A	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP581	GP581.D	0.03 E	0.02	0.31 E	0.04	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP581.C	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP581.B	0.05 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP581.A	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP582	GP582.A	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
GP583	GP583.D	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP583.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP583.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP583.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP584	GP584.D	ND	0.00	ND	0.12	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP584.C	ND		0.06 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP584.B	ND		0.41 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP584.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP585	GP585.D	0.02 E	0.01	ND	0.00	ND	0.48	ND	ND	ND	38.4	8.4	15.6	1.8
	GP585.C	0.02 E		ND		1.9		ND	ND	ND	1.7	ND	ND	ND
	GP585.B	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP585.A	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP585.E	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP586	GP586.C	**55.2**	15.4	**23.9**	5.0	10.2	2.4	ND	ND	ND	ND	ND	ND	ND
	GP586.B	**18.5**		3.1		2.1		ND	ND	ND	ND	ND	ND	ND
	GP586.A	0.22 E		0.03 E		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	5		5		70		2	–	5	1,000	700	10,000	10,000
GP587	GP587.D		0.45 E	0.09	7.5	1.6	9.3	2.7	ND	5.1	ND	ND	ND	ND	ND
	GP587.C		0.14 E		2.8		6.1		ND	2.0	ND	ND	ND	ND	ND
	GP587.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP587.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP588	GP588.D		0.01 E	0.01	0.47 E	0.07	6.9	0.86	ND	ND	ND	ND	ND	ND	ND
	GP588.C		0.01 E		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP588.B		0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP588.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP589	GP589.D		ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP589.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP589.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP589.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP590	GP590.D		ND	0.00	ND	0.01	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP590.C		ND		0.02 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP590.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP590.A		ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
GP591	GP591.B		ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP591.A		ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
GP592	GP592.D		ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP592.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP592.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP592.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP593	GP593.D		ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP593.C		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP593.B		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP593.A		ND		ND		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number	PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
	MCL	5		5		70		2	-	5	1,000	700	10,000	10,000
GP594	GP594.D	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP594.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP594.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP594.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP595	GP595.D	0.01 E	0.00	0.05 E	0.01	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP595.C	ND		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP595.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP595.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP596	GP596.D	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP596.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP596.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP596.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP597	GP597.D	ND	0.00	0.24 E	0.05	1.7	0.21	ND	ND	ND	ND	ND	ND	ND
	GP597.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP597.B	ND		0.09 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP597.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP598	GP598.B	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP598.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP599	GP599.D	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP599.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP599.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP599.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP600	GP600.D	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP600.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP600.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP600.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number	PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
	MCL	5		5		70		2	–	5	1,000	700	10,000	10,000
GP601	GP601.C	ND	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP601.B	ND		ND		ND		ND	ND	ND	0.42 E	ND	ND	ND
	GP601.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP602	GP602.F	0.31 E	12.4	0.07 E	2.4	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP602.E	1.5		0.24 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP602.D	**40.2**		2.5		ND		ND	ND	ND	ND	ND	ND	ND
	GP602.C	**32.7**		**11.6**		ND		ND	ND	ND	ND	ND	ND	ND
	GP602.B	0.06 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP602.A	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP603	GP603.D	0.01 E	0.01	0.01 E	0.02	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP603.C	0.01 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP603.B	0.02 E		0.03 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP603.A	0.02 E		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND
GP604	GP604.D	0.01 E	0.01	0.01 E	0.02	ND	0.50	ND	ND	ND	ND	ND	ND	ND
	GP604.C	0.01 E		0.02 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP604.B	0.01 E		0.04 E		1.3		ND	ND	ND	ND	ND	ND	ND
	GP604.A	0.02 E		0.05 E		1.6		ND	ND	ND	ND	ND	ND	ND
GP605	GP605.C	0.39 E	0.22	0.31 E	0.17	1.1	0.73	ND	ND	ND	ND	ND	ND	ND
	GP605.B	0.45 E		0.31 E		1.7		ND	ND	ND	ND	ND	ND	ND
	GP605.A	0.05 E		0.07 E		ND		ND	ND	ND	ND	ND	ND	ND
GP606	GP606.D	0.07 E	0.44	0.13 E	0.39	ND	3.3	ND	ND	**5.6**	0.84 E	ND	5.2	ND
	GP606.C	0.44 E		0.51 E		1.1		ND	ND	2.3	ND	ND	ND	ND
	GP606.B	1.2		0.82		9.4		ND	ND	ND	ND	ND	ND	ND
	GP606.A	0.17 E		0.32 E		5.7		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number	PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
	MCL	**5**		**5**		**70**		**2**	**–**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP607	GP607.E	0.04 E	0.01	1.0	0.10	7.8	2.6	ND	ND	4.3	ND	ND	1.6 E	ND
	GP607.D	ND		ND		9.2		ND	ND	3.0	0.63 E	ND	ND	ND
	GP607.C	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP607.B	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP607.A	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP608	GP608.D	ND	0.01	0.06 E	0.24	ND	45.2	ND	ND	**39.9**	1.4	3.4	6.6	ND
	GP608.C	0.02 E		0.92		**180**		ND	ND	**8.7**	12.7	ND	ND	ND
	GP608.B	ND		ND		0.98		ND	ND	ND	ND	ND	ND	ND
	GP608.A	0.01 E		ND		ND		ND	ND	ND	ND	ND	0.64 E	ND
GP609	GP609.D	0.12 E	0.03	0.20 E	0.00	63.5	7.9	ND	ND	ND	ND	ND	ND	ND
	GP609.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP609.B	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP609.A	0.09 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
GP610	GP610.C	ND	0.01	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP610.B	0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP610.A	0.05 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP611	GP611.D	**45.0**	22.0	**73.5**	80.6	**505**	172	ND	ND	**14.9**	2.5	1.4	4.1	1.6
	GP611.C	**65.4**		**285**		**437**		ND	ND	ND	1.6	ND	3.9	ND
	GP611.B	0.12 E		0.09 E		ND		ND	ND	ND	ND	ND	2.5 E	ND
	GP611.A	0.13 E		0.11 E		ND		ND	ND	ND	ND	ND	2.9	ND
GP613	GP613.C	0.04 E	0.02	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP613.B	0.02 E		ND		ND		ND	ND	ND	1.2 E	ND	ND	ND
	GP613.A	0.02 E		0.01		ND		ND	ND	ND	1.8	ND	ND	ND
GP614	GP614.D	0.53 E	0.30	0.62 E	0.20	53.8	14.4	ND	ND	ND	ND	ND	ND	ND
	GP614.C	0.88 E		0.44 E		30.6		ND	ND	ND	ND	ND	ND	ND
	GP614.B	0.05 E		0.05 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP614.A	0.04 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number	PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
	MCL	5		5		70		2	–	5	1,000	700	10,000	10,000
GP615	GP615.D	**33.9**	4.3	4.2	0.55	**203**	25.4	ND	3.7	1.1	ND	ND	ND	ND
	GP615.C	0.20 E		0.02 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP615.B	0.06 E		0.05 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP615.A	0.04 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
GP616	GP616.C	0.05 E	0.04	0.01 E	0.02	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP616.B	0.08 E		0.04 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP616.A	0.04 E		0.01 E		ND		ND	ND	ND	ND	ND	ND	ND
GP617	GP617.C	ND	0.01	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP617.B	0.03 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP617.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP618	GP618.C	0.38 E	0.18	0.76 E	0.36	36.9	10.8	ND	8.1	**34.2**	1.9	0.60 E	ND	1.6
	GP618.B	0.35 E		0.64 E		15.1		ND	ND	ND	3.5	ND	ND	ND
	GP618.A	0.04 E		0.13 E		ND		ND	ND	ND	ND	ND	ND	ND
GP619	GP619.C	2.3	1.7	0.67 E	0.44	11.2	2.1	ND	ND	ND	ND	ND	ND	ND
	GP619.B	1.7		0.41E		ND		ND	ND	ND	ND	ND	ND	ND
	GP619.A	4.6		1.2		1.1		ND	ND	ND	ND	ND	ND	ND
GP620	GP620.D	ND	0.00	0.18 E	0.02	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP620.C	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP620.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP620.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP621	GP621.C	0.01 E	0.00	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP621.B	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP621.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP622	GP622.C	0.01 E	0.01	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP622.B	0.02 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP622.A	ND		ND		ND		ND	ND	ND	ND	ND	ND	ND

Appendix 2. *Concentrations of volatile organic compounds in ground-water samples collected from direct-push boreholes at sites FT03, LF13, and WP14/LF15, Dover Air Force Base, Delaware, November–December 2000*—Continued

Borehole number	Sample identification number		PCE (µg/L)	Vertically averaged PCE (µg/L)	TCE (µg/L)	Vertically averaged TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vertically averaged *cis*-1,2-DCE (µg/L)	VC (µg/L)	MTBE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	*p,m*-xylene (µg/L)	*o*-xylene (µg/L)
		MCL	**5**		**5**		**70**		**2**	**-**	**5**	**1,000**	**700**	**10,000**	**10,000**
GP623	GP623.D		0.01 E	0.02	ND	0.00	ND	0.00	ND	ND	ND	ND	ND	ND	ND
	GP623.C		0.03 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP623.B		0.01 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
	GP623.A		0.04 E		ND		ND		ND	ND	ND	ND	ND	ND	ND
GP624	GP624.D		**7.5**	2.6	**6.9**	2.2	2.2	0.81	ND	ND	ND	ND	ND	ND	ND
	GP624.C		**5.1**		3.8		1.8		ND	ND	ND	ND	ND	0.64 E	ND
	GP624.B		0.28 E		0.48 E		ND		ND	ND	ND	ND	ND	ND	ND
	GP624.A		0.10 E		0.16 E		ND		ND	ND	ND	ND	ND	ND	ND
GP625	GP625.D		**38.1**	8.1	**71.2**	14.7	10.4	2.1	ND	ND	ND	ND	ND	ND	ND
	GP625.C		**10.8**		**21.8**		3.2		ND	ND	ND	ND	ND	ND	ND
	GP625.B		1.7		1.2		ND		ND	ND	ND	ND	ND	ND	ND
	GP625.A		1.5		0.51 E		ND		ND	ND	ND	ND	ND	ND	ND