

Prepared in cooperation with the Naval Facilities Engineering Command Southeast

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina



Scientific Investigations Report 2009–5161

Cover photograph. Still picture from a video taken by a borehole camera in the now abandoned sanitary sewer system from the former dry-cleaning facility at Site 45, Parris Island, showing cracks in the sewer with roots extending through the cracks. Video by Deigler Waste Services, Inc. (Ridgeland, South Carolina).

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina

By Don A. Vroblesky, Matthew D. Petkewich, James E. Landmeyer, and Mark A. Lowery

Prepared in cooperation with the Naval Facilities Engineering Command Southeast

Scientific Investigations Report 2009–5161

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit <http://www.usgs.gov> or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit <http://www.usgs.gov/pubprod>

To order this and other USGS information products, visit <http://store.usgs.gov>

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this report is in the public domain, permission must be secured from the individual copyright owners to reproduce any copyrighted materials contained within this report.

Suggested citation:

Vroblesky, D.A., Petkewich, M.D., Landmeyer, J.E., and Lowery, M.A., 2009, Source, transport, and fate of groundwater contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina: U.S. Geological Survey Scientific Investigations Report 2009–5161, 80 p.

Contents

Abstract.....	1
Introduction.....	1
Methods.....	4
Well Installation	4
Water-Level Measurements	8
Sewer Mapping.....	8
Sediment Sampling.....	10
Surface-Water and Storm-Drain Sampling	11
Well Sampling.....	11
Compound-Specific Isotope Analysis	12
Investigation-Derived Waste	12
Site Description.....	12
Hydrogeology.....	12
Groundwater Chemistry.....	16
Distribution of Chlorinated-Solvent Groundwater Contamination.....	18
Areal Distribution of Groundwater Contamination.....	18
Vertical Distribution of Groundwater Contamination.....	23
Source of Chlorinated-Solvent Groundwater Contamination in the Southern Plume.....	26
Transport and Fate of Chlorinated Solvents	28
Storm-Sewer Influences on Transport.....	28
Biodegradation.....	32
Contaminant Concentration Changes in the Direction of Transport	34
Other Influences.....	38
Summary and Conclusions.....	38
References.....	40
Appendixes 1–14.....	45

Figures

1–9.	Maps showing—	
1.	Location of Site 45 and Marine Corps Recruit Depot, Parris Island, South Carolina	2
2.	Location of above-ground storage tanks and approximate boundary of groundwater contamination, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	3
3.	Locations of monitoring wells used in the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	5
4.	Locations of temporary wells installed and sampled as part of the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	6
5.	Locations of Membrane Interface Probe borings installed during the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	7
6.	Storm sewers and sanitary sewers at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	9
7.	Locations of storm sewers and surface-water and sediment samples collected at the storm-sewer discharge from Site 45 to Ballast Creek, Marine Corps Recruit Depot, Parris Island, South Carolina, June 16–17, 2008	10
8.	Groundwater levels in the SU wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.....	14
9.	Groundwater levels in the SL wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.....	15
10–11.	Graphs showing—	
10.	Water levels in selected monitoring wells and storm-sewer manhole STS06, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 11–13, 2007.....	16
11.	Vertical profile of specific conductance at well PFM-02, Marine Corps Recruit Depot, Parris Island, South Carolina, June 14, 2007.....	17
12–16.	Maps showing—	
12.	Generalized distribution of tetrachloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008	19
13.	Generalized distribution of trichloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008	20
14.	Generalized distribution of <i>cis</i> -1,2-dichloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008	21
15.	Generalized distribution of vinyl chloride in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008	22
16.	Locations of sampling points shown in figures 17 and 18, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.....	24
17.	Lithologic log, electron-capture-detector logs from Membrane Interface Probe investigation, trichloroethene concentrations in water from multiple depths in temporary wells, and total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.....	25

18. Lithologic log, electron-capture-detector log from Membrane Interface Probe investigation, field analysis of volatile organic compounds in sediment cores, trichloroethene concentrations in water from multiple depths in temporary wells, and total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, 2008	27
19. Map showing movement of dye tracer and arrival times in the storm sewer from Site 45 to the Ballast Creek tributary, Marine Corps Recruit Depot, Parris Island, South Carolina, August 30, 2007	31
20. Graphs showing total chlorinated solvents, individual chlorinated solvents, parent/daughter ratios, and compound-specific stable carbon isotopes in wells along the axis of contamination in the southern plume, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, September 2008, unless otherwise noted.....	35
21. Map showing relative molar percentage of tetrachloroethene, trichloroethene, <i>cis</i> -1,2-dichloroethene, and vinyl chloride in groundwater from monitoring wells and selected temporary wells representing multiple sampling events, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.....	36

Tables

1. Concentrations of total organic carbon in sediment cores, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.....	18
2. Concentrations of chlorinated volatile organic compounds in shallow and deeper temporary-well groundwater samples near the new dry cleaning facility, March 5, 2008	26
3. Concentrations of selected constituents in storm sewers, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.....	29
4. Concentrations of compound-specific stable carbon isotope analysis on water from wells and a storm sewer, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008	32
5. Molecular analysis of phylogenic groups and functional genes in groundwater samples from the southern plume at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2006.....	33
6. Concentrations of total organic carbon in soil borings, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.....	38

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m ³)
gallon (gal)	3.785	cubic decimeter (dm ³)
cubic inch (in ³)	0.01639	liter (L)
cubic foot (ft ³)	28.32	cubic decimeter (dm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
Flow rate		
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Volume		
liter (L)	0.2642	gallon (gal)
cubic meter (m ³)	264.2	gallon (gal)
cubic decimeter (dm ³)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in ³)
cubic decimeter (dm ³)	0.03531	cubic foot (ft ³)
cubic meter (m ³)	35.31	cubic foot (ft ³)
Flow rate		
meter per minute (m/min)	3.281	foot per minute (ft/min)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year (ft/yr)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
metric ton per day	1.102	ton per day (ton/d)
megagram per day (Mg/d)	1.102	ton per day (ton/d)
megagram per day per square kilometer [(Mg/d)/km ²]	2.8547	ton per day per square mile [(ton/d)/mi ²]
megagram per year (Mg/yr)	1.102	ton per year (ton/yr)
metric ton per year	1.102	ton per year (ton/yr)
Hydraulic conductivity		
meter per day (m/d)	3.281	foot per day (ft/d)
Hydraulic gradient		
meter per kilometer (m/km)	5.27983	foot per mile (ft/mi)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Abbreviations

‰	per mil: a unit expressing the ratio of stable isotope abundance of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand.	mg/kg	milligrams per kilogram
¹² C	carbon 12 isotope	mg/mL	milligrams per milliliter
¹³ C	carbon 13 isotope	MIP	Membrane Interface Probe
16S rRNA	16S ribosomal ribonucleic acid	mRNA	messenger ribonucleic acid
BLS	below land surface	mS/M	millisiemens per meter
BVC	functional gene associated with vinyl chloride reductase	nM	nanomoles per liter
bvcA	reductase gene in <i>Dehalococcoides</i> strain BAV1	PCE	tetrachloroethene
cDCE	<i>cis</i> -1,2-dichloroethene	ppm	parts per million
cm/d	centimeters per day	PVC	polyvinyl chloride
CSIA	compound-specific isotope analysis	<i>qDHB</i>	DNA or 16SrRNA associated with <i>Dehalobacter</i> sp.
DNA	deoxyribose nucleic acid	<i>qDHC</i>	DNA or 16SrRNA associated with <i>Dehalococcoides</i> sp.
DNAPL	dense nonaqueous-phase liquid	<i>qDSM</i>	DNA or 16SrRNA associated with <i>Desulfuromonas</i> sp.
DO	dissolved oxygen	<i>qEBAC</i>	DNA or 16SrRNA associated with <i>Eubacteria</i>
DSR	functional gene associated with sulfate-reducing bacteria	<i>qMGN</i>	DNA or 16SrRNA associated with methanogenic bacteria
ECD	electron-capture detector	RNA	ribonucleic nucleic acid
f_{oc}	fraction organic carbon	TCE	trichloroethene
ft/d	feet per day	TceA	trichloroethene reductase gene
ft/yr	feet per year	<i>tDCE</i>	<i>trans</i> -1,2-dichloroethene
H ₂	molecular hydrogen	TEAP	terminal electron accepting process
I.D.	inside diameter	TOC	total organic carbon
IDW	investigation-derived waste	USEPA	U.S. Environmental Protection Agency
K	hydraulic conductivity	USGS	U.S. Geological Survey
K_d	distribution coefficient between water and sediment	VC	vinyl chloride
K_{oc}	organic carbon sorption coefficient	VcrA	vinyl chloride reductase gene
log K_{oc}	soil absorption coefficient for organic carbon	VOA	volatile organic analysis
MBT	molecular biological tool	VOC	volatile organic compound
MCL	maximum contaminant level	$\delta^{13}C$	ratio of ¹³ C/ ¹² C relative to a reference standard of the Vienna Pee Dee Belemnite
MCRD	Marine Corps Recruit Depot	μS/cm	microsiemens per centimeter
		μV	microvolts

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina

By Don A. Vroblesky, Matthew D. Petkewich, James E. Landmeyer, and Mark A. Lowery

Abstract

Groundwater contamination by tetrachloroethene and its dechlorination products is present in two partially intermingled plumes in the surficial aquifer near a former dry-cleaning facility at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina. The northern plume originates from the vicinity of former above-ground storage tanks. Free-phase tetrachloroethene from activities in this area entered the groundwater and the storm sewer. The southern plume originates at a nearby new dry-cleaning facility, but probably was the result of contamination released to the aquifer from a leaking sanitary sewer line from the former dry-cleaning facility. Discharge of dissolved groundwater contamination is primarily to leaking storm sewers below the water table. Extensive biodegradation of the contamination takes place in the surficial aquifer; however, the biodegradation is insufficient to reduce trichloroethene to less than milligram-per-liter concentrations prior to discharging into the storm sewers. The groundwater volatile organic compounds entering the storm sewers are substantially diluted by tidal flushing upon entry and are subject to volatilization as they are transported through the storm sewer to a discharge point in a tributary to Ballast Creek. TCE concentrations of about 2–6 micrograms per liter were present in storm-sewer water near the discharge point (sampled at manhole STS26). On three out of four sampling events at manhole STS14, the storm-sewer water contained no vinyl chloride. During a time of relatively high groundwater levels, however, 20 micrograms per liter of vinyl chloride was present in STS14 storm-sewer water. Because groundwater leaks into that storm sewer and because the storm sewer upgradient from manhole STS14 is adjacent to part of the aquifer where 2,290 micrograms per liter of vinyl chloride have been detected, there is a potential for substantially increased concentrations of vinyl chloride to discharge at the storm-sewer outfall under conditions of high groundwater levels and low tidal flushing. In addition, the observation that free-phase tetrachloroethene may have entered the storm-sewer system during the 1994 discharge means that dense nonaqueous phase liquid tetrachloroethene could have leaked from various parts of the storm sewer or discharged to surface water at the storm-sewer outfall.

Introduction

Marine Corps Recruit Depot (MCRD), Parris Island, is in the southeastern part of South Carolina (fig. 1). Site 45 is a former dry-cleaning facility and the surrounding area near the intersections of Panama Street, Samoa Street, and Kyushu Street (fig. 2). The area includes a new dry-cleaning facility. Groundwater contamination is present at the site, consisting primarily of tetrachloroethene (PCE) and its dechlorination products trichloroethene (TCE), *cis*-1,2-dichloroethene (*c*DCE), and vinyl chloride (VC).

The former dry-cleaning facility began operations in the 1950s. In 1988, above-ground storage tanks were installed in an overflow catch basin (fig. 2). On March 11, 1994, one of the above-ground tanks was overfilled with PCE, and PCE spilled into the catch basin. The PCE was released from the catch basin to the surrounding soil when the containment basin was drained following heavy rains (S&ME, Inc., 1994). PCE may have entered the storm drains during this event. Evidence for entry of PCE to the storm drain was that when the site was investigated in the days after the spill, there was a wedge-shaped area of dead vegetation widening away from the spill area and intersecting Panama Street (James Clark, Environmental Officer, Parris Island, oral commun., 2008). A storm drain was present on Panama Street within a few tens of feet from the area where the wedge intersected the street. Multiple solvent releases were reported in 1995 (James Clark, Environmental Officer, Parris Island, oral commun., 2008), and the field investigation associated with the 1994 release concluded that additional solvent releases of lesser magnitude occurred over time predating the 1994 spill (S&ME, Inc., 1994). Underground storage tanks, possibly containing petroleum-based solvents, also were present at the site and were removed prior to construction of the above-ground storage tanks (S&ME, Inc., 1994). The former dry-cleaning facility was demolished, and related structures were removed from the site in early 2001 (Tetra Tech NUS, Inc., 2004). Groundwater contamination in the vicinity of and downgradient from the area of former above-ground storage tanks is designated as the northern plume in this report (fig. 2).

In late 1997, the dry-cleaning operations were moved to a new facility, approximately 130 feet (ft) west of the former

2 Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, SC

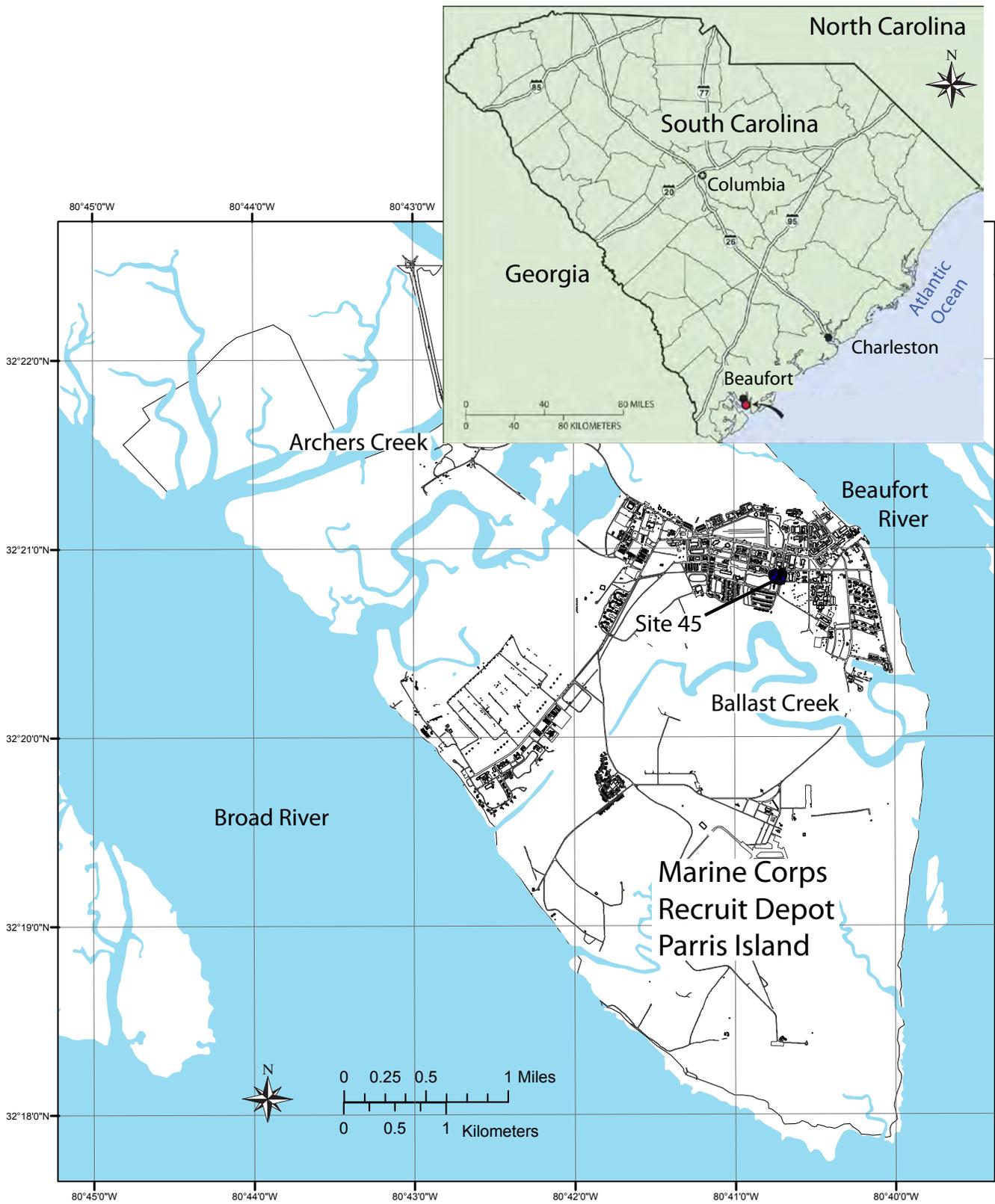


Figure 1. Location of Site 45 and Marine Corps Recruit Depot, Parris Island, South Carolina.

dry-cleaning building (fig. 2). With the move to a new facility, the dry-cleaning operation switched from using PCE as the cleaning solvent to using a non-hazardous hydrocarbon-based cleaner (ExxonMobil DF-2000®) that contains no chlorinated solvents, and the equipment was replaced with refrigeration for recirculation and recovery of the solvent (Center for Waste Minimization, 2000). Investigations in 2005 and 2006 showed the presence of a second groundwater contamination plume of chlorinated solvents, hereafter known as the southern plume,

south and southwest of the former dry-cleaning facility (fig. 2), appearing to originate from the new dry-cleaning facility (Tetra Tech NUS, Inc., 2005; Mark Sladic, Tetra Tech NUS, Inc., written commun., 2006). Groundwater flow directions were to the southeast, making it improbable that the contamination at the new dry-cleaning facility was caused by groundwater transport from the documented spill at the former dry-cleaning facility.

Prior to initiation of the present investigation, the U.S. Geological Survey (USGS) conducted groundwater

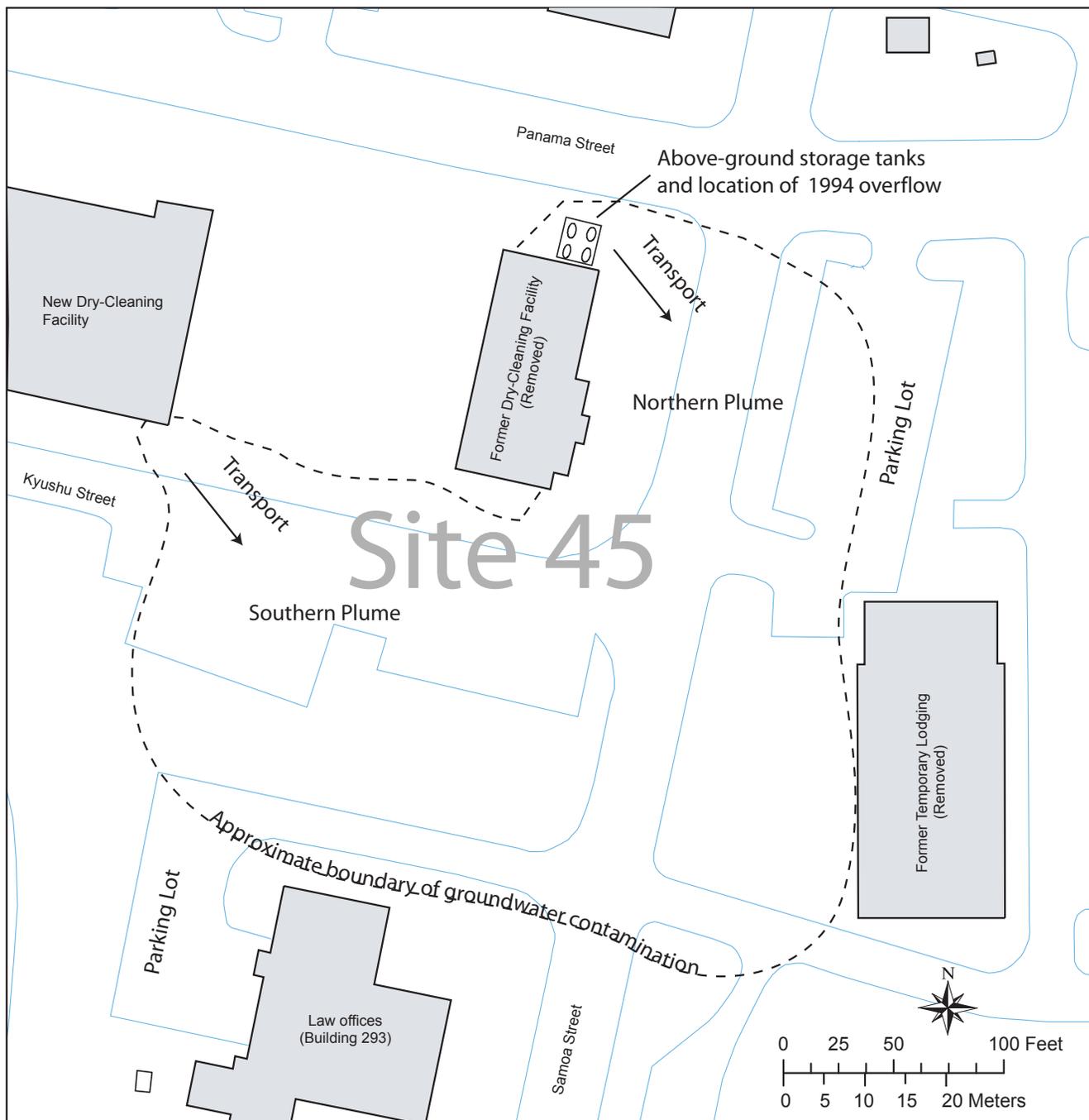


Figure 2. Location of above-ground storage tanks and approximate boundary of groundwater contamination, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

investigations at Site 45 beginning in 2005 to examine issues related to the influence of in-well convection on groundwater sample quality (Vroblesky and others, 2007). The USGS initiated the present investigation in 2007 for several reasons. (1) Measurements made by the USGS indicated that several storm-sewer lines intersecting the site were below the water table, and information was needed on whether those sewer lines influenced contaminant movement. (2) Further delineation of the southern plume was needed. (3) Additional information was needed on the fate and transport of the southern plume.

The purposes of this report are (1) to examine the role that sewer lines play in contaminant source, distribution, attenuation, and transport in both the northern and southern plumes, (2) to present data further delineating the main body of contamination in the southern plume and on the potential for contaminant movement to the deeper aquifer system, and (3) to examine natural attenuation aspects of groundwater contamination in the southern plume. The investigation involved examination of historical records and engineering drawings of buildings, video imaging of storm sewers, water-level monitoring by synoptic measurements in wells and by use of continuous data loggers, installation and sampling of temporary wells, and water and sediment sampling. The water sampling included wells, storm drains, and surface water. Water samples were collected from 23 permanent wells in the target aquifer, several of which were sampled on multiple occasions. Five of these wells were installed during this investigation. The wells were located predominantly in the southern plume. Samples were analyzed for volatile organic compounds (VOCs) and water chemistry. Selected groundwater samples were analyzed for molecular biological tools (MBTs) and for compound-specific stable carbon isotopes. Groundwater samples also were collected from four wells screened deeper than the known contamination, three of which were installed during this investigation. Water samples were collected from 96 temporary wells installed during this investigation. Membrane Interface Probe (MIP) logs were collected at seven borings in the southern plume. Additional water samples for VOC analysis were collected from storm sewers and from surface water at the sewer outfall. Sediment was collected for VOC analysis at the storm-sewer outfall. Aquifer core samples were analyzed for total organic carbon. This report contains several appendixes, which include well-construction and lithologic information, water and sediment chemistry, and synoptic water-level data.

Methods

This investigation involved monitoring existing permanent wells and installation and monitoring of additional permanent and temporary wells (figs. 3 and 4). Monitoring also involved determination of groundwater levels by collecting synoptic and continuous water-level data from wells and storm sewers. Subsurface sewer lines were mapped, sampled, and subjected to a dye test to measure transport times. Sediment

samples and surface-water samples were collected and analyzed. Water-level data and well samples were not collected from wells with the prefix PFM (originally used for a passive flux-meter investigation) because the 15-ft well screens were substantially longer than in the other monitoring wells (4–5 ft) in the surficial aquifer (fig. 3). One of the PFM wells was used, however, to obtain a vertical distribution of specific conductance in the surficial aquifer.

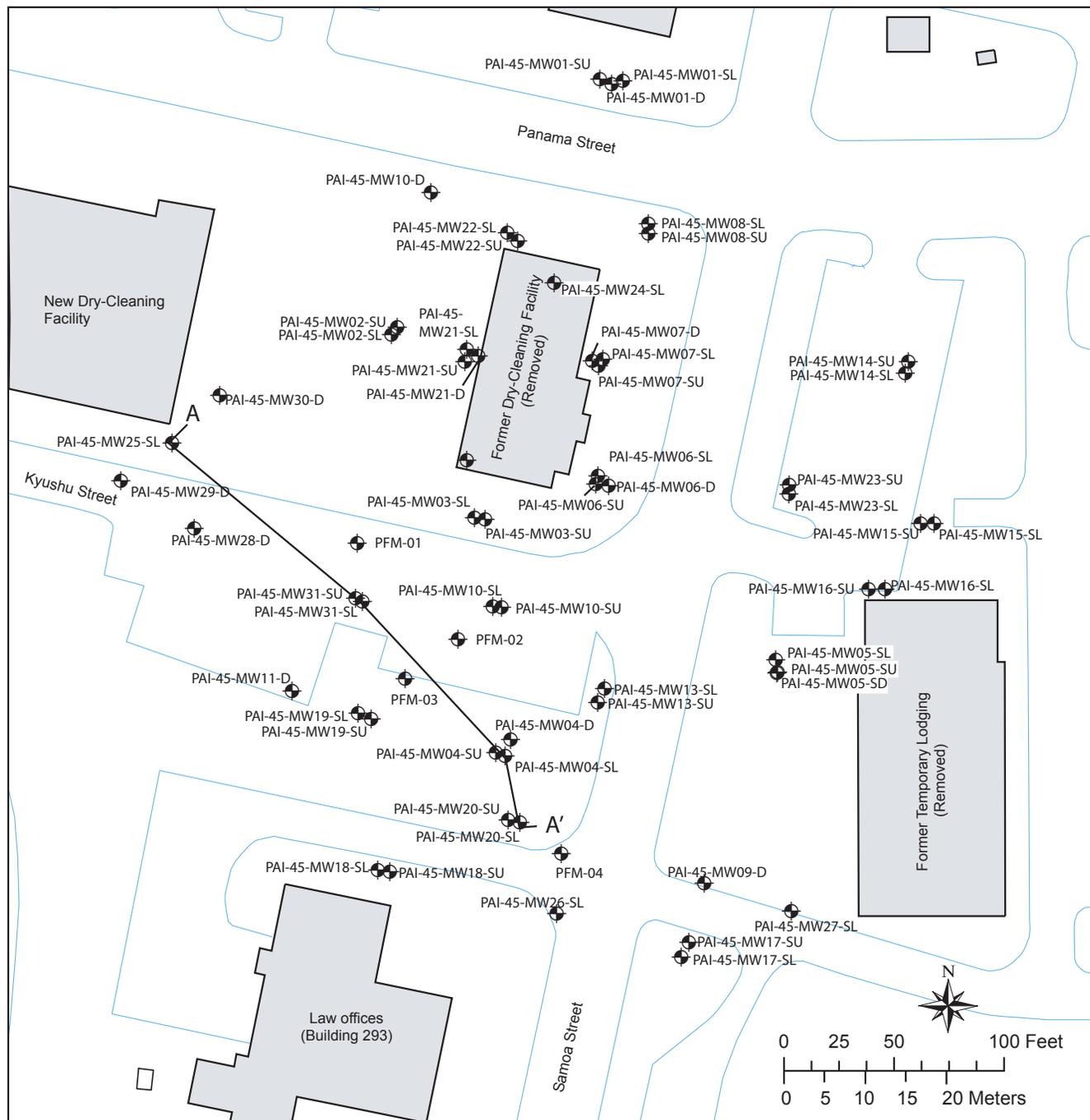
Well Installation

Temporary borings were installed using direct-push technology. MIP logs run in the temporary borings at seven locations in the southern plume provided information on the depth of the contamination (fig. 5). An MIP is a semi-quantitative field-screening device that typically is advanced into the soil and sediment by push technology and detects volatile organic compounds by heating and capturing vapor from the soil and transporting it to the surface for onsite analysis (U.S. Environmental Protection Agency, 2005).

Other temporary borings functioned as wells for water sampling or as sources for analysis of sediment cores. Temporary wells were constructed by advancing a stainless-steel well screen with a retractable cover to the target depth. Retracting the cover at the target depth exposed 4 ft of screen. The depth of investigation at each site was based primarily on vertical profiling using MIPs during this investigation and a previous investigation (Tetra Tech NUS, Inc., 2005). The depth of maximum electron-capture-detector (ECD) response on the MIP logs in areas outside the 1994 PCE spill area varied from about 9.5 to 14 ft. Therefore, the targeted depth for exposing the 4-ft screened interval of investigation was within the range of 5 to 15 ft depth, with the site-specific depth depending on nearby MIP data.

At some temporary-well locations, water samples were collected from multiple depths. On the east side of the facility at wells PAI-45-USGS-TW9 and PAI-45-USGS-TW20, multiple depths were sampled by sampling in two different boreholes, each with its own well name (PAI-45-USGS-TW18 and PAI-45-USGS-TW21, respectively). Near the new dry-cleaning facility, multiple depths were obtained by advancing the retractable well point to a shallow depth, sampling the well, removing and cleaning the equipment, and using the same borehole to advance the retractable well point to a deeper depth for sampling. The temporary wells and MIP borings installed as part of this investigation were filled in by grouting with Portland® cement within 24 hours of sampling.

A South Carolina certified well driller installed all permanent wells. The permanent wells in the surficial aquifer were installed using hollow-stem augers. The wells were 2-inch inside diameter (ID) polyvinyl chloride (PVC) flush-threaded casing with 5-ft screen lengths having 0.010-inch openings. The filter pack consisted of clean silica #1 sand installed adjacent to the screen from approximately 3–6 inches below the bottom of the well to approximately 2 ft above the well screen. The seal overlying the sand pack consisted of a minimum

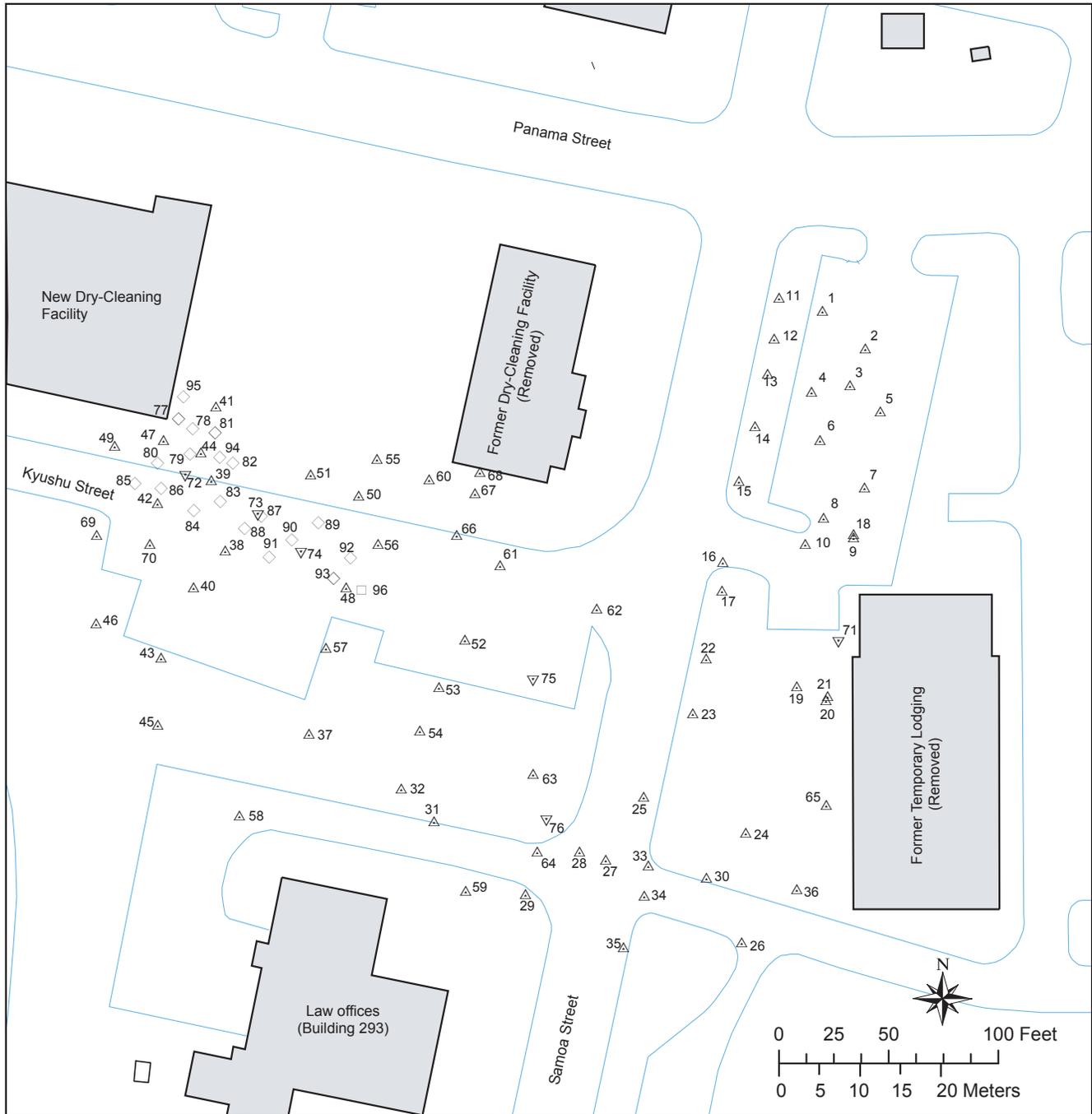


EXPLANATION

- PAI-45-MW21-SL
 Monitoring well and identifier
- A A'
 Location of hydrologic section shown in figure 20

Figure 3. Locations of monitoring wells used in the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

6 Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, SC

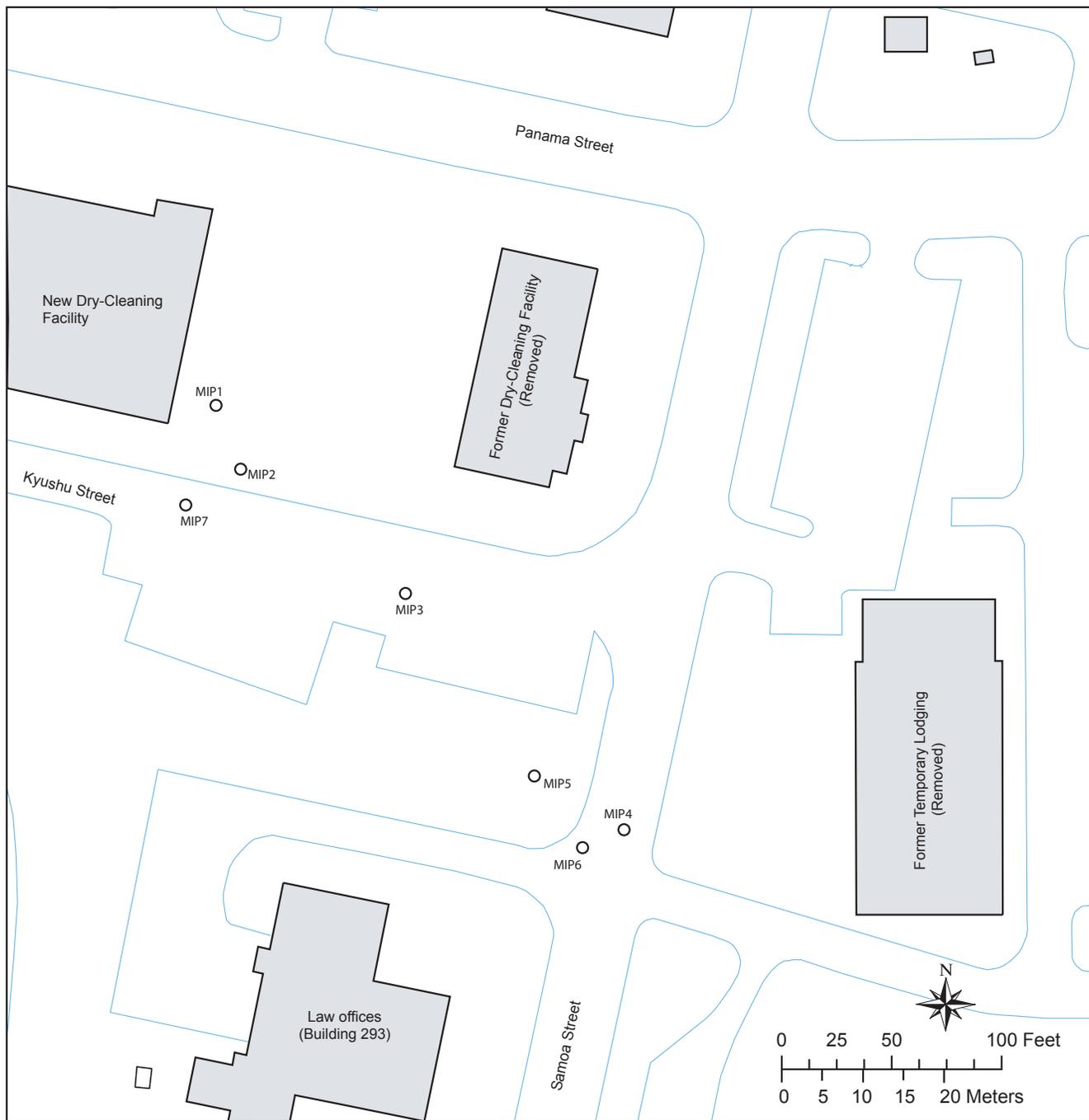


EXPLANATION

- 96 □ Temporary well installed and sampled April 2008, and abbreviated well name
- 92 ◇ Temporary well installed and sampled March 2008, and abbreviated well name
- 76 ▽ Temporary well installed and sampled August 2007, and abbreviated well name
- 41 △ Temporary well installed and sampled June 2007, and abbreviated well name

Abbreviated well names refer to names prefixed by "PAI-45-USGS-TW"

Figure 4. Locations of temporary wells installed and sampled as part of the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.



EXPLANATION

MIP1
 ○ Membrane Interface Probe (MIP) location and identifier

Figure 5. Locations of Membrane Interface Probe borings installed during the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

2-ft-thick layer of 100 percent sodium bentonite pellets that were allowed to hydrate for 1 hour or longer before grouting. Portland cement (100 percent) grout filled the remaining annular space above the bentonite seal to a point at least 2 ft below ground surface. The wells were flush mounted with at-grade protective steel casings equipped with sealing, locking caps, at-grade covers, and concrete pads at the well heads. All monitoring wells were developed by pumping to remove formation cuttings and residual fluids from drilling prior to initial sampling.

The three wells beneath the surficial aquifer were installed using hollow-stem augers and mud rotary. The driller used hollow-stem augers to set 6-inch-diameter Schedule-40 PVC outer casing from land surface to within the clay confining unit at the base of the surficial aquifer at a depth of approximately 19 to 20 ft. After grouting the surface casing in place with Portland® cement, the casing grout cured for approximately 24 hours. The driller then used a 5- to 5-5/8-inch-diameter roller cone bit with mud rotary to drill through the grouted bottom of the surface casing to a total depth of approximately 34–35 ft. The well constructed within the surface casing consisted of 2-inch ID PVC flush-threaded casing with 10-ft screen length having 0.010-inch openings. The primary filter pack consisted of clean silica #1 sand from approximately 3–6 inches below the bottom of the well to approximately 2 ft above the well screen. The overlying seal consisted of a minimum 2-ft-thick seal of 100 percent sodium bentonite pellets installed directly above the primary filter pack and allowed to hydrate for 1 hour or longer before grouting. Portland® cement (100 percent) grout filled the remaining annular space above the bentonite seal to a point at least 2 ft below ground surface. The wells were flush mounted with at-grade protective steel casings equipped with sealing, locking caps, at-grade covers, and concrete pad at the well heads. The monitoring wells were developed by pumping to remove formation cuttings and residual fluids from drilling prior to initial sampling.

On July 3, 2008, measurements of wells PAI-45-MW26-SL and PAI-45-MW27-SL showed that fine-grained sand had filled the screened interval, apparently as a result of the driller using a sand pack that was too coarse for the aquifer material. The driller returned to the site and modified the wells by removing the sand and constructing a 1-inch ID PVC well within each of the existing 2-inch diameter casings. The driller filled the remaining annular space of about 3/8 inch with sand. Subsequent examination of the wells showed that the modification was adequate to prevent further infilling with sand. A private surveying company, Andrews and Burgess, Inc., determined new vertical datums for the modified wells.

Water-Level Measurements

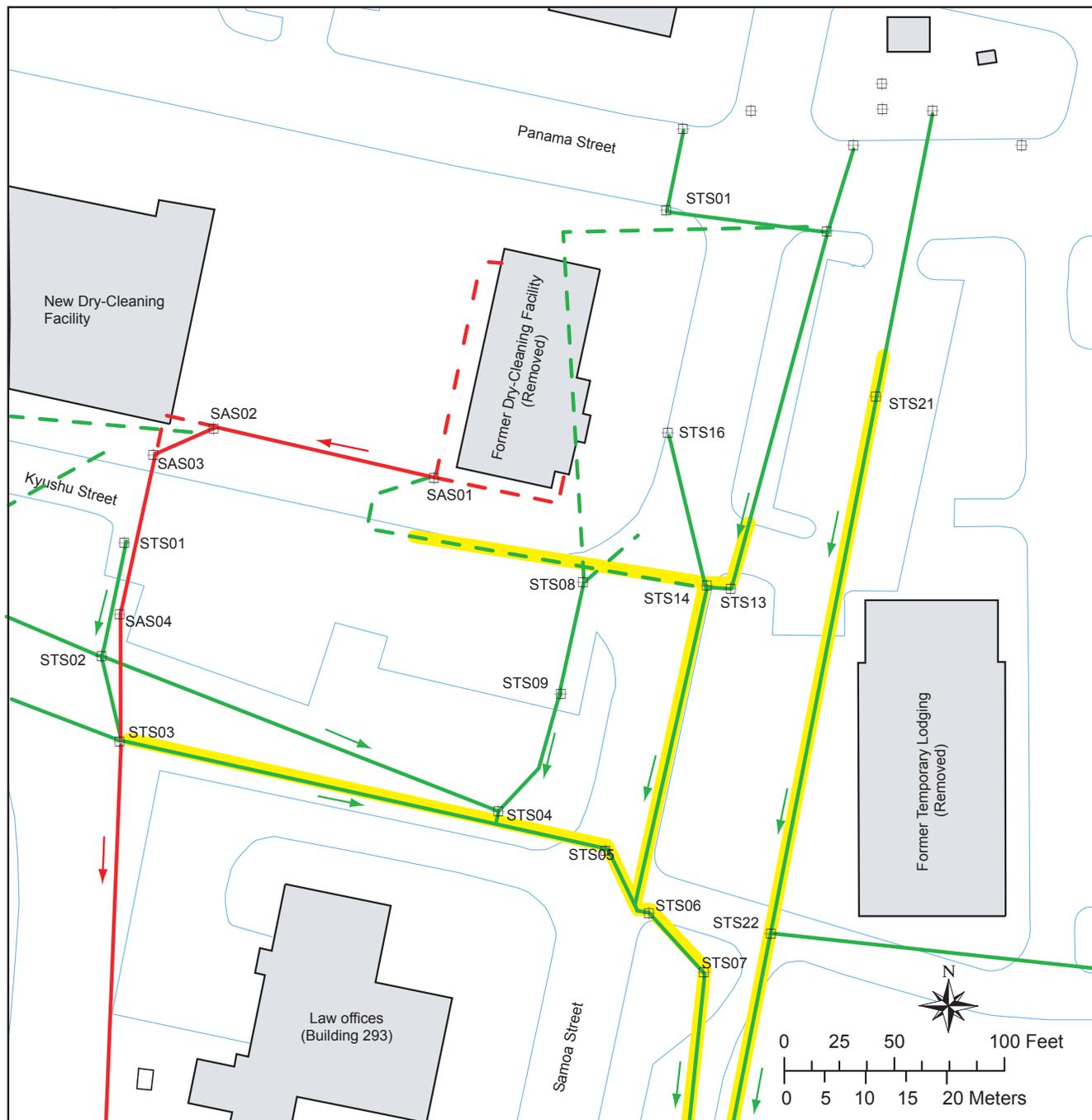
Water-level measurements in monitoring wells at Site 45 provided information to determine groundwater flow directions. Continuous water-level data from the storm sewers and

the aquifer indicated that water levels increase in both during high tide. Before the data loggers provided information on the tidal influence, a synoptic water-level measurement on April 14, 2007, resulted in data that were not reproducible, with groundwater depths changing over the course of minutes in some wells. Therefore, subsequent synoptic water-level measurements were made at low tide, when water levels changed little over the course of hours. The measurements involved opening the caps on all of the wells and allowing the water levels to stabilize for at least 30 minutes, then deploying multiple people to measure water levels using electric tapes in a time period of less than about 30 minutes. To ensure that the water levels were corrected to a uniform datum, Andrews and Burgess, Inc., remeasured the altitudes of all of the wells in 2008. The water-level measurements provided synoptic data for six dates in the surficial aquifer and five dates in the deeper aquifer. Solinst Leveloggers provided continuous water-level monitoring in several wells and selected storm sewers.

Sewer Mapping

This investigation used a variety of approaches to map and investigate the sanitary and storm sewers at Site 45 (fig. 6). In the initial stages of this investigation, the direction of transport in an abandoned sanitary sewer that drained the former dry-cleaning facility was determined by pouring water into the manhole. Scanned images of historical as-built engineering drawings of buildings and sewer lines imported into a geographic information system map of the site, including surveyed locations of manholes, provided the framework for generating the map of sanitary- and storm-sewer locations. A commercial in-line sewer camera, used in the sanitary sewer from the former dry-cleaning facility and in several of the storm sewers, provided information on sewer integrity and confirmed connections between manholes. The altitudes of the sewer inverts (bottom of the pipe entering a manhole) were determined by comparing surveyed altitudes of manholes to field tape-down measurements. The nomenclature for manholes and storm-sewer drains in this report includes a prefix of “SAS” for sanitary sewer or “STS” for storm sewer, followed by a numeric identifier.

The USGS conducted a dye test on August 30, 2007, to verify the location of the storm-sewer discharge and to determine the time-of-transport for water in the storm sewer to reach the discharge location from Site 45. The test involved inserting 1 liter of Red 25 dye (KingsCote Chemicals®) into manhole STS06 at 12:51, 12 minutes after high tide (fig. 6). Monitoring of the dye transport with the outgoing tide took place in two manholes along the storm sewer and at the outfall to a tributary to Ballast Creek. A chlorophyll fluorometric sensor in manhole STS25 (fig. 7A) detected the arrival of the dye pulse.



EXPLANATION

- STS05

 Sanitary sewer, manhole, and location identifier. Sewer dashed where historical or uncertain location. Arrows show direction of drainage at low tide.
- SAS01
 Sanitary sewer, manhole, and location identifier. Sewer dashed where historical. Arrows show direction of drainage.
- Section of storm sewer that is known or suspected to be lower than the water table.

Figure 6. Storm sewers and sanitary sewers at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

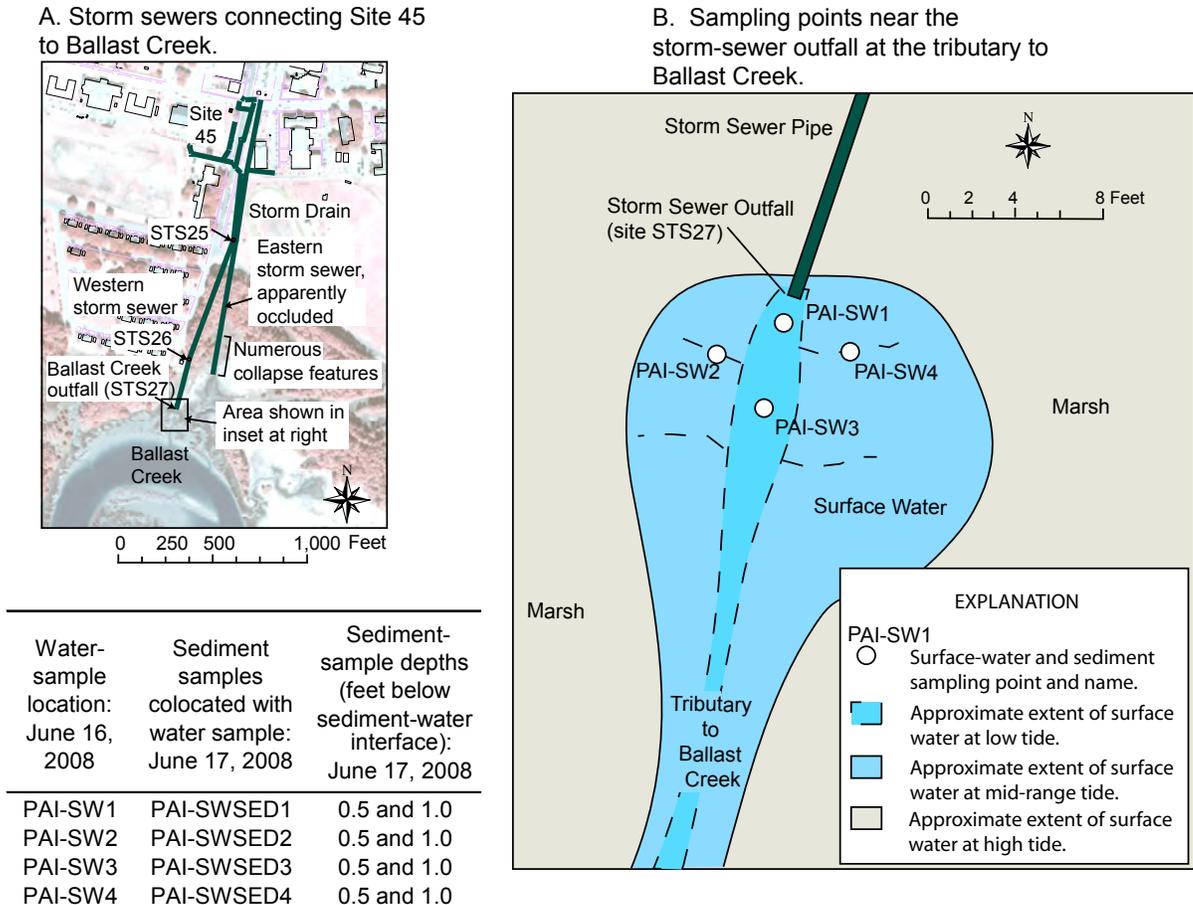


Figure 7. Locations of (A) storm sewers and (B) surface-water and sediment samples collected at the storm-sewer discharge from Site 45 to Ballast Creek, Marine Corps Recruit Depot, Parris Island, South Carolina, June 16–17, 2008.

Sediment Sampling

This investigation included collection of sediment samples from the tributary to Ballast Creek in the vicinity of the storm-sewer outfall at high tide using a 424-B40 hand corer (Wildlife Supply Company) (fig. 7B). Field personnel used the corer to collect the sediment in cellulose acetate liners, and then they extruded the sediment from the acetate liners into sampling syringes. The syringes were part of a U.S. Environmental Protection Agency (USEPA) Method 5035 O2SI Sample Smart Field Preservation Kit for sediment sampling (O2SI Smart Solutions, P.O. Box 30712, Charleston, SC). This kit consists of preserved syringes that allow a 14-day holding time for VOCs and analysis of moisture content. Sediment sample depths were 0.5 and 1 ft below the bed surface at each of four locations (fig. 7). Samples were analyzed for VOC content and percentage of moisture.

A limited number of sediment samples from the aquifer and confining material were analyzed for total organic carbon (TOC) content by method SW846-9060 (U.S. Environmental Protection Agency, 1999). A split-spoon sampler provided the core material from well PAI-45-MW28-D, and a direct-push technology method provided the core material from temporary well PAI-45-USGS-TW96. The sediment sample from well PAI-45-MW26-SL consisted of fine-grained sand that infiltrated the well screen after the well was completed, and, therefore, was skewed toward material fine enough to pass the well screen.

Selected core samples were analyzed onsite by the AQR Color-Tec® method (Kelso, 2005). This method consisted of collecting sediment by push technology and placing the sediment in a volatile organic analysis (VOA) vial with deionized water to make a slurry. The slurry was aerated by bubbling to collect the dissolved gas, which was passed through a colorimetric indicator tube. The colorimetric response is a relative response of total chlorinated VOC concentration.

Surface-Water and Storm-Drain Sampling

Water samples from surface water and storm drains were collected by means of a peristaltic pump attached to clean polyethylene tubing. The tubing was inserted through the center of a piece of rigid PVC pipe and extended to the sampling location. The tubing was then extended to beneath the water surface, and a water sample was collected by means of the peristaltic pump. Water samples were collected from the storm sewers at or soon after low tide while storm-sewer water was still moving toward Ballast Creek. An exception was on June 25, 2007, when a sample was collected during high tide from storm drain STS21 to measure pH, specific conductance, and temperature of incoming water (fig. 6).

Well Sampling

Water samples from the temporary wells were collected immediately after well installation by extending tubing to the screened interval and removing water with a peristaltic pump until the apparent turbidity diminished. Stabilization to field properties was not done because the wells were sampled immediately after opening the retractable well-screen cover, and, therefore, no stagnant casing water should have been in the borehole. The water samples were analyzed for VOCs.

Permanent wells at Site 45 were sampled by a variety of methods. The sampling approaches included low-flow methodology, diffusion-sampler methodology, and multiple casing-volume purges prior to sampling.

Prior to September 2007, all of the pumped water samples from wells were obtained by using low-flow methodology (Barcelona and others, 1994; Shanklin and others, 1995). Low-flow sampling, however, proved difficult and raised questions about sample quality because of tidal effects and the presence of vertically stratified specific conductance. The proximity of the well screens to specific-conductivity stratification sometimes resulted in continuous changes in specific conductance during low-flow stabilization that were more related to induced movement of low-conductivity or high-conductivity water toward the well rather than to well purging. For example, in July 2006, well PAI-45-MW20-SL was pumped by low-flow methodology for 2 hours and 17 minutes in an attempt to stabilize field properties so that low-flow samples could be collected. At that point, specific conductance was still slowly decreasing; however, the samples were collected because of concern that continued pumping would result in samples that no longer represented groundwater in the immediate vicinity of the well screen. In addition, recent work has shown that in-well convection cells can develop during the winter, resulting in a mixing of water during low-flow sampling that can substantially increase equilibration times, can cause false stabilization of indicator properties, can give false indications of the redox state, and can provide microbiological data that are not representative of the aquifer conditions (Vroblecky and others, 2007).

To reconcile these low-flow sampling issues, all of the wells except the deep well (PAI-45-MW-04D) were sampled in September 2007 by first evacuating three casing volumes of water from the top of the well casing and then lowering the sampling tubing to the screened interval and collecting the water samples. This was done to simplify the sampling process and to produce samples thought to be more representative of the immediate vicinity of the screened interval. The wells were purged by peristaltic pump from the top of the water column, and the intake tubing followed the water column down if drawdowns occurred. After three casing volumes were purged, the peristaltic tubing was lowered to the top of the screened interval, and approximately 0.5 to 1 gallon was purged, followed by field parameter measurement and sample collection. Stabilization to field properties was not done because the change in properties with continued pumping would reflect movement of conductivity interfaces in the aquifer rather than being related to the reliability of the well purge. In general, water levels were not allowed to drop into the screened interval during the three-casing-volume purge.

Low-flow sampling of wells continued to be used in wells where the static water level was within the screened interval of the well. In those cases, it was advisable to limit the amount of drawdown during pumping so as to avoid contaminant volatilization as water cascaded down the well screen. During low-flow sampling, the wells were purged at 120–250 milliliters per minute (mL/min), until the temperature, pH, dissolved oxygen (DO), and specific conductivity stabilized and no additional water-level drawdowns were observed. Stabilization of temperature, pH, dissolved oxygen, and specific conductance was observed by passing the water through a flow-through cell containing field-calibrated sensors. The field properties were considered to be stabilized when the observed changes over three 3-minute intervals were within ± 3 percent for temperature and specific conductance, within ± 0.1 unit for pH, and within ± 10 percent for dissolved oxygen. VOCs and dissolved gases were collected with no headspace in 40-mL vials preserved by hydrochloric acid, and were analyzed by USEPA method 8260B at General Engineering Lab in Charleston, SC. Samples for dissolved metals were preserved with nitric acid, samples for dissolved total organic carbon were preserved with sulfuric acid, and anions were preserved by chilling. Molecular hydrogen samples were collected by a bubble-strip method and analyzed by Microseeps, Inc. Samples for molecular analysis were obtained by filtering water and sending the filters to Microbial Insights for analysis.

A vertical profile of specific conductance was measured in well PFM02, which is fully screened across the saturated zone from about 4 to about 20 ft below land surface. The profile was accomplished by using a YSI XLM conductivity sonde on June 14, 2007. The sonde was lowered into the well to a depth of about 2.7 ft. The readings of temperature, specific conductance, dissolved oxygen, and pH were allowed to stabilize, which generally took about 7 or 8 minutes. Readings were recorded and the sonde was lowered to the next measurement depth. Measurements were made at depth intervals of 3.28 ft, moving from the shallowest to the deepest depth.

Compound-Specific Isotope Analysis

Selected water samples were collected for compound-specific isotope analysis (CSIA) using carbon in the chlorinated solvents. CSIA can be used to examine biodegradation of contaminants. The two stable isotopes of carbon are ^{12}C and ^{13}C , of which ^{12}C is the lighter, more abundant, and more readily biodegraded. The ratio of $^{13}\text{C}/^{12}\text{C}$ relative to a reference standard of the Vienna Pee Dee Belemnite ($\delta^{13}\text{C}$) usually is reported in units of parts per thousand, or per mil (‰). Because the lighter isotope is more readily biodegraded, the resulting fractionation, or change in the $\delta^{13}\text{C}$, can indicate biodegradation. As the reaction proceeds, the reactant that remains becomes enriched in the heavier isotope, and the $\delta^{13}\text{C}$ value becomes progressively less negative (Hunkeler and others, 1999). Carbon isotope fractionation is not significant (for example, <0.5 ‰) for non-degradative processes such as sorption, but can be on the order of tens of ‰ for degradative processes (Dempster and others, 1997; Harrington and others, 1999; Poulson and Drever, 1999; Slater and others, 1999, 2000). The use of isotope ratio measurements of carbon in both parent and daughter compounds, therefore, can complement the conventional approach to monitoring of chlorinated-solvent concentrations and site geochemistry (Hunkeler and others, 1999; Sherwood Lollar and others, 1999, 2001; Song and others, 2002; Vieth and others, 2003).

Investigation-Derived Waste

Investigation-derived waste (IDW) generated during this investigation included waste sediment cuttings from drilling operations and wastewater from well development, purging, and sampling. All IDW was containerized. The drilling contractor removed all IDW associated with drilling operations. In 2007, removal of the IDW from the site was the responsibility of the Navy. In 2008, removal of IDW from USGS operations was the responsibility of the USGS. The USGS containerized all surplus water from well sampling during 2008 in 55-gallon drums, and Fenn Vac, Inc., removed the waste from the site on September 29, 2008.

Site Description

MCRD, Parris Island, is a military training site surrounded by the Broad River to the west, the Beaufort River to the east, the confluence of those two rivers to the south, and Archers Creek to the north (fig. 1). The island is interfingered by several tidal creeks. Site 45 is relatively flat lying and is approximately 6 to 9 ft above North American Vertical Datum of 1988 (NAVD 88).

Movement of groundwater contamination at Site 45 is controlled by site hydrology. The site hydrology is influenced by a complex mixture of hydrogeologic aspects and by exchange of groundwater and surface water from leakage at storm sewers.

Hydrogeology

The surficial aquifer at Site 45 consists of sand interspersed with discontinuous beds of clay, silty clay, silty clayey sand, and clayey silt and extends to a depth of about 18 ft below land surface (BLS) (Tetra Tech NUS, Inc., 2004). Monitoring wells in this undifferentiated zone are referred to as SU wells if they are screened predominantly shallower than about 11 ft BLS and are referred to as SL wells if they are screened predominantly deeper than about 10 ft BLS.

A peat layer, which is a few feet thick, has been reported at depths of about 17 to 27 ft BLS overlying a clay layer that functions as a confining bed (Tetra Tech NUS, Inc., 2004). The part of the aquifer below this clay is considered to be the "D" horizon. Core samples collected during this investigation showed the peat layer to be a complex mixture of sand, silt, and clay with a substantial amount of black to brown organic material. The layer was encountered at a depth of 17.8 ft BLS in well PAI-45-MW28-D and 18.7 to 18.8 ft BLS at wells PAI-45-MW29-D and PAI-45-MW30-D. Sediment that probably was the top part of the layer was encountered at a depth of 15.2 ft BLS at well PAI-45-USGS-TW96.

The thickness of the clay at the base of the surficial aquifer was about 5 to 8 ft in wells drilled during a previous investigation (Tetra Tech NUS, Inc., 2004). During the present investigation, descriptions on the clay layer are based partly on split-spoon samples (top part of the clay) and partly on cuttings from mud-rotary drilling (bottom part of the clay). Thus, there is some uncertainty about the thickness of the clay. The clay layer at well PAI-45-MW28-D appeared to be about 3.5 ft thick at well PAI-45-MW28-D and between 2 and 3 ft thick at well PAI-45-MW30-D. At well PAI-45-MW29-D, an organic rich silt was encountered at a depth of 18.8 ft BLS. Mud-rotary cuttings below a depth of 19.6 ft BLS in well PAI-45-MW19-D showed a thin layer of sand, possibly at a depth of about 20–21 ft BLS, underlain by about 7.5 ft of clay.

The surficial aquifer at well PAI-45-MW28-D consists of silty sand with a zone of fine-grained very loose sand between about 6 and 11.4 ft BLS. The loose-sand zone probably constitutes the most permeable part of the surficial aquifer at well PAI-45-MW28-D. In the midpart of the plume at temporary well PAI-45-USGS-TW96 (near wells PAI-45-MW31-SL and PAI-45-MW31-SU), the sediment between depths of 4 and 16 ft BLS is sandiest between depths of 8 and 15.3 ft BLS, with fine-grained, loose sand at a depth of 8–10 ft BLS. The 8- to 10-ft zone probably constitutes the most permeable part of the surficial aquifer at well PAI-45-USGS-TW96. These findings are consistent with a previous passive-flux study showing a zone of relatively high Darcy flux between depths of about 9.5 and 11 ft BLS near the midpart of the southern plume at wells PFM-02 and PFM-03 (EnviroFlux, LLC, 2007). The lithologic and passive-flux data indicate that the most permeable part of the surficial aquifer in the southern plume beneath Kyushu Street probably is in the range of 6–11.4 ft BLS near the new dry-cleaning facility and about

8–10 ft BLS in the approximate midpart of the plume near wells PAI-45-MW31-SL and PAI-45-MW31-SU.

In the downgradient part of the plume near well clusters PAI-45-MW04 and PAI-45-MW20, passive-flux tests from the previous investigation showed a higher Darcy flux in the SU wells relative to the SL wells (EnviroFlux, LLC, 2007; Hackett and others, 2008). These findings are consistent with previously published slug-test data showing that the geometric mean of hydraulic conductivity (K) calculated from upper surficial aquifer wells [8 feet per day (ft/d)] was slightly greater than that calculated from the lower surficial aquifer wells (2 ft/d) (Tetra Tech, NUS, Inc., 2004).

A broad range of groundwater flow rates can be calculated from previously reported well tests at Site 45. Typical Darcy velocities estimated from passive-flux meter tests were about 0.027 ft/d [0.82 centimeter per day (cm/d)] at well MW10SL and about 0.020 to 0.095 ft/d (0.6 to 2.9 cm/d) at well PFM-01 (Enviroflux, LLC, 2007). At wells PFM-02 and PFM-03, the Darcy velocities ranged from about 0.033 to 0.164 ft/d (1 to 5 cm/d) at depths below 10 ft. Using a geologically reasonable porosity of 0.3 to 0.45, the calculated seepage velocity (Darcy velocity divided by porosity) ranges from about 16 to 199.5 feet per year (ft/yr).

Slug tests in the lower surficial aquifer by Tetra Tech NUS, Inc. (2004) showed a geometric mean K of about 2 ft/d. The hydraulic gradients between wells PAI-45-MW25-SL and PAI-45-MW31-SL and between wells PAI-45-MW31-SL and PAI-45-MW20-SL are about 0.0052 to 0.0053, based on the average of instantaneous gradients measured at 15-minute intervals between September 10 and September 29, 2008, during the present investigation. Using an assumed range of porosity of about 0.3–0.45, the seepage velocity [$(K \times \text{hydraulic gradient})/\text{porosity}$] can be calculated to be about 9–13 ft/yr.

Aquifer tests from a previous investigation gave an overall average K for the surficial aquifer of about 15.3 ft/d (Tetra Tech NUS, Inc., 2004). Using a hydraulic gradient of about 0.0052–0.0053 and a range of porosity of about 0.3–0.45, the calculated seepage velocity is about 65–97 ft/yr.

The variety of calculated seepage velocities in the previous discussion illustrates the uncertainty with calculations of groundwater velocity. The actual groundwater velocity almost certainly varies across the site with aquifer heterogeneity. Based strictly on aquifer tests (Tetra Tech NUS, Inc., 2004), the mean groundwater velocity in the southern plume is between the end values of about 9 and 97 ft/yr.

The surficial aquifer at Site 45 is unconfined. Depth to water is about 2–6 ft. Groundwater is recharged primarily from rainfall infiltration in non-paved areas. Some amount of recharge also may take place during rainfall events through partially collapsed storm sewers. For example, on June 4, 2008, repairs were done on partially collapsed storm sewer STS01 (fig. 6). Prior to the repairs, runoff from Kyushu Street south of the new dry cleaner collected and flowed into the asphalt cracks adjacent to the storm drain rather than into the storm drain. Thus, rainfall-derived runoff flowed into a

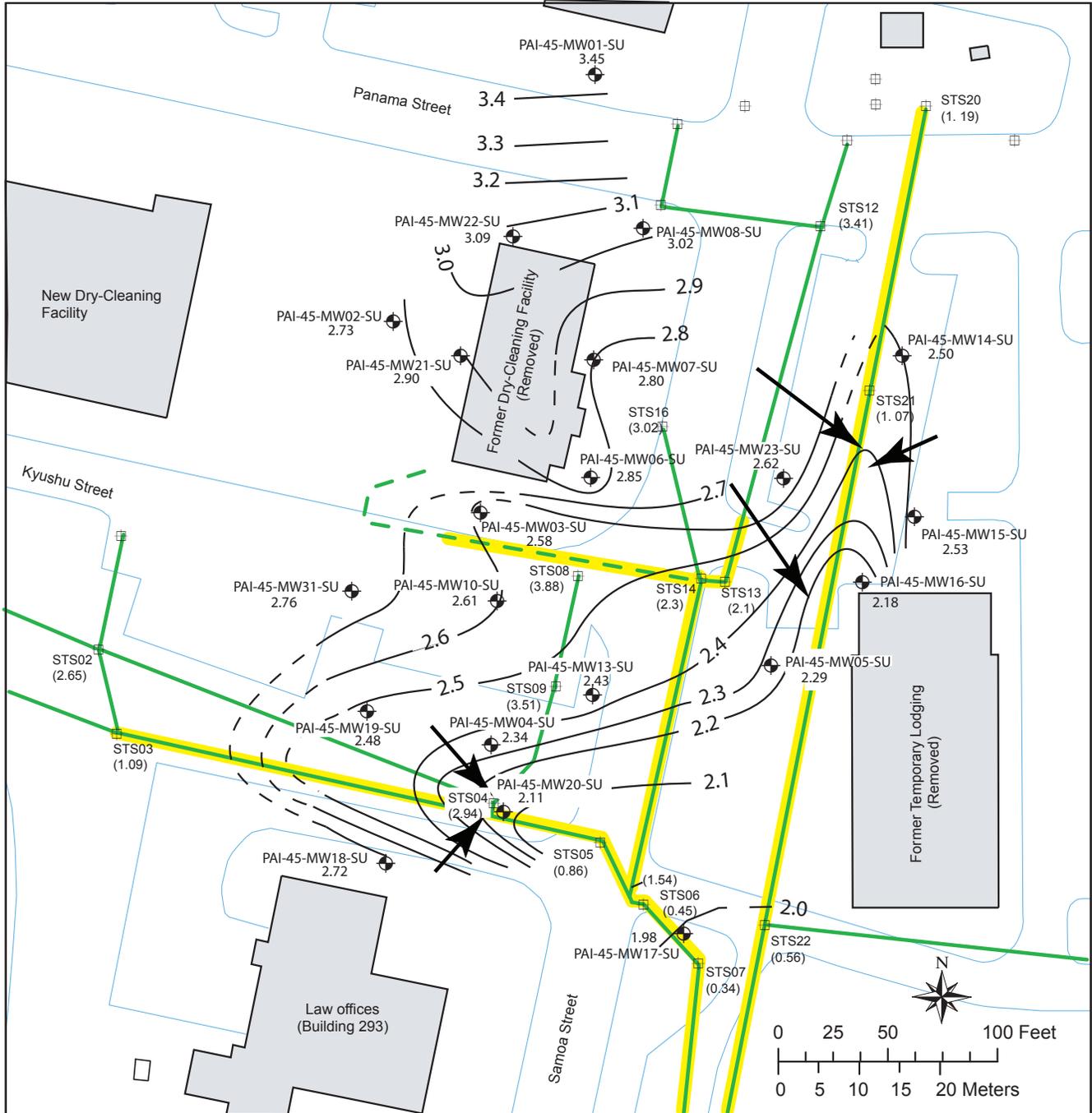
focused part of the aquifer rather than being diverted offsite by the storm-sewer system. Because partially collapsed storm sewers are not always obvious from a casual surface inspection, there is the possibility that such localized rainfall infiltration is or has been influential in other parts of the site.

A primary discharge path for groundwater at Site 45 appears to be to storm sewers. The inverts (bottoms) of some sections of the storm-sewer system at Site 45 are below the high-tide level and below the groundwater levels (figs. 8 and 9). At the downgradient part of the southern plume, the bottoms of manholes STS05 and STS06 are at altitudes of 0.86 and 0.45 ft relative to NAVD 88 (about 5.5 and 5.4 ft BLS) and about 1.2 and 2.4 ft below the water table, respectively (fig. 8). At the downgradient part of the northern plume, the bottoms of manholes STS13 and STS21 are at altitudes of 2.1 and 1.07 ft relative to NAVD 88 (about 4.3 to 4.6 ft BLS) and about 0.3 to 1.3 ft below the water table, respectively (fig. 8).

Groundwater in both the SU and SL wells shows a general movement from the northwest to the southeast (figs. 8 and 9). The groundwater contours in the SU wells show strong curvature toward some of the storm sewers where the inverts of the sewers are deeper than the water table (fig. 8). These data indicate that groundwater discharges to the storm-sewer system in those areas. Curvature of the groundwater contours is less pronounced for the SL wells than for the SU wells, possibly reflecting a diminished hydraulic influence from the storm sewers on the deeper part of the surficial aquifer (fig. 9).

Infiltration of groundwater into sewers is not unusual when the sewers are below the water table, and in some municipal systems, infiltration of groundwater to sewer systems can be widespread and overwhelming (Wolf and others, 2003; Jamison, 2007). Discharge of groundwater to storm sewers at Navy bases may be more common than currently recognized considering the low altitude of many Navy bases and a previous report of groundwater discharge to storm sewers at U.S. Naval Air Station, Jacksonville, Florida (Davis, 2003).

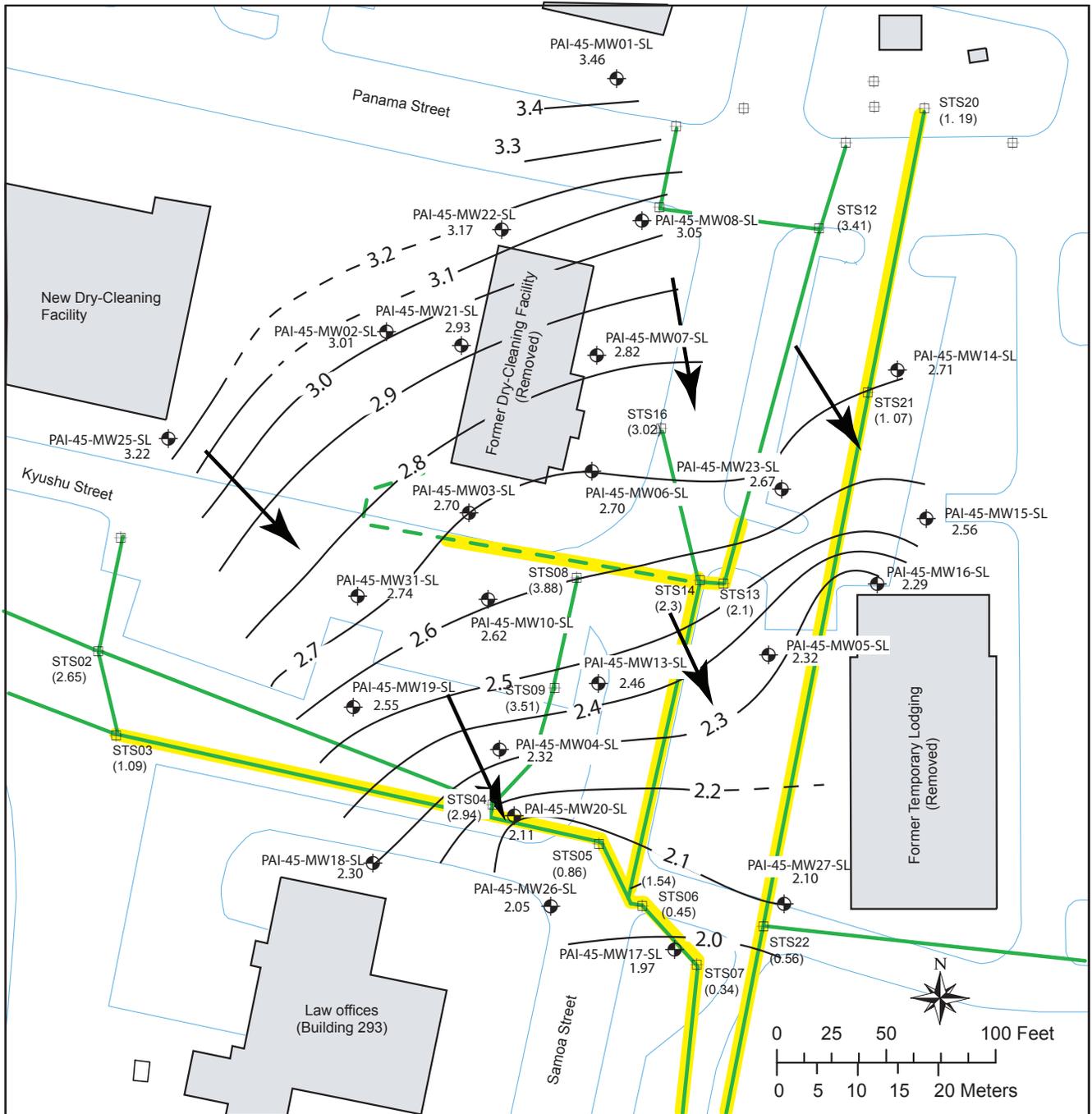
Because the storm-sewer system connects to tidally influenced Ballast Creek, tidal water enters the storm drains through an open drain approximately 1,400 ft south of Site 45 during incoming tides. Incoming tidal water moves inland through the sewer system at least as far as to Site 45. A water-level logger recorded tidally induced water-level increases of more than 3 ft in the storm sewer at manhole STS06 (fig. 10). Surficial aquifer groundwater levels in the vicinity of the storm sewers also rise and fall in response to tidal cycles. In general, where the invert of the storm sewer is below the water table, groundwater levels tend to be higher than water levels in the storm sewer at low tide and lower than in the storm sewer about 1 to 2 hours preceding and following high tide. The higher water levels in the storm sewers than in the groundwater about 1 to 2 hours preceding and following high tide indicate a short-term potential for movement of tidal water from the storm sewers to the aquifer.



EXPLANATION

- 2.3 — - Water-level contour, June 27, 2008. Interval is 0.1 foot. Datum is North American Vertical Datum of 1988 (NAVD 88). Dashed where inferred. Arrows show general direction of groundwater movement.
- PAI-45-MW20-SU
2.61
Monitoring well, identifier, and water level, in feet above NAVD 88, June 27, 2008, low tide.
- STS06
(0.45)
Storm sewer, manhole or drain, and location identifier. Line dashed where historical or uncertain location. Storm sewer is highlighted in yellow where it is known or suspected to be below the water table. Number in parentheses is estimated altitude of invert, in feet above NAVD 88.

Figure 8. Groundwater levels in the SU wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.



EXPLANATION

- 2.3 - - Water-level contour, June 27, 2008. Interval is 0.1 foot. Datum is North American Vertical Datum of 1988 (NAVD 88). Dashed where inferred. Arrows show approximate direction of groundwater movement.
- PAI-45-MW20-SL
2.11

 Monitoring well, identifier, and water level, in feet above NAVD 88, June 27, 2008, low tide.
- STS06
(0.45) Storm sewer, manhole or drain, and location identifier. Line dashed where historical or uncertain location. Storm sewer is highlighted in yellow where it is known or suspected to be below the water table. Number in parentheses is estimated altitude of invert, in feet above NAVD 88.

Figure 9. Groundwater levels in the SL wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.

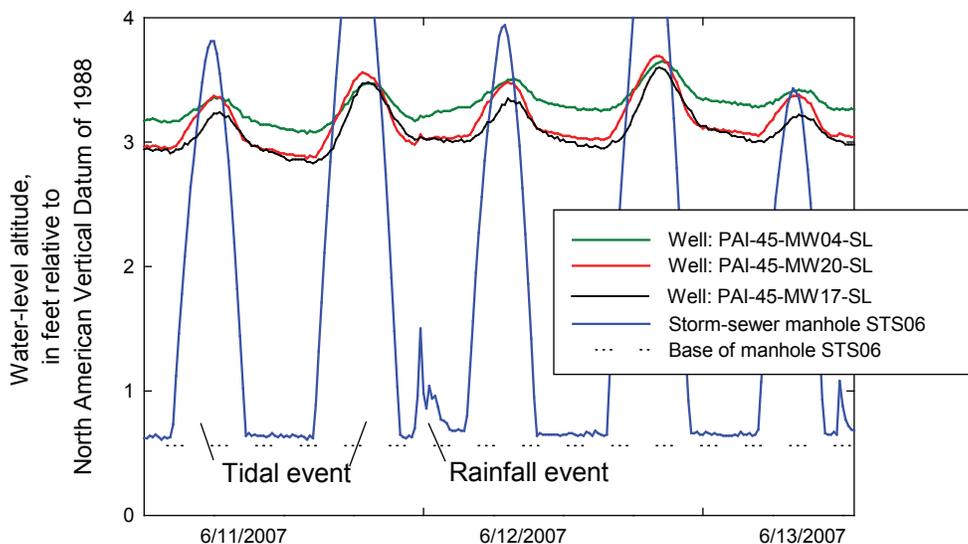


Figure 10. Water levels in selected monitoring wells and storm-sewer manhole STS06, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 11–13, 2007.

A groundwater map for the “D”-horizon wells is not shown because groundwater levels across the site on June 27, 2008, differed by only 0.16 ft or less, with the exception of well PAI-45-MW11-D. In general, the slight hydraulic gradient was from the northwest to the southeast. In contrast, the groundwater level in well PAI-45-MW11-D typically showed a marked dissimilarity from the other D-horizon wells. For example, on June 27, 2008, the groundwater level in well PAI-45-MW11-D was more than 1 ft lower than the groundwater level in any other D-horizon well and appeared to be more sensitive to tidal fluctuations than the remaining D-horizon wells. Water levels in well PAI-45-MW11-D were more than 2 ft lower than in wells in the overlying SL horizon. Releveling of the well measuring point revealed no significant datum error. The reason for the anomalous water levels in well PAI-45-MW11-D was not investigated further.

Groundwater Chemistry

The surficial aquifer at Site 45 is anaerobic at most locations, with DO concentrations less than 0.3 milligram per liter (mg/L) and sometimes less than 0.025 mg/L. Although aerobic groundwater conditions in the shallow part of the surficial aquifer were observed during two events at well PAI-45-MW-20-SU (September 29, 2006, and September 10, 2007) and during one event at well PAI-45-MW-05-SU (September 8, 2008), anaerobic conditions also prevailed in groundwater from these wells on other sampling dates. Thus, the dominant redox reactions in the contaminated aquifer are anaerobic.

The specific terminal electron accepting process (TEAP) probably varies spatially in the study area. The patchy brown

coloring of the sand in some shallow parts of the surficial aquifer (less than about 6–8 ft BLS) indicates that iron reduction probably is an active electron accepting activity in the shallowest sediment (lithologic logs from wells PAI-45-MW28-D and PAI-45-USGS-TW96). The USEPA reported an increase in acid-extractable iron from sediment cores with depth from about 8.4 to 16 ft BLS in the upgradient part of the southern plume (Scott Huling, U.S. Environmental Protection Agency, written commun., 2009). These data may mean that iron reduction continues to be a predominant TEAP to a depth of at least 16 ft BLS; however, it also is possible that the acid-extractable iron does not represent bioavailable ferric iron. Data from the present investigation indicate that the dominant TEAP in groundwater from some of the SL wells is more reducing than iron reduction.

The sediment is predominantly gray at depths below about 8 ft in parts of the southern plume, indicating less of a potential for iron reduction at depth than in shallower sediment. When ferric iron is unavailable and sulfate is present in an anaerobic aquifer, sulfate reduction is commonly the predominant TEAP. Sulfate concentrations in groundwater in the vicinity of the southern-plume source area are about 40 to 50 mg/L (well PAI-45-MW25-SL). In the downgradient part of the southern plume at well PAI-45-MW20-SL, sulfate concentrations in the groundwater are about 112 to 130 mg/L. In anaerobic aquifers lacking more efficient electron acceptors, such as ferric iron, these concentrations are sufficient to allow sulfate reduction to outcompete methanogenesis (Vroblesky and others, 1996). If the gray sediment at depths below 8 ft indicates that there is insufficient bioavailable ferric iron to support iron reduction, then it is likely that sulfate reduction is the predominant TEAP in much of the contaminated

aquifer of the southern plume. Although sulfide typically was not detected in the wells, 0.28 to 0.47 mg/L of sulfide was detected in groundwater at well PAI-45-MW20-SU during 2008. In addition, molecular hydrogen (H_2) measurements ranged from 1.1 to 3.4 nanomoles per liter (nM) in six out of the seven tested wells in the surficial aquifer. H_2 concentrations in anaerobic systems can be classified as follows: less than 0.1 nM, characteristic of denitrification; 0.2–0.8 nM, characteristic of iron reduction; 1–4 nM, characteristic of sulfate reduction; and greater than 5 nM, characteristic of methanogenesis, with in-between ranges being not diagnostic (Chapelle and others, 1997). Thus, most of the measured H_2 concentrations were in the range of sulfate reduction. The H_2 concentration in one out of the seven tested wells was in the range characteristic of methanogenesis.

The methane concentrations in groundwater from the source-area well of the southern plume (PAI-45-MW25-SL) are relatively low [180–754 micrograms per liter ($\mu\text{g/L}$)]; however, methane concentrations in groundwater from a number of other wells in the southern plume are greater than 1,000 $\mu\text{g/L}$. The elevated methane concentrations may partly represent methane from probable methanogenic degradation in the organic-rich layer (peat zone) at the base of the surficial aquifer, below the screened intervals of the monitoring wells. The presence of paved areas has the potential to trap some methane otherwise released from groundwater to the atmosphere, possibly explaining why methane concentrations are higher in the shallower SU wells than in the deeper SL well beneath Kyushu Street at well clusters PAI-45-MW10 and PAI-45-MW31. Low concentrations of acetic acid (0.11–0.33 mg/L) are present in groundwater from a number of wells in the southern plume, however, indicating that part of the methane probably represents localized pockets of methanogenesis in the surficial aquifer at or near the screened intervals of wells. Support of this hypothesis is that the H_2 value of groundwater at well PAI-45-MW31-SL was 31 nM on September 9, 2008, which is in the range of methanogenic conditions.

Groundwater in the SL wells had a greater specific conductance and greater chloride concentration than groundwater in the SU wells. The contrast is most pronounced at well cluster PAI-45-MW17, where the specific conductance of water was 622–942 microsiemens per centimeter ($\mu\text{S/cm}$) from the SU well and 4,264–5,917 $\mu\text{S/cm}$ from the SL well. Chloride concentrations ranged from about 68 to 162 mg/L in groundwater at the SU screen and from about 1,160 to 1,750 mg/L in groundwater at the SL screen. Because this well cluster is near a storm sewer that is more than 1 ft below the water table, the conductivity contrast may represent density stratification from leakage of saltwater from the storm sewer at high tide. Although not as pronounced as at well cluster PAI-45-MW17, the elevated specific conductance, chloride, and sodium concentrations in SL wells (compared with the SU wells) at other tested well clusters indicates some degree of vertical density stratification elsewhere in the surficial aquifer. Additional evidence for conductivity stratification can be

seen at well PFM-02 (fig. 3) in the central part of the southern plume, where the specific conductance substantially increases with depths greater than 15 ft BLS (fig. 11).

In the three D-horizon wells tested below the surficial aquifer in this investigation (wells PAI-45-MW28-D, -MW29-D, and -MW30-D), the chloride and specific conductance were substantially greater than in the surficial aquifer. Chloride concentrations ranged from 1,940 to 5,520 mg/L, and specific conductance ranged from 7,050 to 17,714 $\mu\text{S/cm}$. Salinity measured in well PAI-45-MW29-D [8.1 milligrams per milliliter (mg/mL)] indicated that water in the D horizon is brackish.

Low levels of non-chlorinated-solvent constituents are present in groundwater in the surficial aquifer at concentrations exceeding USEPA maximum contaminant levels (MCLs). In September 2008, six wells in the surficial aquifer were sampled for dissolved arsenic. Of these six wells, two were SU wells, and neither contained arsenic at a detection limit of 0.005 mg/L. The four remaining wells were SL wells; three out of the four of these wells contained dissolved arsenic concentrations in the range of 0.13 to 0.22 mg/L, which is greater than the USEPA MCL of 0.01 mg/L (U.S. Environmental Protection Agency, 2002).

Finally, low concentrations of petroleum hydrocarbons were present in well PAI-45-MW27-SL near the former temporary lodging facility (table 1, fig. 3). The petroleum hydrocarbons were detected at similar concentrations in the sample and in a duplicate, and the anomalously low sulfate concentration (2.63–2.94 mg/L) and high methane concentration

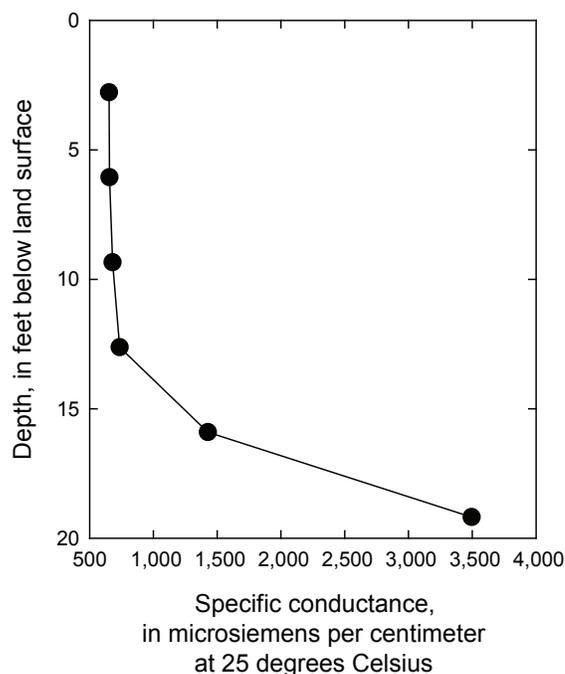


Figure 11. Vertical profile of specific conductance at well PFM-02, Marine Corps Recruit Depot, Parris Island, South Carolina, June 14, 2007.

(7,310–7,630 µg/L) are consistent with a shift from sulfate reduction to methanogenesis, as is common when petroleum hydrocarbons are present in an aquifer. Low concentrations of petroleum hydrocarbons also were detected in temporary wells drilled near the former temporary lodging facility in June and August 2007 (table 1, fig. 4). The source of the petroleum hydrocarbons is not known. Some of the benzene detections were slightly greater than the 5-µg/L MCL established by the USEPA (U.S. Environmental Protection Agency, 2008).

Distribution of Chlorinated-Solvent Groundwater Contamination

This investigation examined aspects related to areal and vertical distribution of the groundwater contamination. Data related to the areal distribution of groundwater contamination were collected for the southern plume and the downgradient part of the northern plume. Data related to the vertical distribution of groundwater contamination were collected only for the southern plume.

Areal Distribution of Groundwater Contamination

Groundwater contamination by chlorinated solvents at Site 45 is present in two lobes with some probable intermingling in downgradient parts (figs. 12–15). The northern plume extends southeastward from the northern part of the former dry-cleaning facility. The southern plume extends

from the southeastern corner of the new dry-cleaning facility to approximately the intersection of Samoa Street and the entrance to the Building 293 driveway. Because the northern plume has been studied extensively in previous investigations (Tetra Tech NUS, Inc., 2004, 2005), the present investigation concentrated on the southern plume and the downgradient part of the northern plume. The distribution of groundwater contamination shown in figures 12–15 represents data from multiple sampling events during an approximate 2-year period. In the southern plume, the data include groundwater samples from temporary wells installed for this investigation on multiple dates, from temporary wells installed during a previous investigation in 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2006), and from permanent wells that were sampled in 2008. Thus, the mapped configurations of individual constituents represent generalized distributions rather than snapshots in time. The data from the northern plume represent samples collected primarily during a single event (June 2007), but include data from a monitoring well sampled in June 2008.

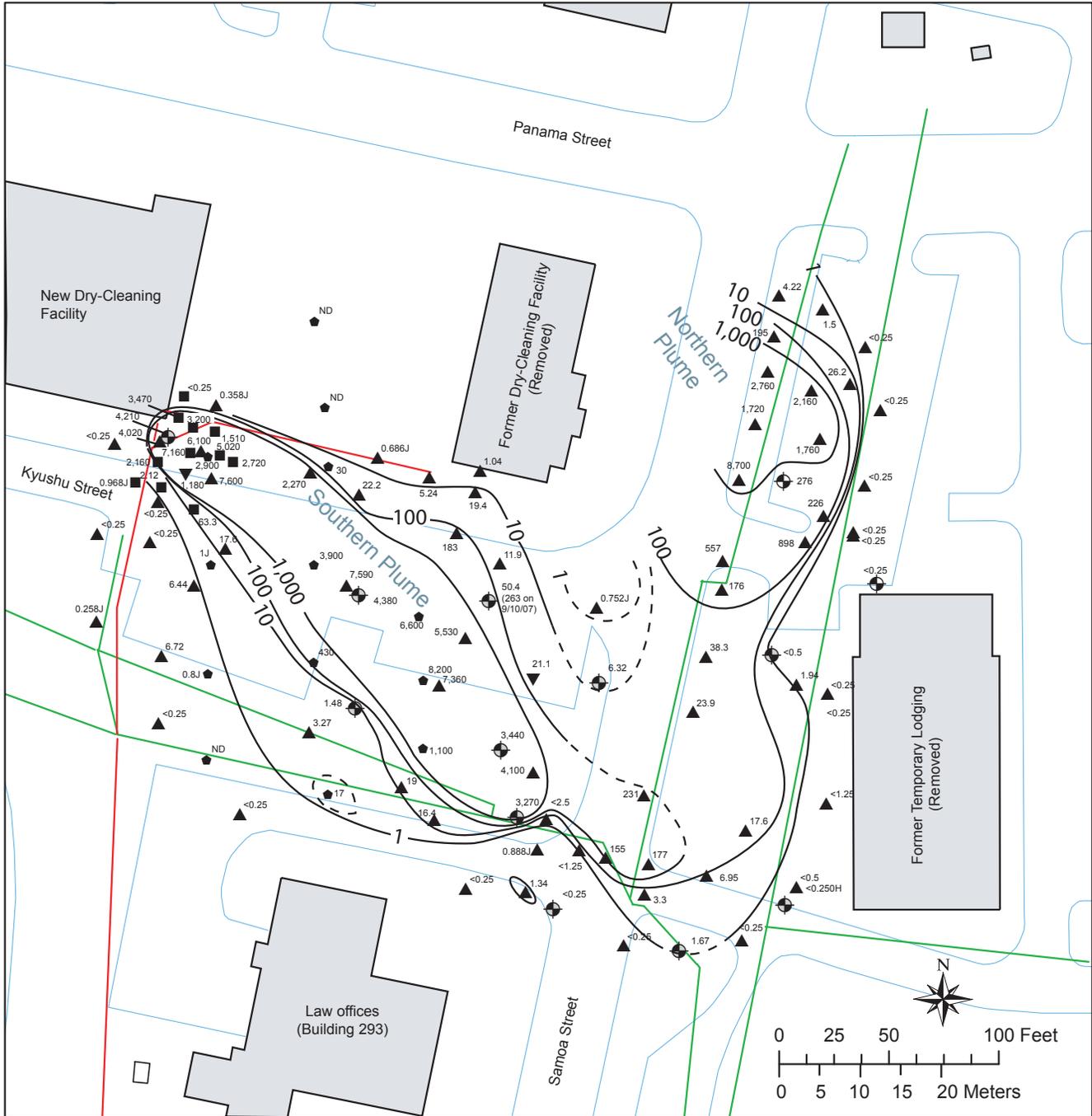
The downgradient part of the northern plume extends southeastward to the storm drain connected to storm drain STS21 (fig. 6). No detectable groundwater contamination was found in temporary or permanent wells east of that storm drain beneath the former temporary lodging parking lot (figs. 12–15).

The main part of groundwater contamination in the southern plume extends from the southeastern corner of the new dry-cleaning facility southeastward toward well PAI-45-MW20-SL (figs. 3 and 12). PCE concentrations in the southern plume were greatest in the source area at the southeastern corner of the new dry-cleaning facility (62,400 µg/L) and were greater than 10,000 µg/L in the middle part of the

Table 1. Concentrations of total organic carbon in sediment cores, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[J, estimated value; <, less than; MCL, maximum contaminant level for drinking water established by the U.S. Environmental Protection Agency, accessed on June 18, 2009, at <http://www.epa.gov/safewater/contaminants/index.html#mcls>]

Well identifier	Date	Concentration, in micrograms per liter				
		Benzene	Toluene	Ethylbenzene	Xylenes (total)	Naphthalene
PAI-45-MW27-SL	September 11, 2007	6.01	1.55J	5.14	8.44	606
PAI-45-MW27-SL duplicate	September 11, 2007	5.94	1.38J	4.94J	8.49	555
PAI-45-USGS-TW21	June 25, 2007	0.952J	<0.25	<0.25	<0.25	6.98
PAI-45-USGS-TW26	June 25, 2007	1.71	<0.25	<0.25	<0.25	<0.25
PAI-45-USGS-TW36	June 25, 2007	4.17	<0.5	1.21J	1.97J	81.9
PAI-45-USGS-TW65	June 28, 2007	5.36	<1.25	3.81J	6.55	397
PAI-45-USGS-TW71	August 29, 2007	2.66	0.759J	0.759J	0.773J	119
MCL	Not applicable	5	1,000	700	10,000	Not established



- ⊕ Monitoring well sampled during June 2008, unless otherwise noted
 - USGS Temporary well sampled during March 2008
 - ▼ USGS Temporary well sampled during August 2007
 - ▲ USGS Temporary well sampled during June 2007
 - ◆ Tetra Tech NUS, Inc., temporary well, 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)
 - 10 — Line of equal trichloroethene concentration, in micrograms per liter. Interval variable as shown. Dashed where uncertain.
 - Storm sewer
 - Sanitary sewer
- <0.25 Concentration of trichloroethene, in micrograms per liter. [<, less than; J, estimated; H, analyzed out of holding time; ND, not detected at unstated detection limit]

Figure 13. Generalized distribution of trichloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

plume beneath Kyushu Street (fig. 12). Concentrations of TCE were relatively uniform along the axis of the southern plume (fig. 13). *c*DCE was most concentrated (1,100–2,180 µg/L) near the middle part of the plume between temporary wells PAI-45-USGS-TW48 and PAI-45-USGS-TW53 (figs. 4 and 14). In general, VC also was most concentrated in the central part of the plume (greater than 100 µg/L) (fig. 15). An exception, however, is a temporary well (PAI-USGS-TW44) near the new dry cleaner where a VC concentration of 201 µg/L was found in the groundwater (fig. 15).

Vertical Distribution of Groundwater Contamination

A variety of lines of evidence contribute to the interpretation of the vertical distribution of groundwater contamination at Site 45. The data include lithologic descriptions, ECD logs from MIP investigations, sediment analysis from core samples, and groundwater samples from temporary and permanent wells (fig. 16).

Although well PAI-45-MW28-D is screened below the surficial aquifer, lithologic data collected during the well installation provide information on the nature of the surficial aquifer at that well. Based only on lithologic considerations from drilling cores at well PAI-45-MW28-D, the most permeable part of the surficial aquifer near the new dry-cleaning facility probably is at a depth of about 6.5 to 11.4 ft BLS (altitude of about –1 to –5.9 ft relative to NAVD 88). That horizon consisted of loose, wet sand (fig. 17A). The zone beneath the sand was siltier and, therefore, less permeable, indicating that a depth of about 11.4 ft probably is the base of the zone transmitting most of the groundwater in the surficial aquifer at well PAI-45-MW28-D. This horizon probably is a few feet deeper at the southeastern corner of the new dry-cleaning facility because of the slight rise in altitude relative to Kyushu Street.

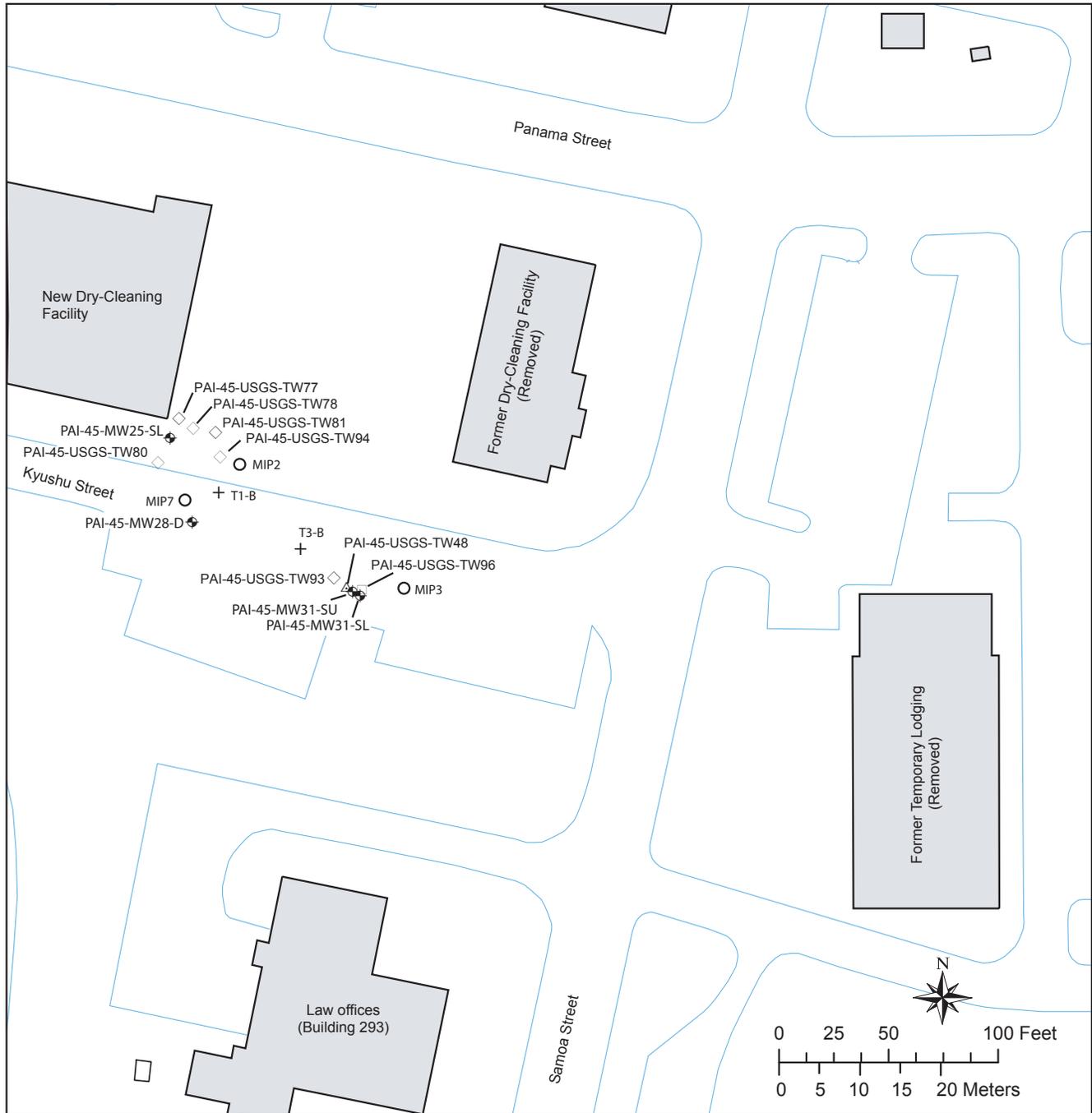
The ECD log indicates that at MIP7, near the new dry-cleaning facility, the VOC contamination begins at a depth of about 8 ft BLS (altitude of about –2.7 ft relative to NAVD 88), with a greater VOC concentration beginning at a depth of about 10–11 ft (altitude of –4.7 to –5.7 ft) below Kyushu Street (fig. 17B). At MIP2, also near the new dry-cleaning facility, but at a slightly higher altitude, a spike in the ECD log indicates a sharp increase in VOC contamination at a depth of about 12 ft BLS (altitude of about –5.3 ft relative to NAVD 88). The sharp increase in VOC contamination of MIP2 corresponds to the zone of increased VOC contamination at MIP7. The top of the zone of increased VOC contamination in MIP2 and MIP7 corresponds to the lowermost foot or so of loose sand at the probable base of the predominant flow regime in the surficial aquifer.

Temporary wells sampled near the new dry-cleaning facility at depths of 7–11 ft BLS had lower concentrations of VOCs than at 11–15-ft BLS (fig. 17C, table 2). Thus, VOC concentrations are greater near the base of the loose sand than near the top. Because the 11–15-ft temporary wells appear

to be partly screened in the loose sand and partly screened in the underlying less permeable material, most of the water sampled from the 11–15-ft temporary wells likely was derived from the loose sand in the top part of the screened interval rather than from the underlying less permeable material. This interpretation is consistent with the soil-core data indicating a sharp decrease in contaminant concentrations at depths greater than 12 ft BLS relative to shallower depths (fig. 17D) (Scott Huling, U.S. Environmental Protection Agency, written commun, 2009). Thus, it is likely that contamination near the new dry-cleaning facility is present from a few feet depth to about 11.5 ft BLS, most of the contamination is at a depth of about 8 to 11.5 ft. BLS, and the greatest concentrations are at the base of the 8–11.5 ft interval.

Further support for this hypothesis is that while temporary wells PAI-45-USGS-TW39 (upgradient part of the southern plume) and PAI-45-USGS-TW48 (midpart of the southern plume) were screened at depths of 10–14 and 10.5–14.5 ft BLS, respectively, and contained about 5,000 to 10,000 µg/L of PCE, several temporary wells between these two wells were screened at depths of 11–15 ft BLS and contained relatively little contamination (less than 250 µg/L and in most cases less than 50 µg/L of PCE). These wells included PAI-45-USGS-TW73, -TW74, -TW83, -TW87, -TW88, -TW90, -TW91, -TW92, and -TW93 (fig. 4). The data are consistent with the interpretation that 11- to 15-ft-deep wells with comparatively little contamination were screened below the major contamination depth; therefore, wells PAI-45-USGS-TW73, -TW74, -TW83, -TW87, -TW88, -TW90, -TW91, -TW92, and -TW93 are not included in figures 12–15. The depths of these wells were selected based on the MIP-log response showing relatively high ECD indications at depths from about 10 or 12 ft to about 15 ft (fig. 17B). It is likely, however, that as the MIP probe progressed downward, the most reliable reading was at the first encounters with contamination and the deeper ECD responses reflect some level of carry-over. Thus, in the area between temporary wells PAI-45-USGS-TW39 and PAI-45-USGS-TW48, there appears to be comparatively little contamination at depths greater than 11 ft BLS.

In the midpart of the southern plume at temporary well PAI-45-USGS-TW96, the most permeable zone appears to be a loose sand layer from about 8 to 10 ft BLS (figs. 16 and 18A). The shallowest sharp increase in ECD-log response was just above the base of this layer (fig. 18B), and greatest concentrations of VOCs detected in field measurements from this well were in the same layer (figs. 18C and 18E). Relatively high VOC concentrations also were detected at depths below 11 ft (figs. 18C and 18D). The VOC concentrations at temporary well PAI-45-USGS-TW96 decreased with depth below about 13 ft BLS (figs. 18C and 18E) and were not detectable (less than 0.2 parts per million) at depths of 14–14.8 ft directly above the organic-rich silt layer and at 15.2–16 ft in the organic-rich silt layer (fig. 18C). The less porous nature of the organic-rich layer relative to the overlying sand and the downward decrease in VOC concentrations in sediment immediately above the organic-rich layer indicates



EXPLANATION

- PAI-45-MW31-SL  Monitoring well and identifier
- MIP2  Membrane interface probe (MIP) location and identifier
- PAI-45-USGS-TW93  Temporary well installed and sampled March 2008, and identifier
- PAI-45-USGS-TW96  Temporary well cored April 2008, and identifier
- PAI-45-USGS-TW48  Temporary well installed and sampled June 2007, and identifier
- T1-B  Temporary well cored by the U.S. Environmental Protection Agency, 2008, and identifier

Figure 16. Locations of sampling points shown in figures 17 and 18, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

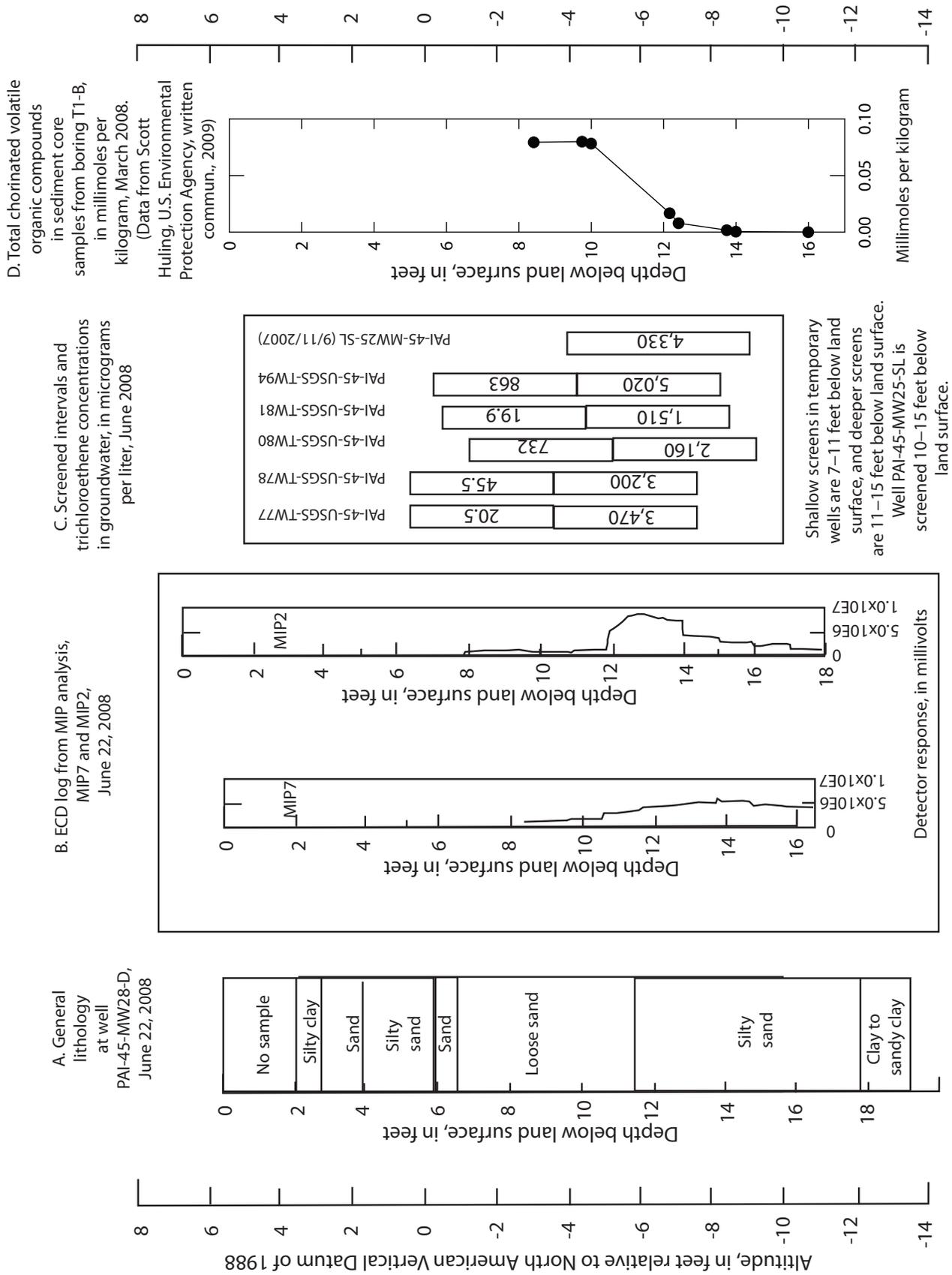


Figure 17. (A) Lithologic log, (B) electron-capture-detector (ECD) logs from Membrane Interface Probe (MIP) investigation, (C) trichloroethene concentrations in water from multiple depths in temporary wells, and (D) total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

Table 2. Concentrations of chlorinated volatile organic compounds in shallow and deeper temporary-well groundwater samples near the new dry cleaning facility, March 5, 2008.

[ft NAVD 88, feet relative to the North American Vertical Datum of 1988; ft BLS, feet below land surface; PCE, tetrachloroethene; TCE, trichloroethene; *c*DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; <, less than; J, estimated value; B, target analyte was detected in the associated blank]

Well identifier	Ground-surface altitude (ft NAVD 88)	Screen interval (ft NAVD 88)	Screen interval (ft BLS)	PCE	TCE	<i>c</i> DCE	VC
PAI-45-USGS-TW77	7.33	0.33	7–11	0.351J	20.5	47.9	<0.3
		–3.67	11–15	454	3,470	365	<15
PAI-45-USGS-TW78	7.34	0.34	7–11	10.1	45.5	117	<0.3
		–3.66	11–15	<12.5	3,200	761	<15
PAI-45-USGS-TW80	5.54	–1.46	7–11	366	732	82.6	<3
		–5.46	11–15	6,170	2,160	112	<30
PAI-45-USGS-TW81	7.67	0.67	7–11	<0.25	19.9	107	<0.3
		–3.33	11–15	14.0J	1,510	573	<7.5
PAI-45-USGS-TW94	6.6	0.67	7–11	331	863	213	<0.3
		–3.33	11–15	754B	5,020	323	2.07

that the organic-rich layer is not a major contaminant-transport pathway at well PAI-45-USGS-TW96. These data indicate that the probable depth of contamination in the midpart of the southern plume at well cluster PAI-45-MW31 is about 6–14 ft BLS, with most of the contamination between about 8 and 11 or 12 ft BLS and the largest potential for lateral transport between about 8 and 10 ft BLS.

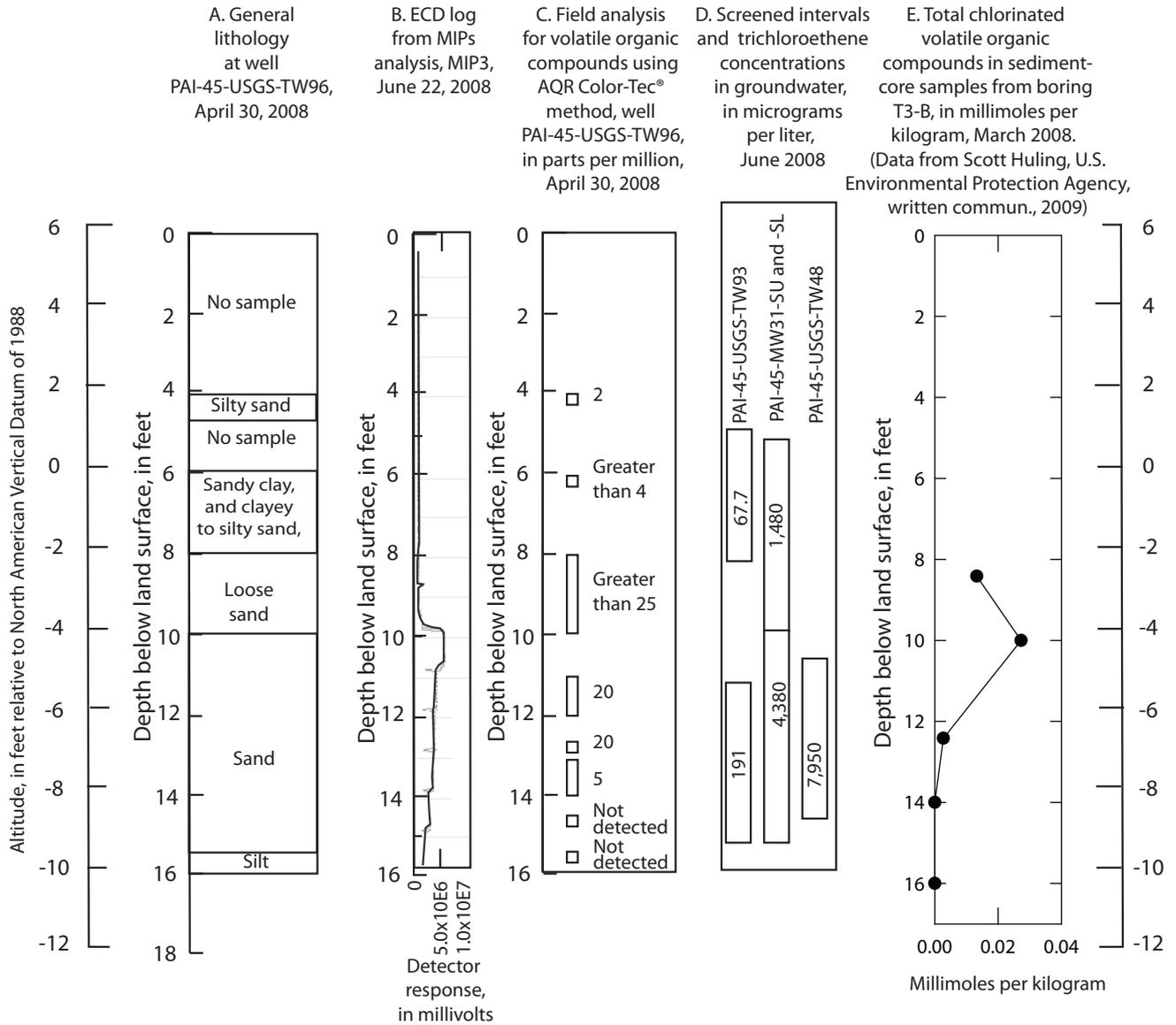
Wells PAI-45-MW28-D, PAI-45-MW29-D, and PAI-45-MW30-D (fig. 3) were installed below the clay layer at the base of the surficial aquifer to gain further information on water levels and water quality below the surficial aquifer. It cannot be stated with certainty that no VOC contamination is in the D horizon underlying the clay that defines the base of the surficial unit because the wells in the D horizon near the new dry-cleaning facility were installed slightly offset from the main body of contamination in the surficial aquifer to avoid the risk of inadvertent downward transport of possible free product from the surficial to the deeper aquifer during drilling. Groundwater levels in the D-horizon wells are lower than levels in the surficial aquifer wells, indicating that if there were a discontinuity in the clay layer, it is likely that there would be downward flow from the surficial to the deeper aquifers. Contamination, however, is unlikely to be present in the brackish D-horizon aquifer for several reasons. No evidence of groundwater contamination by VOCs was found in groundwater samples collected from D-horizon wells PAI-45-MW28-D, -29-D, and -30-D on June 7, 2008, and well PAI-45-MW28-D was near the main body of contamination. Water samples from the wells contained less than 0.25 µg/L of PCE and TCE, less than 0.3 µg/L of *c*DCE, and less than 0.5 µg/L of VC. By virtue of its nearness to the main body of contamination in the southern plume and the probable slight hydraulic gradient to the southeast, it is likely that contamination would have been

detected at well PAI-45-MW28-D if substantial contamination were present in the aquifer beneath the surficial aquifer. In addition, there are substantially lower VOC concentrations near the base of the surficial aquifer than in the vertical midpart of the surficial aquifer, indicating a low potential for downward transport through the base of the surficial aquifer. Finally, the organic-rich peat at the base of the surficial aquifer provides a substantial sorptive buffer for VOCs.

Source of Chlorinated-Solvent Groundwater Contamination in the Southern Plume

Although the southern plume spatially originates from the new dry-cleaning facility, it is unlikely that the new dry-cleaning facility is the source of the contamination. From the beginning of its operation, the new dry-cleaning facility used ExxonMobil DF-2000 fluid as the cleaning solvent; this is a petroleum-based solvent and would not be a viable source of chlorinated-solvent contamination in the aquifer.

Several lines of evidence indicate that the contaminant source in the southern plume was a leak from a sanitary sewer in the vicinity of the new dry-cleaning facility. In the initial stages of the present investigation, the USGS uncovered manhole SAS01 and determined it to be an abandoned sanitary sewer system shallower than the water table. When water was poured into the manhole, the water exited the manhole in the direction leading to the new dry-cleaning facility (fig. 6). Examination of engineering blueprints of historic and existing structures at Site 45 showed that the system was the sanitary



TCE concentrations in wells in midpart of plume (ug/L)

Figure 18. (A) Lithologic log, (B) electron-capture-detector (ECD) log from Membrane Interface Probe (MIP) investigation, (C) field analysis of volatile organic compounds in sediment cores, (D) trichloroethene concentrations in water from multiple depths in temporary wells, and (E) total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, 2008.

sewer for the former dry-cleaning facility. The original sanitary sewer line, in place since the mid-1950s, appears to have extended to beneath what is now the southeastern corner of the new dry-cleaning facility and then turned about 90 degrees southward. The corner of the former sanitary sewer line that extended beneath the new dry-cleaning facility was replaced by a diagonal section of pipe extending from manhole SAS02 to SAS03 sometime in the mid- to late-1990s.

The sanitary sewer line was constructed of vitrified clay. A sewer-inspection camera was used to examine the integrity of the sewer line in 2007. The camera revealed that although the existing pipe between the former and new dry-cleaning facilities contained no collapsed sections, it contained many cracks, and grass roots extended into the pipe. Thus, it is highly probable that the abandoned sanitary sewer is leaky.

The aquifer at the southeastern corner of the new dry-cleaning facility, where the section of the sanitary sewer was removed, contained the greatest PCE concentrations, the greatest PCE/daughter-product ratios, and the lightest PCE CSIA values in the southern plume. The direction of groundwater flow is to the southeast and the chemical data indicate that the area where the sanitary sewer was removed contains the most concentrated and least degraded parent compound in the southern plume. The southeastern corner of the new dry cleaning facility is, therefore, the likely source area for the southern plume.

The coincidence of the southern plume source area with a removed section of sanitary sewer that was part of a cracked sanitary sewer system, the existence of documented and potentially undocumented PCE spills in the former dry-cleaning facility connected to that sanitary sewer, and the lack of a viable source for the PCE spill at the new dry-cleaning facility indicate that the probable source of the contamination at that location was leakage from the sanitary sewer system. In general, sewer leaks (exfiltration) have been recognized as potential contamination sources for many years (Amick and Burgess, 2000; Wakida and Lerner, 2004; Wolf and others, 2004; Rutsch and others, 2005; Held and others, 2006; Reynolds and Barrett, 2007). Leaking sewer lines have produced groundwater VOC contamination elsewhere (Squillace and others, 2004), including PCE contamination from dry-cleaning operations (State of Wisconsin, 1996).

An additional underground pipe was encountered during this investigation in a boring near well PAI-45-MW31-SU. This unmarked and unused pipe was not found on site blueprints. Therefore, other unidentified subsurface utilities may influence groundwater or contaminant transport.

Transport and Fate of Chlorinated Solvents

Groundwater contamination at Site 45 is subject to a variety of influences. One of the most important influences is site hydraulics, which are affected by the storm sewers. Other important influences include biodegradation and sorption.

Storm-Sewer Influences on Transport

Data indicate that groundwater contamination in the northern plume discharges to the storm sewer containing storm grate STS21 and possibly to the section of storm sewer near manholes STS13 and STS14. These sections of storm drains are below the water table, and VOCs have been detected in the storm sewer at STS13, STS14, and STS21 (fig. 6 and table 3). In addition, the curvature of water-table contours around the storm sewer downgradient from storm grate STS21 indicates movement of groundwater to the storm drain from both sides (figs. 8 and 9).

Data from temporary wells sampled during this investigation at the downgradient edge of the northern plume provide further evidence indicating an influence from the storm-sewer system on the groundwater-contamination distribution. Groundwater from temporary wells PAI-45-USGS-TW4, -TW6, -TW8, and -TW10 immediately west of the storm sewer containing storm grate STS21 had more than 1,000 $\mu\text{g/L}$ of *c*DCE at the 7–11 or 7.5–11.5 ft BLS (figs. 4, 6, and 14). In contrast, wells PAI-45-USGS-TW7 (screened at 7–11 ft BLS) and adjacent wells PAI-45-USGS-TW9 and PAI-45-USGS-TW18 (screened at 7.5–11.5 ft BLS and 12–14.5 ft BLS, respectively) on the eastern side of the storm drain did not contain detectable VOCs (figs. 4, 6, and 12–15). The depth to water in that area was 3.24 to 3.75 ft (based on wells PAI-45-MW14-SU and PAI-45-MW23-SU, respectively), and the depth of the storm drain containing manhole STS21 is about 4.6 ft or greater. Thus, it is unlikely that the wells east of the storm sewer vertically missed the contamination beneath the former temporary lodging parking lot. The hydraulic gradients and lack of detectable VOCs east of the storm drain indicate that the storm-sewer system probably is a main discharge zone for the northern plume and effectively limits further expansion of the main axis of contamination in the northern plume.

In the downgradient part of the northern plume near the entrance to the former temporary lodging parking lot, the storm sewer containing manholes STS13 and STS14 is shallower than the storm drain containing storm grate STS21 (fig. 8). Thus, much of the groundwater contamination in the northern plume appears to underflow the western storm drain (containing STS14) and move toward the deeper storm drain farther east (containing STS21) (figs. 12–15). It is clear that some groundwater contamination discharges to the western storm sewer because TCE and *c*DCE were found in water at manhole STS14 on most of the sampling dates (table 3). During three out of the four sampling events at manhole STS14, groundwater levels were relatively low, compared with measurements in nearby well PAI-45-MW23-SU (2.54 to 2.66 ft relative to NAVD 88). On those dates, TCE concentrations in water from manhole STS14 ranged from less than 0.25 to 3.86 $\mu\text{g/L}$, and *c*DCE concentrations ranged from an estimated value of 0.937 to 4.78 $\mu\text{g/L}$. On September 8, 2007, however, the measured water level in well PAI-45-MW23-SU was 3.54, about a foot higher than on the previous sampling dates. The following day (September 9, 2008) a water sample

Table 3. Concentrations of selected constituents in storm sewers, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance; Temp, temperature; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; <, less than; —, not analyzed; J, estimated concentration; R, duplicate sample; Sample points PAI-SW1 and PAI-SW1R are within 1.5 feet of sample point STS26]

Site identifier	Date (month/day/year)	Time (hours after low tide)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>trans</i> -DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp (°C)
STS05	5/31/2007	0.50	<0.3	35	<0.3	<0.25	34	<0.25	0.91BJ	20	77	<0.25	0.736J	2.6	<0.25	—	—	—
STS05	6/27/2007	0.18	<5	—	—	—	70	—	—	30	100	—	<5	7.0	—	—	—	—
STS13	4/30/2007	1.5	<0.3	3.0	<0.3	<0.25	2.7	<0.25	<0.25	<0.25	2.2	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	4/30/2007	1.5	<0.3	5.2	<0.3	<0.25	4.7	<0.25	<0.25	0.27J	2.4	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	5/14/2007	4.0	<0.3	4.8	<0.3	<0.25	4.8	<0.25	<0.25	<0.25	3.9	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	6/16/2008	2.9	<0.3	0.94J	<0.3	<0.25	0.94J	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	9/9/2008	0.5	0.7J	410	<0.3	<0.25	390	<0.25	<0.25	30	180	<0.25	7.4	20	<0.25	—	—	—
STS21	4/30/2007	1.5	<0.3	7.4	<0.3	<0.25	6.7	<0.25	22	<0.25	2.4	<0.25	<0.3	<0.50	<0.25	—	—	—
STS21	5/14/2007	4.0	<0.3	<0.30	<0.3	<0.25	<0.30	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.50	<0.25	—	—	—
STS21	6/25/2007	high tide	—	—	—	—	—	—	—	—	—	—	—	—	—	5.44	50,047	30.01
STS22	6/16/2008	3.0	<0.3	41	<0.3	<0.25	40	<0.25	9.3	0.60J	13	<0.25	0.693J	4.5	<0.25	—	—	—
STS22	9/9/2008	0.5	<0.3	1.3	<0.3	<0.25	1.3	<0.25	0.58J	<0.25	0.77J	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	9/10/2007	0	<0.3	2.5	<0.3	<0.25	2.5	<0.25	0.75J	0.69J	4.3	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	9/10/2007	3.0	<0.3	3.5	<0.3	<0.25	3.5	<0.25	0.90J	1.1	5.6	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	6/16/2008	1.0	<0.3	2.9	<0.3	<0.25	2.9	<0.25	0.27J	0.77J	2.3	<0.25	<0.3	<0.50	<0.25	—	—	—
STS27	9/9/2008	0	<0.3	0.59J	<0.3	<0.25	0.59J	<0.25	<0.25	<0.25	0.43J	<0.25	<0.3	<0.50	<0.25	—	—	—
PAI-SW1	6/16/2008	0.3	<0.3	1.6	<0.3	<0.25	1.6	<0.25	0.33J	0.44J	1.3	<0.25	<0.3	<0.50	<0.25	—	—	—
PAI-SW1R	6/16/2008	0.3	<0.3	1.7	<0.3	<0.25	1.7	<0.25	<0.25	0.48J	1.3	<0.25	<0.3	<0.50	<0.25	—	—	—

from manhole STS14 contained substantially greater VOC concentrations than on previous dates (183 µg/L of TCE and 387 µg/L of *c*DCE). Most importantly, water from manhole STS14 contained 20.1 µg/L of VC. The western storm drain containing STS14 is a receptor of groundwater contamination from the northern plume and is more important as a receptor during periods of high groundwater levels than during periods of low groundwater levels. This is important because temporary well PAI-45-USGS-TW15 (fig. 4) had groundwater contamination containing 2,290 µg/L of VC (June 25, 2007) and is immediately adjacent to that storm sewer (figs. 4 and 15). Thus, at high groundwater levels, there is the potential for increased amounts of VC to enter the storm sewer. If such an event occurs at a time when tidal flushing is low, then increased concentrations of VC could discharge at the storm-sewer outfall. The MCL for VC in drinking water established by the USEPA is 2 µg/L, and VC has been associated with potential increased risk of cancer in adults (U.S. Environmental Protection Agency, 2008).

During times of low groundwater levels, relatively low concentrations of VOCs in the southernmost part of the northern plume may move southeastward beneath storm drain STS14. Based on this consideration and on groundwater flow directions (figs. 8 and 9), such movement may account for some of the low concentrations of TCE and *c*DCE detected in groundwater immediately west of the former temporary lodging (figs. 13 and 14).

Data indicate that storm sewers also intercept contamination in the southern plume. Chlorinated solvents were detected in water from STS05 (30 µg/L of PCE, 100 µg/L of trichloroethene [TCE], 70 µg/L of *c*DCE, and 7 µg/L of VC in June 2007) (table 3, fig. 6). Well PAI-45-MW20-SL, a few feet north of the storm drain containing manhole STS05, contained more than 1,000 µg/L of TCE, while TCE in most of the temporary wells on the opposite of the storm drain contained less than 5 µg/L of TCE (fig. 13). Thus, it appears that the storm drain below the water table near well PAI-45-MW20-SL is a discharge zone for groundwater contamination. Manholes STS05 and STS06 are near each other and are about the same depth (fig. 8); therefore, the hydrology of the two manholes probably is similar. Because the groundwater levels in SL wells near these manholes is usually more than 2 ft higher than the water levels in the manholes (fig. 10), there probably is movement of contaminated water from parts of the aquifer deeper than the manholes upward toward the manholes, storm sewer, and the granular base material below the storm sewer.

The presence of VOCs in water from manhole STS05 and the sharp decline in contaminant concentrations from one side of the storm sewer to the other side indicate that a substantial part of the southern plume is captured by the storm sewer. The presence of VOCs in some temporary wells on the downgradient side of the storm sewers, however, indicates that some of the contamination in the southern plume bypasses the storm sewers. For example, 110–339 µg/L of *c*DCE was detected in groundwater on the downgradient side of the storm drain at temporary wells PAI-45-USGS-TW27,

PAI-45-USGS-TW28, and PAI-45-USGS-TW64, and 155 µg/L of TCE was detected in groundwater at well PAI-45-USGS-TW27 (figs. 4, 13, and 14).

Relatively low concentrations of groundwater contamination bypass the storm sewers at Site 45, as evidenced by concentrations of *c*DCE of about 5–7 µg/L in temporary wells between the storm sewer and the former temporary lodging (fig. 14). Based on site hydrology and the relatively leaky nature of the storm sewers, the groundwater contaminants probably are captured eventually by discharge to a deep storm sewer. Potential receptors include the storm sewers near manholes STS06, STS07, and STS22 (fig. 6).

Once in the storm-sewer system, VOCs are subject to a variety of contaminant-reduction influences. The largest influence is tidal action. The storm sewers at Site 45 range in diameter from 12 to 36 inches; thus, a tidal change of greater than 3 ft in some of the storm sewers at Site 45 represents a substantial amount of marsh water entering and exiting the pipes relative to the comparatively small amount of groundwater leaking into them. The tidal exchange dilutes the VOC concentrations in the storm sewers. Volatilization probably also removes some of the VOC contamination in the storm sewers.

During outgoing tides, the diluted contamination in the storm sewer is transported southward and discharges to Ballast Creek. Based on a dye test, the contaminant-transport time through approximately 1,400 ft of storm sewer from Site 45 to Ballast Creek during outgoing tides is a little more than 1 hour (fig. 19). A sample from manhole STS26 in the storm sewer approximately 320 ft from the Ballast Creek discharge contained PCE, TCE, and *c*DCE concentrations of 0.69 (estimated), 4.26, and 2.53 µg/L, respectively, at low tide and concentrations of 1.06, 5.63, and 3.48 µg/L, respectively, 1 hour after low tide. At 1 hour after low tide, water at manhole STS26 was moving in the storm sewer toward the creek. Because no additional storm-sewer pipes appear to enter the main storm sewer between STS26 and Ballast Creek, there is no additional dilution between STS26 and Ballast Creek, and the detected contaminant concentrations at STS26 represent VOC concentrations from Site 45 being discharged to Ballast Creek. Maximum detected VOC concentrations detected in storm-sewer water at STS26 during three sampling events (on two different dates) were 1.06 µg/L of PCE, 5.63 µg/L of TCE, 3.48 µg/L of *c*DCE, and less than 0.5 µg/L of VC (September 10, 2007, 1 hour after low tide) (table 3).

The above data indicate that the storm sewers function as discharge points for the major parts of both the northern and southern plumes. Part of the groundwater contamination may bypass some of the storm sewers below the water table; however, the bypassing concentrations are relatively low. Although substantial concentrations of VOCs are present in the groundwater near the storm sewers (more than 1,000 µg/L of TCE in the southern plume and more than 1,000 µg/L of *c*DCE in the northern plume), the groundwater that leaks into the storm sewers is subjected to dilution and volatilization effects that result in low concentrations of VOCs in water

from the sampled manholes (maximum detection of 387 $\mu\text{g/L}$ of *c*DCE and 183 $\mu\text{g/L}$ of TCE; table 3) and at the discharge point. Thus, the storm sewers appear to be preventing substantial additional expansion of the plumes and usually discharging relatively low concentrations of VOCs (less than about 10 $\mu\text{g/L}$ of total VOCs to Ballast Creek).

Finally, in an interview during this investigation, the Parris Island environmental officer who investigated the 1994 solvent spill at the above-ground storage tanks stated that there was evidence that PCE may have entered the storm drains during this event (James Clark, Environmental Officer, Parris Island, oral commun., 2008). Because a substantial amount of PCE was released to the environment, PCE entering the storm drain would have been transported through the storm-sewer system. The most probable receptors would have been storm drains STS01 or STS16 (fig. 6). Both of these storm drains connect to the same storm sewer and ultimately discharge to the Ballast Creek tributary at STS27 (fig. 19). Few data are available on the nature of a historic storm sewer extending from beneath the former above-ground storage-tank area southeastward to storm grate STS08 (fig. 6) except that video imaging of that section of the sewer during this investigation showed it to be presently occluded by a concrete plug approximately 94 ft northeast of STS08. If the historic sewer line had been a receptor, then it would have connected to the same storm sewer that drains STS01 and STS16.

The potential historical presence of free-phase PCE in the storm sewer is important for several reasons. The previously discussed leaky nature of parts of the storm sewer means that the dense nonaqueous phase liquid (DNAPL) could have leaked from various parts of the storm sewer in route to the Ballast Creek discharge. If DNAPL was transported all the way to the Ballast Creek discharge point at STS27, then it likely would have sorbed to and sunk into the sediments not far from STS27. A reconnaissance survey of shallow sediment collected near the STS27 outfall during this investigation showed no detectable chlorinated-solvent contamination at depths of 0.5 and 1 ft below the sediment surface (fig. 7); however, due to a laboratory error, the sediment sample from 1-ft depth at the outfall (PAI-SWSED1, June 17, 2008) had unusually high detection limits [32 to 81 milligrams per kilogram (mg/kg)]. Low concentrations of toluene were detected in sediment from PAI-SWSED1, 0.5 ft depth (estimated 0.67 mg/kg), and at PAI-SWSED3, 1.0 ft depth (3.96 mg/kg). The lack of detectable chlorinated-solvent contamination in the sediment does not eliminate the possibility of deeper contamination because reworking of the shallow sediment could have destroyed the shallow signature. Examination of deeper sediment and a search for potential PCE leaks from the storm sewer outside of Site 45 were beyond the scope of the present investigation.

Historical contamination could have exited the storm sewer east of STS26 through the eastern storm sewer that now contains numerous collapse features (fig. 19). This eastern storm sewer and the storm sewer containing

sewer-outfall point STS27 are now connected at manhole STS25. The connection at STS25 probably was made to facilitate drainage of the storm sewer that extended from approximately beneath the former temporary lodging parking lot to a tributary to Ballast Creek after the collapse features occluded the pipe near the outfall point. Evidence that the occlusions limit or prevent direct discharge from the eastern storm sewer to Ballast Creek can be seen in the directions of water flow in the sewers. During an outgoing tide, water drains into manhole STS25 (fig. 19) from both the northern and southern sections of the eastern storm sewer. Water then flows laterally to the western storm sewer and then moves southward toward Ballast Creek. The flow directions reverse during an incoming tide, with water moving from the western storm sewer through manhole STS25 and into both the northern and southern sections of the eastern storm sewer. Thus, it appears that there is no significant exit or entrance for the eastern storm sewer at Ballast Creek.

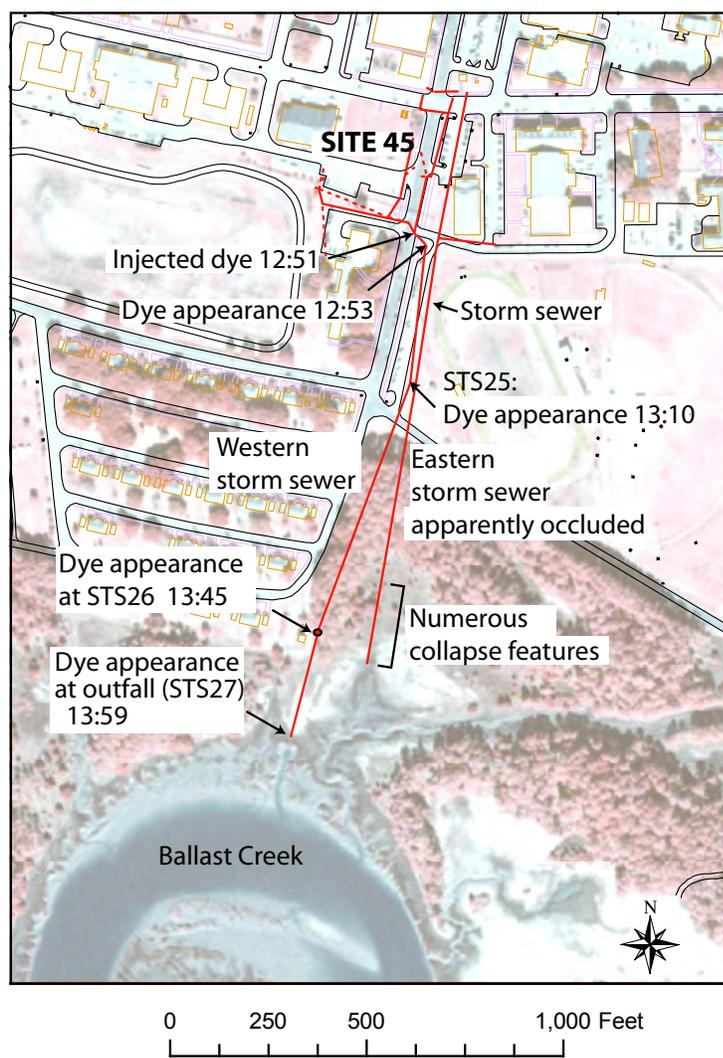


Figure 19. Movement of dye tracer and arrival times in the storm sewer from Site 45 to the Ballast Creek tributary, Marine Corps Recruit Depot, Parris Island, South Carolina, August 30, 2007.

If the spill occurred during a period when the eastern and western storm drains were connected, then some level of contaminant could have been transported in the eastern storm drain. Such transport, however, seems less likely than transport in the storm sewer containing discharge point STS27 because the storm sewer containing STS27 is more directly connected to the probable receptor drains for the spill and because of predominance of flow at the STS27 discharge point relative to the occluded sewers.

It is unlikely that substantial DNAPL from the original spill is still present in the storm sewers because of substantial flushing by daily tides and by rainfall events, including hurricanes. It also is unlikely that the VOCs detected during this investigation in the storm sewers are simply a measurement of remnant DNAPL because the presence of TCE, *c*DCE, and VC in the storm sewer indicates that the PCE has been degraded by reductive dechlorination (table 3), a process unlikely to occur in an aerobic storm sewer. In addition, the $\delta^{13}\text{C}$ of PCE in water from manhole STS05 (-20.51‰) reflected a substantial amount of degradation relative to manufactured PCE (-27.0 to -37.2‰ ; van Warmerdam and others, 1995; Jendrejewski and others, 2001), but was similar to the $\delta^{13}\text{C}$ of PCE in groundwater from nearby well PAI-45-MW20-SL

(-20.8‰) (table 4). Thus, the chlorinated solvents presently in the storm-sewer water are from groundwater.

Biodegradation

Several lines of evidence indicate the presence of VOC biodegradation in the aquifer at the southern plume. These data include microbial considerations, chlorinated-solvent parent/daughter-product ratios, and stable carbon isotopes. Despite a substantial decrease in the total mass of chlorinated solvents from the upgradient source area near the new dry-cleaning facility to downgradient well PAI-45-MW20-SL, however, a substantial concentration of TCE (3,500–5,840 $\mu\text{g/L}$) is still present in the aquifer at well PAI-45-MW20-SL near a storm drain (STS05) known to be a recipient of groundwater contamination. Thus, biodegradation alone is not sufficient to decrease TCE concentrations to values less than milligram-per-liter levels prior to discharge to the storm sewers.

Molecular analysis as part of this investigation indicated the presence of *Dehalococcoides* sp. and *Dehalobacter* sp., which are microbes known to degrade chlorinated solvents (table 5). A variety of microorganisms are capable

Table 4. Concentrations of compound-specific stable carbon isotope analysis on water from wells and a storm sewer, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[1,1-DCE, 1,1-dichloroethylene; PCE, tetrachloroethylene; TCE, trichloroethylene; *c*DCE, *cis*-1,2-dichloroethylene; *t*DCE, *trans*-1,2-dichloroethylene; VC, vinyl chloride; DIC, dissolved inorganic carbon as carbon dioxide; R, laboratory rerun of a sample at a later date than the original analysis; D, duplicate sample; —, not analyzed or not reliable due to low concentrations; all concentrations are per mil units of the $^{13}\text{C}/^{12}\text{C}$ ratio from a reference standard of the Vienna Pee Dee Belemnite]

Site identifier	Sample date (month/day/year)	1,1-DCE	PCE	TCE	<i>c</i> DCE	<i>t</i> DCE	VC	DIC
PAI-45-MW04-SL	8/25/2005	-36.60	-25.10	-29.20	-30.30	—	—	-12.0
PAI-45-MW20-SL	8/25/2005	-38.80	-20.80	-29.20	-30.30	—	—	-11.9
PAI-45-USGS-TW44	6/27/2007	-22.10	-26.01	-31.03	-30.76	-41.53	-22.57	—
PAI-45-USGS-TW39	6/27/2007	—	-29.49	-30.19	-31.61	—	-20.25	—
PAI-45-USGS-TW48	6/27/2007	-33.06	-27.22	-30.24	-29.79	-39.54	-19.21	—
PAI-45-USGS-TW48 R	6/27/2007	—	—	—	-29.71	-39.70	-18.76	—
PAI-45-USGS-TW53	6/27/2007	-32.70	-26.16	-30.43	-30.56	-38.56	-18.22	—
PAI-45-USGS-TW53 D	6/27/2007	—	-25.84	—	-30.42	-37.39	-17.91	—
PAI-45-USGS-TW63	6/28/2007	-35.88	-26.07	-26.61	-33.82	-50.92	-6.17	—
PAI-45-USGS-TW63 R	6/28/2007	-35.22	—	-26.52	-33.60	-50.65	-4.98	—
STS05 (storm sewer)	6/27/2007	—	-20.51	-27.99	-31.03	—	-20.25	—
PAI-45-USGS-TW3	6/25/2007	—	—	5.64	-27.81	—	-19.62	—
PAI-45-USGS-TW12	6/25/2007	—	-15.39	-21.69	-27.50	—	-23.37	—
PAI-45-USGS-TW12 R	6/25/2007	—	-14.98	-21.26	-27.25	—	-24.09	—
PAI-45-USGS-TW43	6/27/2007	—	—	-23.78	-28.60	—	-3.07	—
PAI-45-MW25-SL	6/19/2008	—	-29.16	-30.93	-32.71	—	-22.58	—
PAI-45-MW31-SL	6/18/2008	—	-25.51	-29.76	-30.35	—	-21.41	—
PAI-45-MW31-SU	6/18/2008	—	-25.55	-29.32	-29.76	—	-24.11	—

Table 5. Molecular analysis of phylogenetic groups and functional genes in groundwater samples from the southern plume at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2006.

[DNA, deoxyribose nucleic acid; RNA, ribonucleic acid; 16S rRNA, 16S ribosomal RNA; mRNA, messenger RNA; BVC, vinyl chloride reductase associated with *Dehalococcoides* sp. Strain BAV1; DSR, sulfate-reducing bacteria; sMMO, methane monooxygenase; TceA, trichloroethene reductase; VcrA, vinyl chloride reductase; c/mL, cells per milliliter; <, less than; —, data not collected; gc/mL, gene copies per milliliter; E, scientific notation; J, estimated value]

Well identifier	Date (month/day/year)	DNA or RNA	Units	Phylogenetic groups						Functional genes						Percent recovery	
				<i>Eubacteria</i>	<i>Dehalobacter</i> sp.	<i>Dehalococcoides</i> sp.	Methanogenic bacteria	<i>Desulfuromonas</i> sp.	Type 1 methanotrophic bacteria	Type 2 methanotrophic bacteria	BVC	DSR	sMMO	TceA	VcrA		
PAI-45-MW04-SL	8/25/2005	RNA	gc/mL	3.59E+07	5.38E+04	2.30E+03	<1.00E+00	<1.00E+00	1.05E+08	1.22E+05	<5E-01	9.69E+06	4.43E+06	<5E-01	<5E-01	<5E-01	—
PAI-45-MW04-SL	9/28/2006	RNA	gc/mL	5.66E+05	8.35E+00	4.07E+01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	65.53	
PAI-45-MW04-SL	9/28/2006	RNA	gc/mL	2.27E+04	—	6.64E+01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	98.24	
PAI-45-MW04-SL	10/10/2006	DNA	c/mL	8.29E+05	2.34E+03	1.14E+05	—	—	—	—	6.67E-03(J)	—	—	<5E-01	1.18E+05	98.72	
PAI-45-MW04-SL	10/10/2006	RNA	gc/mL	3.97E+05	<1E+0	<5E-01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	42.03	
PAI-45-MW20-SL	8/25/2005	RNA	gc/mL	2.09E+07	3.68E+04	6.40E+02	<1.00E+00	4.16E+00	9.25E+07	3.73E+04	<5E-01	1.38E+07	3.08E+06	<5E-01	<5E-01	—	
PAI-45-MW20-SL	9/26/2006	DNA	c/mL	1.85E+06	1.09E+02	2.88E+02	—	—	—	—	4.47E-02(J)	—	—	<5E-01	<5E-01	76.48	
PAI-45-MW20-SL	9/26/2006	RNA	gc/mL	7.32E+02	—	<5E-01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	38.18	
PAI-45-MW20-SL	10/10/2006	DNA	c/mL	2.12E+06	2.18E+03	1.22E+02	—	—	—	—	2.23E-01(J)	—	—	<5E-01	<5E-01	71.99	
PAI-45-MW20-SL	10/10/2006	RNA	gc/mL	2.89E+05	3.37E+00	<5E-01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	36.38	
PAI-45-MW20-SU	9/26/2006	DNA	c/mL	1.11E+06	1.23E+01	1.47E+04	—	—	—	—	2.53E+01	—	—	5.37E+00	7.36E-01	93.43	
PAI-45-MW20-SU	9/26/2006	RNA	gc/mL	2.33E+04	—	1.61E+04	—	—	—	—	<5E-01	—	—	<5E-01	1.3E-02J	47.01	
PAI-45-MW20-SU	10/10/2006	DNA	c/mL	2.15E+06	4.61E+03	7.01E+02	—	—	—	—	6.30E-1	—	—	2.05E-01	<5E-01	58.53	
PAI-45-MW20-SU	10/10/2006	RNA	gc/mL	1.98E+05	4.78E+00	<5E-01	—	—	—	—	<5E-01	—	—	<5E-01	<5E-01	62.22	

of dechlorinating PCE and TCE; however, only microorganisms associated with the genus *Dehalococcoides* are known to dehalorespire *c*DCE and VC to ethylene (Hendrickson and others, 2002; Cupples and others, 2003; He and others, 2003a, 2003b; Schmidt and de Vos, 2004). The species *Dehalococcoides etheneogenes* is capable of complete sequential dechlorination of PCE to ethylene (Maymo-Gatell and others, 1999). *Dehalobacter* sp. also has been identified as bacteria associated with dechlorination of chloroethenes (Holliger and others, 1998; Maymo-Gatell and others, 1997). In nature, anaerobic dechlorination typically is carried out by mixed cultures of dechlorinators (Bradley, 2003), and complete dechlorination of PCE to ethylene has been observed in a mixed culture that did not contain the *Dehalococcoides* sp. (Flynn and others, 2000). Thus, the absence of *Dehalococcoides* sp. and *Dehalobacter* sp. does not necessarily preclude complete dechlorination. Their presence in groundwater at Site 45, however, indicates a strong probability of microbial dechlorination of the contamination.

In areas where the dominant driver of biodegradation is *Dehalococcoides* sp., the rate of biodegradation appears to be related to the cell density. Dennis (2005) detected ethylene production from dechlorination in 78 percent of the groundwater samples where the density of *Dehalococcoides* sp. was between 1×10^4 and 9.9×10^5 cells per liter and in 83 percent of the samples where the density was between 1×10^6 and 9.9×10^7 cells per liter. In general, a density of 1×10^7 cells per liter is considered to be necessary to produce a useful rate of natural attenuation (Lu and others, 2006; Dennis, 2009). At Site 45, multiple groundwater samples contained *Dehalococcoides* sp. at greater than 10^4 cells per milliliter (10^7 cells per liter), indicating that sufficient quantities of *Dehalococcoides* sp. are present to produce robust biodegradation of chlorinated solvents to ethylene.

An additional way to examine microbial activity in groundwater is to examine enzymes. The enzymes responsible for reductive dehalogenation in *Dehalococcoides* are reductive dehalogenases, or reductases (Krajmalnik-Brown and others, 2004). Microbial analysis of enzymes in groundwater from the southern plume showed the presence of BVC, which is the functional gene of vinyl chloride reductase associated with *Dehalococcoides* sp. strain BAV1 (table 5). The reductase gene (*bvcA*) in *Dehalococcoides* strain BAV1 grows using all dichloroethene (DCE) isomers and VC as electron acceptors and cometabolizes PCE and TCE, efficiently converting these compounds to ethylene and inorganic chloride (He and others 2003b; Krajmalnik-Brown and others, 2004).

The reductase associated with VC degradation in *Dehalococcoides* strain VS and other strains is *VcrA* (Magnuson and others, 2000; Muller and others, 2004). *VcrA* was detected in groundwater from wells PAI-45-MW4-SL and PAI-45-MW20-SU in the southern plume during some sampling events (table 5). The reductase responsible for trichloroethene reduction is *TceA* in *Dehalococcoides* strain 195 and other strains. *TceA* was detected in DNA in groundwater in the southern plume at well PAI-45-MW20-SU during one sampling event.

The presence of these enzymes supports the finding that microbial degradation of the chlorinated solvents is occurring in the southern plume.

The pH of water in the surficial aquifer containing greater than 1 micromole per liter of chlorinated solvents averaged 5.77 pH units (standard deviation of 0.32) in monitoring wells and 6.03 pH units (standard deviation of 0.25) in temporary wells. In general, maximum microbial reductive dechlorination has been observed between pH values of about 6.8 to 7.6 with diminished reduction at lower pH values (Holliger and others, 1993; Zhuang and Pavlostathis, 1995; Wiedemeier and others, 1996; Cirpka and others, 1999; Fennell and Gossett, 2003). Although the pH in contaminated groundwater at Site 45 is slightly below the optimum level, the presence of chlorinated-solvent reductive dechlorination daughter products indicates that the pH is not low enough to prohibit reductive dechlorination. Reductive dechlorination of chlorinated solvents in a low-pH environment (2–4 range) has been reported elsewhere in a Fenton's reagent treatment area (Bradley and others, 2007).

Contaminant Concentration Changes in the Direction of Transport

Total chlorinated-solvent concentrations decrease in the southern plume along the transport path from the source area to well PAI-45-MW04-SL (fig. 20A). A variety of lines of evidence in addition to the previously discussed microbial consideration indicate that the decrease is partly due to contaminant biodegradation.

PCE is degrading to TCE in the southern plume. The PCE concentrations substantially decrease from upgradient to downgradient areas (fig. 20B). The PCE/TCE ratio decreases from PAI-45-MW25-SL to PAI-45-MW31-SL to PAI-45-MW04-SL, indicating a decrease of PCE relative to TCE (fig. 20C). In general, the upgradient parts of the southern plume tend to be dominated by PCE, while more downgradient parts of the plume tend to be dominated by TCE or *c*DCE reflecting dechlorination activity (fig. 21). In addition, the $\delta^{13}\text{C}$ of PCE in groundwater indicates a shift from isotopically light (negative) to isotopically heavier (more positive) from the source area to well PAI-45-MW20-SL (fig. 20D), indicating a depletion in the PCE mass of the more readily degradable, lighter isotopes.

Although PCE is the dominant VOC in the source area at the southeastern corner of the new dry-cleaning facility, the presence of TCE indicates some degree of near-source-area PCE degradation. Additional evidence indicating PCE degradation near the source area can be seen in the $\delta^{13}\text{C}$ data. The $\delta^{13}\text{C}$ of manufactured PCE can vary depending on the manufacturer and the timeframe of production, with values ranging from -27.0 to -37.2 ‰ (Jendrejewski and others, 2001; van Warmerdam and others, 1995). These values are consistent with the $\delta^{13}\text{C}$ of PCE in the source area at well PAI-45-MW-5-SL (-29.16 ‰) and in temporary well PAI-45-USGS-TW39 (-29.49 ‰), approximately 30 ft downgradient from the

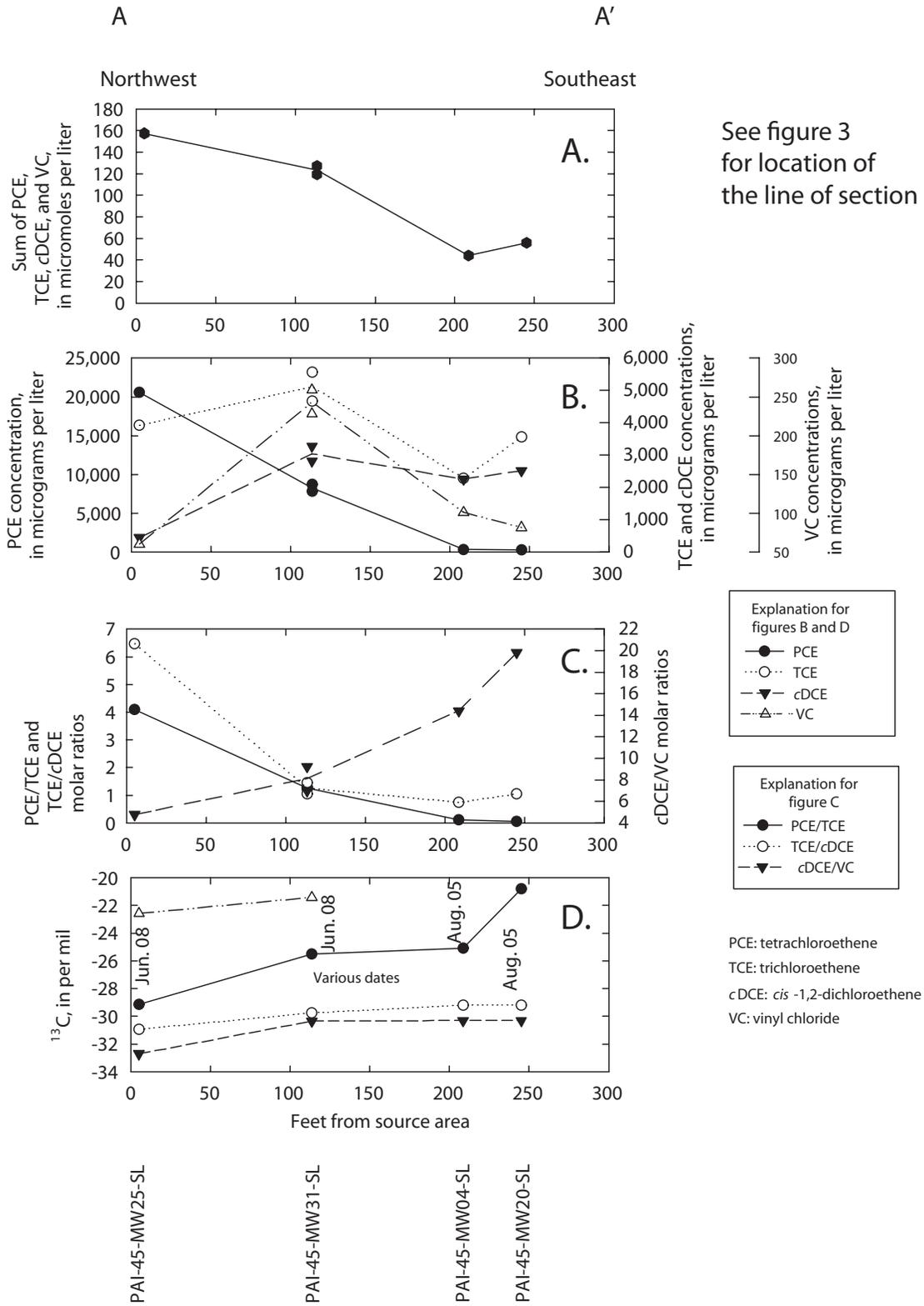
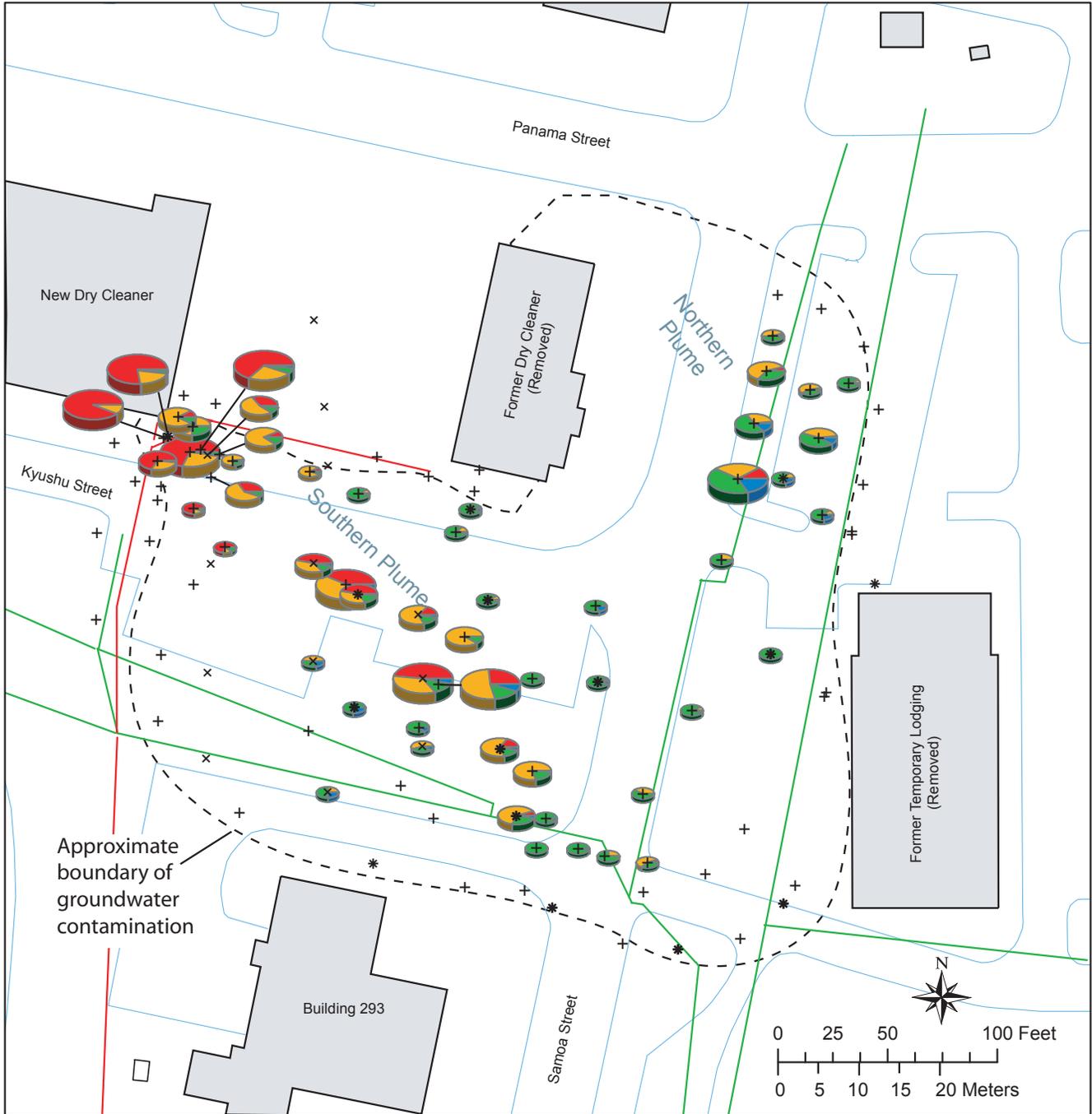


Figure 20. (A) Total chlorinated solvents, (B) individual chlorinated solvents, (C) parent/daughter ratios, and (D) compound-specific stable carbon isotopes ($\delta^{13}C$) in wells along the axis of contamination in the southern plume, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, September 2008, unless otherwise noted.



- * Monitoring well sampled July 2007 to June 2008
- + USGS temporary well sampled June 2007 to March 2008
- x Tetra Tech NUS, Inc., temporary well sampled 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)
- Storm sewer
- Sanitary sewer

EXPLANATION



- Concentration of total PCE + TCE + cDCE + VC.
- Greater than 100 micromoles per liter
 - 31-100 micromoles per liter
 - 0.5-30 micromoles per liter
 - Symbols without pie diagram: Less than 0.5 micromole per liter

Figure 21. Relative molar percentage of tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene (cDCE), and vinyl chloride (VC) in groundwater from monitoring wells and selected temporary wells representing multiple sampling events, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

source area (table 4), possibly indicating little degradation or proximity to free product (Morrill and others, 2003). In temporary well PAI-45-USGS-TW44, which is nearer to the source area than PAI-45-USGS-TW30, the $\delta^{13}\text{C}$ of PCE in groundwater was substantially enriched (-26.01‰), indicating dechlorination of the PCE. This temporary well also contained a substantially higher VC concentration ($201\text{ }\mu\text{g/L}$; figs. 4 and 15) than in nearby wells, further attesting to dechlorination activity. Thus, there is sufficient dechlorination activity to produce VC in parts of the surficial aquifer near the source area at the southeastern corner of the new dry-cleaning facility.

There also is evidence that TCE is dechlorinating to *c*DCE in groundwater in the southern plume. The most compelling evidence is the sharp decrease in the TCE/*c*DCE ratio between the source area and mid-plume well PAI-45-MW31-SL (fig. 20C), despite the observation that the TCE concentration increased over that interval. The change in ratio indicates a gain of *c*DCE relative to TCE.

Direct evidence indicating TCE biodegradation between the midpart of the southern plume at well PAI-45-MW31-SL and the downgradient axis of the plume at well PAI-45-MW20-SL is limited because there is almost no change in the TCE/*c*DCE ratio or in the $\delta^{13}\text{C}$ of TCE in this part of the plume (figs. 20C and 20D), despite a slight decrease in TCE concentration (about 25–35 percent). TCE biodegradation, however, can occur under all anaerobic conditions; it occurs most efficiently under sulfate-reducing and methanogenic conditions (Yang and McCarty, 1998; Bradley, 2003). Because the aquifer is anaerobic and the most contaminated part probably is dominated by sulfate-reducing conditions with probable pockets of methanogenesis, the TEAP conditions are conducive to TCE degradation.

Because H_2 appears to be the most important donor for anaerobic dechlorination of chlorinated VOCs (Fennell and Gossett, 1998), the competition between sulfate-reducing bacteria (SRB) and chlorinated-VOC-degrading bacteria has the potential to limit dechlorination activity; however, in one laboratory study of microcosms containing *Dehalococcoides* sp., high sulfate concentrations (400 to $1,100\text{ mg/L}$) under limiting electron donor conditions significantly inhibited TCE reduction, but had a negligible effect at 30 mg/L compared to the zero-sulfate case (Panagiotakis and others, 2008). At the comparatively low sulfate concentrations in the southern plume (about 23 to 143 mg/L), sulfate is not expected to inhibit dechlorination activity.

Thus, it is likely that TCE dechlorination to *c*DCE is taking place in the downgradient part of the southern plume. The relative lack of degradation signature in the TCE/*c*DCE ratio or in the $\delta^{13}\text{C}$ of TCE may be due to a combination of simultaneous production and degradation of TCE, the relatively small $\delta^{13}\text{C}$ fractionation factor associated with TCE to *c*DCE degradation (Song and others, 2002), and slow degradation rates associated with natural attenuation.

It is clear that some level of *c*DCE dechlorination takes place in the aquifer simply because of the presence of VC, a daughter product of *c*DCE reduction. VC is more concentrated

in the central part of the southern plume near well PAI-45-MW31-SL (about 120 to $420\text{ }\mu\text{g/L}$) than in most wells near the source area (about 5 to $50\text{ }\mu\text{g/L}$) (figs. 15 and 20B). This indicates that production of VC by dechlorination of *c*DCE takes place as the contamination is transported, at least in the upgradient half of the plume. An exception is temporary well PAI-45-USGS-TW44 near the new dry cleaner that had $201\text{ }\mu\text{g/L}$ of VC in groundwater, indicating that substantial dechlorination has taken place in at least some parts of the aquifer in or near the source area.

Reduction of VOCs under the iron- and sulfate-reducing conditions that appear to prevail in the aquifer at Site 45 is substantially less favorable for VC than for PCE and TCE. VC dechlorination can take place under these conditions, however, and has taken place at Site 45, as evidenced by elevated ethylene concentrations (13 – $150\text{ }\mu\text{g/L}$) in groundwater along the axis of the southern plume relative to groundwater in wells outside of the main axis of the plume (less than $10\text{ }\mu\text{g/L}$ at most wells). Oxidation of VC under iron- and sulfate-reducing conditions is more favorable than reduction and probably is taking place in the aquifer at Site 45. The increases in $\delta^{13}\text{C}$ for VC from -22.57‰ at temporary well PAI-45-USGS-TW44 to -18.76 to -19.21‰ at PAI-45-USGS-TW48 and -17.91 to -18.22‰ at PAI-45-USGS-TW53 indicate biodegradation of VC as it is transported along the flowpath (table 4). Further evidence for VC biodegradation can be seen at temporary well PAI-45-USGS-TW63, where only a small amount of VC was present (estimated $30\text{ }\mu\text{g/L}$) and the $\delta^{13}\text{C}$ was enriched (-4.98 to -6.17‰). The isotopic fractionation of VC during biodegradation can be larger than the fractionation of its parent compounds because the fractionation factor for VC is larger than for the parent compounds (Hunkeler and others, 1999; Bloom and others, 2000; Slater and others, 2001) and because while TCE and *c*DCE are being biodegraded, they also may be produced by reductive dehalogenation of parent compounds.

Supporting evidence for VC degradation can be seen in the fact that *c*DCE/VC ratios substantially increase along the transport pathway in the southern plume (fig. 20D). Based on the isotopic evidence for VC degradation, the increase in *c*DCE/VC ratios probably reflects VC degradation.

Although this investigation mostly focused on the southern plume, part of the northern plume approximately 100 to 160 ft downgradient from the tank-spill area also was investigated using temporary wells. In some of those wells, VC constituted a larger percentage of the VOC contamination than in the southern plume, indicating a more advanced state of degradation. The difference between the chemistry in the northern and southern plumes may be partly because the northern plume has been the focus of a variety of treatment pilot studies. An air-sparging pilot study took place in the northern plume in December 1996 (Bechtel Environmental, Inc., 1997). A groundwater pump-and-treat system was in operation from 1998 to 2000, removing an estimated $1,056,410$ gallons of water from the northern plume (Tetra Tech NUS, Inc., 2004). Emulsified zero-valent iron was injected into the aquifer as a treatment in the vicinity of the former above-ground storage

tanks in late 2006 (Suzanne O'Hara, Geosyntec Consultants, written commun., 2008). In contrast, the southern plume has not yet been subjected to engineered remediation. The larger amount of VC in the northern plume than in the southern plume also may be a consequence of probable historic releases of petroleum-based solvents at the former dry cleaning facility (S&ME, Inc., 1994), which could have produced highly reducing conditions conducive to enhanced VC production in parts of what is now the northern plume.

Other Influences

Some degree of sorption of the VOCs is expected to take place in the aquifer. In temporary well PAI-45-USGS-TW96, the total organic carbon (TOC) concentration in a composite sediment sample was 440 mg/kg (0.044 fraction organic carbon [f_{oc}] as percent) at a depth of 8–10 ft and was 2,120 mg/kg (0.212 f_{oc}) at a depth of 12–13 ft (table 6). These values are consistent with TOC analyses of sediment from the southern plume collected by the USEPA for a separate investigation (Scott Huling, U.S. Environmental Protection Agency, written commun., 2009).

The distribution coefficient between water and sediment (K_d) can be calculated from the equation $K_d = K_{oc} \times f_{oc}$, where K_{oc} is the organic carbon sorption coefficient. For PCE, which has a log K_{oc} of about 2.42 (Solutions IES, Inc., and others, 2007), these values produce distribution coefficient between water and sediment (K_d) of about 0.11–0.56. For TCE (log K_{oc} of about 2.03, Solutions IES, Inc., and others, 2007), the calculated K_d is 0.04–0.23. For *c*DCE (log K_{oc} of about 1.65, Solutions IES, Inc., and others, 2007), the calculated K_d is about 0.02–0.06. For VC (log K_{oc} of about 1.23, Solutions IES, Inc., and others, 2007), the calculated K_d is about 0.007–0.036.

The K_d values can be used to calculate a retardation coefficient $\{1 + [(bulk\ density)(K_d)]/porosity\}$ for a range of porosities from 0.25 to 0.45 (Freeze and Cherry, 1979). Using an estimated bulk density of 1.65 grams per cubic centimeter (Mercer and others, 1982), the calculated retardation factors are about 1.4–4.7 for PCE, 1.2–2.5 for TCE, 1.1–1.6 for *c*DCE, and 1.0–1.2 for VC. Thus, PCE has the potential to travel 1.4–4.7 times more slowly than water in the aquifer due to sorption, whereas VC is subject to little or no sorption.

Dispersion is an additional factor affecting contaminant concentrations. Dispersion of contamination in the southern plume may be somewhat enhanced by tidal fluctuations and diversion of flow paths toward multiple leaking storm drains.

Summary and Conclusions

Site 45 is a former dry-cleaning facility and the surrounding area near the intersections of Panama Street, Samoa Street, and Kyushu Street. The area includes a new dry-cleaning facility. Groundwater contamination is present at the site, consisting primarily of PCE, TCE, *c*DCE, and VC. Two plumes of groundwater contamination are present, probably with some degree of intermingling in downgradient areas. The northern plume consists of groundwater contamination in the vicinity of and downgradient (southeast) from an area of former above-ground storage tanks north of the former dry-cleaning facility. The southern plume consists of groundwater contamination extending southeastward from the southeastern corner of the new dry-cleaning facility to about the intersection of Samoa Street and the driveway into the parking lot for Building 293. The USGS, in cooperation with the Naval Facilities Engineering Command Southeast, began investigations at the site to (1) examine the role that sewer lines play in contaminant source, distribution, attenuation, and transport in both the northern and southern plumes; (2) further delineate contamination in the southern plume; and (3) examine natural attenuation aspects of groundwater contamination in the southern plume. The investigation involved examination of historical records and engineering drawings of buildings, video imaging of storm sewers, water-level monitoring by synoptic measurements in wells and by use of continuous data loggers, installation and sampling of temporary wells, sampling of wells, storm sewers, surface water, and sediment, and the use of an MIP.

The northern plume appears to have originated from releases of PCE from the former dry-cleaning facility operation, including a documented spill on March 11, 1994. This spill also resulted in discharge of free-phase PCE into the storm-sewer system. Once in the storm-sewer system, the free-phase PCE probably was transported to a discharge point

Table 6. Concentrations of total organic carbon in soil borings, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; mg/kg, milligrams per kilogram]

Site identifier	Date (month/day/year)	Depth (ft BLS)	Total organic carbon (mg/kg)	Lithology
PAI-45-MW26-SL	6/27/2008	10–15	128	Sand, fine-grained
PAI-45-MW28-D	8/26/2008	18	155,000	Clay, organic-rich
PAI-45-USGS-TW96	4/30/2008	8–10	440	Sand, grayish-tan, fine-grained, loose
PAI-45-USGS-TW96	4/30/2008	12–13	2,120	Sand, black fine-grained

near Ballast Creek. Some PCE also may have leaked from the storm sewer along the way.

In late 1997, the dry-cleaning operations were moved to a nearby new facility, and the new operation used a hydrocarbon-based cleaner that did not contain chlorinated solvents. Nevertheless, investigations identified a southern plume, which appeared to originate in the vicinity of the new dry-cleaning facility. The present investigation, however, indicates that the southern plume was associated with activities at the former dry-cleaning facility.

The unconfined surficial aquifer at Site 45 consists of sand interspersed with discontinuous beds of clay, silty clay, silty clayey sand, and clayey silt and extends to a depth of about 18 ft BLS. Monitoring wells in this undifferentiated zone are referred to as SU wells if they are screened predominantly shallower than about 11 ft BLS and are referred to as SL wells if they are screened predominantly deeper than about 10 ft BLS. A peat layer, which is a few feet thick, has been reported at depths of about 17 to 27 ft BLS overlying a clay layer of variable thickness (possibly about 2 to 8 ft) that functions as a confining bed. The part of the aquifer below this clay is considered to be the D horizon.

Groundwater in the surficial aquifer moves in a generally southeastward direction with strong curvature of flow lines toward some of the storm sewers that are deeper than the water table. The groundwater surface in the D-horizon wells was comparatively flat-lying, with an overall trend toward the southeast. The most permeable part of the surficial aquifer near the new dry-cleaning facility and the midpart of the southern plume probably is the loose sand unit, which is at a depth of about 6–11.4 ft BLS at well PAI-45-MW28-D and at a depth of about 8–10 ft BLS at temporary well PAI-45-USGS-TW96.

The surficial aquifer at Site 45 is anaerobic at most locations, with the predominant TEAP being iron reduction in the shallowest sediment. In deeper sediment containing the main body of contamination, the predominant TEAP appears to be sulfate or iron reduction; however, the presence of methane, the high degree of contaminant dechlorination, and an H_2 value (31 nM) in the range of methanogenesis at one well indicates that methanogenic zones probably also are present. In the deepest part of the surficial aquifer, near the peat layer, the predominant TEAP probably is methanogenesis, by virtue of the abundant available natural organic matter.

Storm sewers that are below the water table appear to have an important influence on groundwater and contaminant movement. The curvature of groundwater flow lines toward the storm sewers and the presence of chlorinated solvents in water from the storm sewers indicate some level of leakage from the contaminated aquifer into the storm sewers. Although there is some contaminant underflow past the storm sewers in the southern plume and possibly in the southernmost part of the northern plume, leakage into the storm sewers appears to intercept and contain the main body of groundwater contamination in both plumes. Thus, the storm sewers are collection points for the dissolved groundwater contamination.

Most of the groundwater contamination near the new dry-cleaning facility is present from a few feet BLS to about 11.5 ft BLS. Within that interval, most of the contamination is at a depth of about 8 to 11.5 ft BLS, with the greatest concentrations near the bottom of that interval. In the middle part of the southern plume at temporary well PAI-45-USGS-TW96, the most contaminated zone appears to be in a loose sand layer about 8 to 11 ft BLS, although relatively high VOC concentrations also were found to a depth of about 14 ft BLS. The VOC concentrations at temporary well PAI-45-USGS-TW96 decreased with depth below about 13 ft BLS and were not detectable (less than 0.2 parts per million) at depths of 14–14.8 ft directly above the organic-rich layer and at 15.2–16 ft in the organic-rich layer. The less porous nature of the organic-rich silt layer relative to the overlying sand and the downward decrease in VOC concentrations in sediment immediately above the organic-rich silt layer indicates that the organic-rich layer is not a major contaminant-transport pathway at well PAI-45-USGS-TW96.

Although it cannot be stated with certainty that no VOC contamination is in the brackish-water D horizon underlying the clay that defines the base of the surficial unit, such contamination is unlikely for several reasons. The uncertainty arises because the wells in the D horizon were installed slightly offset from the main body of contamination in the surficial aquifer so as to avoid the risk of inadvertent transport of possible free product from the surficial to the deeper aquifer during drilling and because groundwater levels in the D-horizon wells are lower than the levels in the surficial aquifer. Thus, if there were a discontinuity in the clay layer, it is likely that there would be downward flow from the surficial to the deeper aquifers. It seems unlikely that there is contamination in the D-horizon aquifer also because (1) no VOCs were detected in any of the D wells despite the fact that at least well PAI-45-MW28-D was near the main body of contamination; (2) substantially lower VOC concentrations were detected near the base of the surficial aquifer than in the vertical midpart of the surficial aquifer, indicating a low potential for downward transport through the base of the surficial aquifer; and (3) the organic-rich peat at the base of the surficial aquifer provides a substantial sorptive buffer for VOCs.

Although the southern plume spatially originates from the new dry-cleaning facility, the new dry-cleaning facility is not likely the source of the contamination. Engineering blueprints, flow testing, and video imaging of sanitary sewers at the site, as well as the lack of a viable contaminant source at the new dry-cleaning facility, indicate that the contaminant source in the southern plume was a leak from a sanitary sewer in the vicinity of the new dry-cleaning facility.

Once in the aquifer, contamination in both the northern and southern plumes is transported southeastward, where most of the dissolved contamination is intercepted by leaky storm sewers. Because the storm sewers at Site 45 range in diameter from 12 to 36 inches and a tidal change of greater than 3 ft takes place in some of the storm sewers at Site 45, the VOCs entering the storm sewers are substantially diluted upon

entry. Volatilization probably also removes some of the VOC contamination in the storm sewers. During outgoing tides, the diluted contamination in the storm sewer is transported southward and discharges to Ballast Creek. A sample from a manhole STS26 in the storm sewer approximately 320 ft from the Ballast Creek discharge contained PCE, TCE, and *c*DCE concentrations of 0.69 (estimated), 4.26, and 2.53 $\mu\text{g/L}$, respectively, at low tide and concentrations of 1.06, 5.63, and 3.48 $\mu\text{g/L}$, respectively, 1 hour after low tide. No chlorinated-solvent contamination was detected in shallow sediment samples in the vicinity of the outfall to Ballast Creek; however, due to a laboratory error, the sediment sample from 1-ft depth at the outfall (PAI-SWSED1, June 17, 2008) had unusually high detection limits (32 to 81 mg/kg).

Despite the low VOC concentrations discharging to Ballast Creek, increases in VOC concentrations potentially are possible in the storm sewers during a time of relatively high groundwater levels and low amounts of tidal flushing. Water from manhole STS14 contained 20 $\mu\text{g/L}$ of VC at a time of relatively high groundwater levels (September 9, 2008). Because manhole STS14 is downstream from the contaminant source along a storm-sewer line that is adjacent to part of the aquifer where 2,290 $\mu\text{g/L}$ of VC was detected (June 25, 2007), there is a potential for substantially increased concentrations of VC to discharge at the storm-sewer outfall under conditions of high groundwater levels and low tidal flushing. In addition, the observation that free-phase PCE may have entered the storm-sewer system during the 1994 overflow means that DNAPL PCE could have leaked from various parts of the storm sewer in route to the Ballast Creek discharge. If the DNAPL was transported all the way to the Ballast Creek discharge point at STS27, then it likely would have sorbed to and sunk into the sediments not far from STS27.

Contaminant concentrations in the aquifer are subject to several influences. Microbes known to degrade chlorinated solvents and enzymes associated with dechlorination are present in the aquifer. The total mass of chlorinated solvents decreases from upgradient to downgradient parts of the southern plume. Parent/daughter-product ratios, stable carbon isotopes, the presence of VC, and higher ethylene concentrations in groundwater along the axis of the southern plume relative to nearby wells indicate extensive dechlorination activity. Oxidation of VC likely is taking place in the aquifer along the southern plume, based on the probable presence of sulfate reduction. Some degree of sorption of the VOCs is expected to take place in the aquifer, with the largest influence being on PCE. Dispersion also may decrease concentrations along the transport pathway. Although biodegradation and other attenuation processes are active in the southern plume, the processes are not sufficient to lower TCE concentrations to less than milligram-per-liter levels prior to intercepting the storm-sewer system.

References

- Amick, R.S., and Burgess, E.H., 2000, Exfiltration in sewer systems: U.S. Environmental Protection Agency, EPA/600R-01/034, 34 p.
- Barcelona, M., Wehrmann, H.A., and Varljen, M.D., 1994, Reproducible well-purging procedures and VOC stabilization criteria for ground-water sampling: *Groundwater*, v. 32, p. 12–22.
- Bechtel Environmental, Inc., 1997, Engineering evaluation and interim removal remediation work plan/interim measure work plan, Site 45/SWMU 45 Dry Cleaners Facility, Building 193, MCRD Parris Island, South Carolina: Consultant's report submitted to Southern Division Naval Facilities Engineering Command, Charleston, South Carolina.
- Bloom, Y., Aravena, R., Hunkeler, D., Edwards, E., and Frappe, S.K., 2000, Carbon isotope fractionation during microbial dechlorination of trichloroethene, *cis*-1,2-dichloroethene and vinyl chloride—Implications for assessment of natural attenuation: *Environmental Science and Technology*, v. 34, p. 2768–2772.
- Bradley, P.M., 2003, History and ecology of chloroethene biodegradation—A review: *Bioremediation Journal*, v. 7, no. 2, p. 81–109.
- Bradley, P.M., Singletary, M.A., and Chapelle, F.H., 2007, Chloroethene dechlorination in acidic ground water—Implications for combining Fenton's treatment with natural attenuation: *Remediation Journal*, v. 18, no. 1, p. 7–19.
- Center for Waste Minimization, 2000, Parris Island Marine Depot dry cleaners—Options Newsletter, Columbia, SC, South Carolina Department of Health and Environmental Control, p. 2.
- Chapelle, F.H., Vroblecky, D.A., Woodward, J.C., and Lovley, D.R., 1997, Practical considerations for measuring hydrogen concentrations in ground water: *Environmental Science and Technology*, v. 31, p. 2873–2877.
- Cirpka, O.A., Windfuhr, C., Bisch, B., Granzow, S., Scholz-Muramatsu, J., and Kobus, H., 1999, Microbial reductive dechlorination in a large-scale sandbox model: *Journal of Environmental Engineering*, v. 125, p. 861–870.
- Cupples, A.M., Spromann, A.M., and McCarty, P.L., 2003, Growth of a *Dehalococcoides*-like microorganism on vinyl chloride and *cis*-dichloroethene as electron acceptors as determined by competitive PCR: *Applied and Environmental Microbiology*, v. 69, no. 2, p. 953–959.

- Davis, J.H., 2003, Fate and transport modeling of selected chlorinated organic compounds at Hangar 1000, U.S. Naval Air Station, Jacksonville, Florida: U.S. Geological Survey Water-Resources Investigations Report 03-4089, 51 p.
- Dempster, H.S., Sherwood Lollar, B., and Feenstra, S., 1997, Tracing organic contaminants in ground water—A new methodology using compound-specific isotope analysis: *Environmental Science and Technology*, v. 31, no. 11, p. 3193–3197.
- Dennis, Philip, 2005, Commercial *Dehalococcoides* testing . . . What tests are available and how to correctly use and interpret results, *in* Proceedings of the 1st International Conference on Challenges in Site Remediation: Proper Site Characterization, Technology Selection and Testing, and Performance Monitoring, Chicago, IL, October 23–27, 2005.
- Dennis, Philip, 2009, Lessons learned from interpreting the quantification of *Dehalococcoides*: Presented at the 17th Annual David S. Snipes/Clemson Hydrogeology Symposium, April 2, 2009, Clemson, SC.
- EnviroFlux, LLC, 2007, Mass flux measurements at Solid Waste Management Unit (SWMU) 45: Marine Corps Recruit Depot (MCRD), Parris Island, South Carolina: Consultant's report submitted to Tetra Tech EM, Inc., 11 p.
- Fennell, D.E., and Gossett, J.M., 1998, Modeling the production of and competition for hydrogen in a dechlorinating culture: *Environmental Science and Technology*, v. 32, no. 16, p. 2450–2460.
- Fennell, D.E., and Gossett, J.M., 2003, Microcosms for site-specific evaluation of enhanced biological reductive dehalogenation, *in* Haggblom, M.M., and Bossert, I.D., eds., *Dehalogenation*: Boston, MA, Kluwer, p. 385–420.
- Flynn, S.J., Löffler, F.E., and Tiedje, J.M., 2000, Microbial community changes associated with a shift from reductive dechlorination of PCE to reductive dechlorination of *cis*-DCE and VC: *Environmental Science and Technology*, v. 34, p. 1056–1061.
- Freeze, R.A., and Cherry, J.A., 1979, *Groundwater*: Englewood Cliffs, NJ, Prentice-Hall, 604 p.
- Hackett, Logan, Howe, Robert, and Burhan, Younus, 2008, Use of passive flux meter (PFM) technology to refine a conceptual site model for chlorinated solvent nature and extent characterization, MCRD Parris Island, South Carolina—A field demonstration, *in* Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey CA, May 19–22, 2008, presentation F-002.
- Harrington, R.R., Poulson, S.R., Drever, J.I., Colberg, P.J.S., and Kelly, E.F., 1999, Carbon isotope systematics of monoaromatic hydrocarbons—Vaporization and adsorption experiments: *Organic Geochemistry*, v. 30, p. 765–775.
- He, J., Ritalahti, K.M., Aiello, M.R., and Löffler, F.E., 2003a, Complete detoxification of vinyl chloride by an anaerobic enrichment culture and identification of the reductively dechlorinating population as a *Dehalococcoides* species: *Applied and Environmental Microbiology*, v. 69, no. 2, p. 996–100.
- He, J., Ritalahti, K.M., Yang, K., Koenigsberg, S.S., and Löffler, F.E., 2003b, Detoxification of vinyl chloride to ethene coupled to growth of an anaerobic bacterium: *Nature*, v. 424, no. 6944, p. 62–65.
- Held, I., Wolf, L., Eiswirth, M., and Hotzl, H., 2006, Impacts of sewer leakage on urban ground water, *in* Tellam, J.H., Rivett, M.O., and Israfilov, R.G., eds., *Urban groundwater management and sustainability*: NATO Science Series, Springer Netherlands, v. 74, p. 189–204.
- Hendrickson, E.R., Payne, Jo Ann, Young, R.M., Starr, M.G., Perry, M.P., Fahnestock, Stephen, Ellis, D.E., and Ebersole, R.C., 2002, Molecular analysis of *Dehalococcoides* 16S ribosomal DNA from chloroethene-contaminated sites throughout North America and Europe: *Applied and Environmental Microbiology*, v. 68, no. 2, p. 485–495.
- Holliger, C., Dittmar, H., Harmsen, H., Ludwig, W., Schumacher, W., Tindall, B., Vazquez, F., Weiss, N., and Zehnder, A.J.B., 1998, *Dehalobacter restrictus* gen. nov. and sp. nov., a strictly anaerobic bacterium that reductively dechlorinates tetra- and trichloroethene in an anaerobic respiration: *Archives of Microbiology*, v. 169, p. 313–321.
- Holliger, C., Schraa, G., Stamms, A.J.M., and Zehnder, A.J.B., 1993, A highly purified enrichment culture couples the reductive dechlorination of tetrachloroethene to growth: *Applied and Environmental Microbiology*, v. 59, p. 2991–2997.
- Hunkeler, D., Aravena, R., and Butler, B.J., 1999, Monitoring microbial dechlorination of tetrachloroethene (PCE) in groundwater using compound-specific stable isotopes—laboratory and field studies: *Environmental Science and Technology*, v. 33, no. 16, p. 2733–2738.
- Jamison, Tim, 2007, Washburn sewer system overwhelmed by groundwater: *Waterloo Courier Newspaper*, Waterloo, IA, September 2, 2007.
- Jendrejewski, N., Eggankamp, H.G.M., and Coleman, M.L., 2001, Characterization of chlorinated hydrocarbons from chlorine and carbon isotope compositions—Scope of application to environmental problems: *Applied Geochemistry*, v. 16, p. 1021–1031.

- Kelso, P.W., 2005, An innovative field-based analytical method for low-level detection of chlorinated compounds in groundwater and soil samples (The Color-Tec Method): accessed June 13, 2008, at http://www.clu-in.org/conf/tio/pasi/colortec_description.pdf.
- Krajmalnik-Brown, R., Holscher, T., Thomson, I.N., Saunders, F.M., Ritalahti, K.M., and Löffler, F.E., 2004, Genetic identification of a putative vinyl chloride reductase in *Dehalococcoides* sp. strain BAV1: Applied and Environmental Microbiology, v. 70, p. 6347–6351.
- Lu, Xiaoxia, Kampbell, D.H., and Wilson, J.T., 2006, Evaluation of the role of *Dehalococcoides* organisms in the natural attenuation of chlorinated ethylenes in groundwater: U.S. Environmental Protection Agency EPA/600/R-06/029, 101 p.
- Magnuson, J.K., Romine, M.F., Burris, D.R., and Kingsley, M.T., 2000, Trichloroethene reductive dehalogenase for *Dehalococcoides ethenogenes*—Sequence of *tceA* and substrate range characterization: Applied and Environmental Microbiology, v. 66, p. 5141–5147.
- Maymo-Gatell, X., Anguish, T., and Zinder, S.H., 1999, Reductive dechlorination of chlorinated ethenes and 1,2-dichloroethane by “*Dehalococcoides Ethenogenes*” 195: Applied and Environmental Microbiology, v. 65, no. 7, p. 3108–3113.
- Maymo-Gatell, X., Chien, Y., Gossett, J.M., and Zender, S.H., 1997, Isolation of a bacterium that reductively dechlorinates tetrachloroethene to ethene: Science, v. 276, p. 1568–1571.
- Mercer, J.W., Thomas, S.D., and Ross, B., 1982, Parameters and variables appearing in repository siting models: NUREG/CR-3066, National Technical Information Service, Springfield, VA, 244 p.
- Morrill, Penny, Seepersad, David, Lacrampe-Couloume, Georges, Edwards, Elizabeth, Sleep, Brent, McMaster, Michaye, and Sherwood Lollar, Barbara, 2003, Stable carbon isotope investigation of biologically enhanced dissolution of tetrachloroethene near the DNAPL source area: 2003 Geological Society of America Annual Meeting, Seattle, Washington, November 2–5, 2003, paper number 143–3.
- Muller, J.A., Rosner, B.M., Von Abendroth, G., Meshulam-Simon, G., McCarty, P.L., and Spormann, A.M., 2004, Molecular identification of the catabolic vinyl chloride reductase from *Dehalococcoides* sp. strain VS and its environmental distribution: Applied and Environmental Microbiology, v. 70, p. 4880–4888.
- Panagiotakis, Raklis, Mamais, Daniel, Patnazidou, Marina, Aulenta, Federico, Rossitti, Simona, and Tandio, Valter, 2008, Effect of sulfate concentration on reductive dechlorination in TCE-fed microcosms: Presented at the 4th European Bioremediation Conference, Chania, Greece, September 3–9, 2008, ID 098, accessed November 5, 2008, at <http://www.srcosmos.gr/srcosmos/showpub.asp?aa=11378>.
- Poulson, S.R., and Drever, J.I., 1999, Stable isotope (C, Cl, and H) fractionation during vaporization of trichloroethylene: Environmental Science and Technology, v. 33, no. 20, p. 3689–3694.
- Reynolds, J.H., and Barrett, M.H., 2007, A review of the effects of sewer leakage on groundwater quality: Water and Environment Journal, v. 17, no. 1, p. 34–39.
- Rutsch, M., Rieckermann, J., and Krebs, P., 2005, Quantification of sewer leakage—a review: Presented at the 10th International Conference on Urban Drainage, Copenhagen/Denmark, August 21–26, 2005.
- S&ME, Inc., 1994, Tetrachloroethylene contamination assessment and conceptual corrective action plan, U.S. Marine Corps Recruit Depot Dry-Cleaning Facility: Consultant’s report to Morale, Welfare and Recreation office, Marine Corps Recruit Depot, Parris Island, SC, 23 p.
- Schmidt, Hauke, and de Vos, W.M., 2004, Anaerobic microbial dehalogenation: Annual Review of Microbiology, v. 58, p. 43–73.
- Shanklin, D.E., Sidle, W.C., and Ferguson, M.E., 1995, Micro-purge low-flow sampling of uranium-contaminated groundwater at the Fernald Environmental Management Project: Groundwater Monitoring and Remediation, v. 15, no. 3, p. 168–176.
- Sherwood Lollar, B., Slater, G.F., Ahad, J.M.D., Sleep, B.E., Spivack, J., Bennan, M., and MacKenzie, P., 1999, Contrasting carbon isotope fractionation during biodegradation of trichloroethylene and toluene—implications for intrinsic bioremediation: Organic Geochemistry, v. 30, p. 812–820.
- Sherwood Lollar, B., Slater, G.F., Sleep, B.E., Witt, M., Klecka, G.M., Harkness, M., and Spivack, J., 2001, Stable carbon isotope evidence for intrinsic bioremediation of tetrachloroethene and trichloroethene at Area 6, Dover Air Force Base: Environmental Science and Technology, v. 35, no. 2, p. 261–269.
- Slater, G.F., Ahad, J.M.E., Sherwood Lollar, B., Allen-King, R.M., and Sleep, B.E., 2000, Carbon isotope effects resulting from equilibrium sorption of dissolved VOCs: Analytical Chemistry, v. 72, no. 22, p. 5669–5672.
- Slater, G.F., Dempster, H.S., Sherwood Lollar, B., and Ahad, J.M.E., 1999, Headspace analysis—A new application for isotopic characterization of dissolved organic contaminants: Environmental Science and Technology, v. 33, p. 190–194.

- Slater, G.F., Sherwood Lollar, B., Sleep, B.E., and Edwards, E.A., 2001, Variability in carbon isotopic fractionation during biodegradation of chlorinated ethenes—Implications for field applications: *Environmental Science and Technology*, v. 35, p. 901–907.
- Solutions IES, Inc., Terra Systems, Inc., and Parsons Infrastructure and Technology Group, Inc., 2007, Final Protocol for in situ bioremediation of chlorinated solvents using edible oil: Prepared for Air Force Center for Engineering and the Environmental Science Division, Technology Transfer Outreach Office, October 2007, various pagination.
- Song, D.L., Conrad, M.E., Sorenson, K.S., and Alvarez-Cohen, Lisa, 2002, Stable carbon isotope fractionation during enhanced in situ bioremediation of trichloroethene: *Environmental Science and Technology*, v. 36, no. 10, p. 2262–2268.
- Squillace, P.J., Moran, M.J., and Price, C.V., 2004, VOCs in shallow groundwater in new residential/commercial areas of the United States: *Environmental Science and Technology*, v. 38, no. 20, p. 5327–5338.
- State of Wisconsin, 1996, In the matter of alleged discharge of a hazardous substance on property owned by Roger and Mildred Brettingen, Located in the City of Beaver Dam, Dodge County, Wisconsin: Case number IH-95-16, Division of Hearings and Appeals, Madison, WI, July 5, 1996, 8 p., accessed March 31, 2008, at <http://dha.state.wi.us/home/Decisions/DNR/1995-1999/ih-95-16.pdf>.
- Tetra Tech NUS, Inc., 2004, Remedial Investigation/RCRA Facilities Investigation for Site/SWMU 45, former MWR dry-cleaning facility, Marine Corps Recruit Depot Parris Island, South Carolina, Volume 1—Consultant's report to Southern Division Naval Facilities Engineering Command, Charleston, SC, various pagination.
- Tetra Tech NUS, Inc., 2005, Remedial investigation addendum for site/SWMU 45, former MWR dry-cleaning facility for Marine Corps Recruit Depot Parris Island, South Carolina—Consultant's report to Southern Division Naval Facilities Engineering Command, Charleston, SC, various pagination.
- U.S. Environmental Protection Agency, 1999, Total organic carbon (TOC) in soil, SW-846 method 9060, 1999, accessed June 12, 2009, at <http://www.epa.gov/region09/qa/pdfs/9060dqi.pdf>.
- U.S. Environmental Protection Agency, 2002, Implementation guidance for the arsenic rule—drinking water regulations for arsenic and clarifications: U.S. Environmental Protection Agency, EPA 816-K-02-018, 83 p.
- U.S. Environmental Protection Agency, 2005, Sensor technologies used during site remediation activities—Selected experiences: U.S. Environmental Protection Agency, EPA 542-R-05-007, 110 p.
- U.S. Environmental Protection Agency, 2008, National primary drinking water regulations 40CFR141.1, accessed February 26, 2009, at http://74.125.47.132/search?q=cache:nNprT-FslQJ:edocket.access.gpo.gov/cfr_2008/julqtr/40cfr141.1.htm+40CFR141.1&hl=en&ct=clnk&cd=1&gl=us.
- van Warmerdam, E.M., Frappe, S.K., Aravena, R., Drimmie, R.J., Flatt, H., and Cherry, J.A., 1995, Stable chlorine and carbon isotope measurements of selected chlorinated organic solvents: *Applied Geochemistry*, v. 10, p. 547–552.
- Vieth, A., Müller, J., Strauch, G., Kästner, M., Gehre, M., Meckenstock, R.U., and Richnow, H.H., 2003, In-situ biodegradation of tetrachloroethene and trichloroethene in contaminated aquifers monitored by stable isotope fractionation: *Isotopes in Environmental and Health Studies*, v. 39, no. 2, p. 113–124.
- Vroblecky, D.A., Bradley, P.M., and Chapelle, F.H., 1996, Influence of electron donor on the minimum sulfate concentration required for sulfate reduction in a petroleum hydrocarbon-contaminated aquifer: *Environmental Science and Technology*, v. 30, no. 4, p. 1377–1381.
- Vroblecky, D.A., Casey, C.C., and Lowery, M.A., 2007, Influence of dissolved oxygen convection on well sampling: *Ground Water Monitoring and Remediation*, v. 27, no. 3, p. 49–58.
- Wakida, F.T., and Lerner, D.N., 2004, Non-agricultural sources of groundwater nitrate—A review and case study: *Water Research*, v. 39, no. 1, p. 3–16.
- Wiedemeier, T.H., Wilson, J.T., and Kampbell, D.H., 1996, Natural attenuation of chlorinated aliphatic hydrocarbons at Plattsburg Air Force Base, New York, *in* Symposium on Natural Attenuation of Chlorinated Organics in Ground Water: U.S. Environmental Protection Agency, EPA/540/R-96/509, p. 74–82.
- Wolf, Leif, Eiswirth, Matthias, and Hötzl, Heinz, 2003, Assessing sewer-groundwater interaction at the city scale based on individual sewer defects and marker species distributions: *Materials and Geoenvironment*, v. 50, no. 1, p. 423–426,
- Wolf, Leif, Held, Inka, Eiswirth, Matthias, and Hötzl, Heinz, 2004, Impact of leaky sewers on groundwater quality: *Acta Hydrochimica et Hydrobiologica*, v. 32, no. 4–5, p. 361–373.
- Yang, Y., and McCarty, P.L., 1998, Competition for hydrogen within a chlorinated solvent dehalogenating anaerobic mixed culture: *Environmental Science and Technology*, v. 32, no. 22, p. 3591–3597.
- Zhuang, Ping, and Pavlostathis, S.G., 1995, Effect of temperature, pH, and electron donor on the microbial reductive dechlorination of chloroalkenes: *Chemosphere*, v. 31, no. 6, p. 3537–3548.

Appendixes 1–14

1. Monitoring-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	46
2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina	48
3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.....	51
4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008	55
5. Concentrations of field-measured constituents in groundwater from monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.....	59
6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.....	61
7. Concentrations of selected volatile organic compounds in soil borings from temporary well PAI-45-USGS-TW7, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.....	66
8. Concentrations of total organic carbon in soil borings, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008	67
9. Concentrations of selected volatile organic compounds in surface water near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008	67
10. Concentrations of selected volatile organic compounds in sediment near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008	68
11. Synoptic water-level measurements at approximately low tide in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.....	69
12. Lithologic logs for permanent wells at site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008	71
13. Lithologic log for temporary well PAI-45-USGS-TW96, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, April 30, 2008.....	73
14. Membrane Interface Probe logs, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008, for boring—	
MIP1	74
MIP2.....	75
MIP3.....	76
MIP4.....	77
MIP5.....	78
MIP6.....	79
MIP7.....	80

46 Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, SC

Appendix 1. Monitoring-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

[NAVD 88, North American Vertical Datum of 1988]

Site identifier	Well diameter (inches)	Depth to top of screen (feet below land surface)	Depth to bottom of screen (feet below land surface)	Northing	Easting	Top of riser datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)	Surveyor and date (month/day/year) of survey for Northing and Easting
PAI-45-MW01-D	2	30	40	187465.456	2099311.961	6.60	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW01-SL	2	11.6	14	187466.139	2099316.097	6.52	Doolan, Inc., 2005 (month and day unavailable)
PAI-45-MW01-SU	2	3	7	187467.026	2099306.621	6.54	Doolan, Inc., 2005 (month and day unavailable)
PAI-45-MW02-SL	2	9	14	187351.015	2099211.018	6.22	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW02-SU	2	3	7	187354.829	2099212.934	6.12	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW03-SL	2	9	14	187268.683	2099249.515	6.54	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW03-SU	2	3	7	187267.674	2099253.593	6.59	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW04-D	2	31	41	187166.810	2099265.215	5.78	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW04-SL	2	9	14	187159.374	2099262.953	5.91	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW04-SU	2	3	7	187160.950	2099259.013	5.93	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW05-D	2	34	44	187197.820	2099386.421	7.63	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW05-SL	2	9	14	187202.721	2099386.456	7.24	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW05-SU	2	3	7	187197.962	2099386.971	7.59	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW06-D	2	30	40	187282.019	2099309.350	6.44	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW06-SL	2	9	14	187287.357	2099305.627	6.48	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW06-SU	2	3	7	187283.229	2099304.531	6.52	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW07-D	2	30	40	187339.823	2099306.986	6.63	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW07-SL	2	9	14	187338.979	2099302.924	6.68	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW07-SU	2	3	7	187336.809	2099304.945	6.63	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW08-SL	2	9	14	187401.386	2099328.184	6.50	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW08-SU	2	3	7	187397.064	2099327.899	6.57	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW09-D	2	31	41	187100.747	2099353.889	6.24	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW10-D	2	31	41	187415.892	2099229.520	6.25	Data from Mark Sladic, Tetra Tech NUS, Inc., written commun., 2008
PAI-45-MW10-SL	2	11	16	187227.568	2099257.425	5.85	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW10-SU	2	3	8	187226.768	2099261.530	5.90	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW11-D	2	31	41	187188.732	2099166.370	5.43	Andrews & Burgess, Inc. 6/16/08
PAI-45-MW13-SL	2	11	16	187190.163	2099307.653	6.39	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW13-SU	2	4	9	187184.776	2099306.465	6.48	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW14-SL	2	10	15	187334.096	2099445.045	5.76	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW14-SU	2	4	9	187338.682	2099445.653	5.84	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW15-SL	2	13	18	187265.544	2099457.147	8.13	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW15-SU	2	4	9	187266.012	2099452.700	8.32	Andrews & Burgess, Inc. 4/2/08

Appendix 1. Monitoring-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988]

Site identifier	Well diameter (inches)	Depth to top of screen (feet below land surface)	Depth to bottom of screen (feet below land surface)	Northing	Easting	Top of riser datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)	Surveyor and date (month/day/year) of survey for Northing and Easting
PAI-45-MW16-SL	2	13	18	187234.892	2099433.936	9.17	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW16-SU	2	4	9	187234.935	2099429.243	9.14	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW17-SL	2	10	15	187067.734	2099344.179	5.96	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW17-SU	2	4	9	187075.099	2099346.330	6.17	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW18-SL	2	11	16	187107.267	2099205.285	6.98	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW18-SU	2	4	9	187105.786	2099210.709	6.99	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW19-SL	2	11	16	187178.241	2099196.676	5.64	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW19-SU	2	3	8	187176.220	2099201.993	5.64	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW20-SL	2	11	16	187129.003	2099270.471	6.67	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW20-SU	2	4	9	187129.327	2099264.864	6.72	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-SL	2	10	15	187345.345	2099245.914	6.27	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-SU	2	3	8	187339.024	2099245.269	6.37	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-D	2	27	37	187340.975	2099246.902	6.27	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW22-SL	2	10	15	187397.664	2099263.094	6.43	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW22-SU	2	3	8	187392.941	2099266.426	6.51	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW23-SL	2	10	15	187278.133	2099390.679	6.28	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW23-SU	2	3	10	187283.155	2099392.057	6.37	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW24-SU	2	3	8	187373.509	2099284.908	6.62	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW25-SL	2	10	15	187302.168	2099111.404	6.64	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW26-SL	1	10	15	187087.084	2099286.783	5.61	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW27-SL	1	10	15	187088.779	2099392.332	6.58	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW28-D	2	23.7	33.7	187263.583	2099121.183	5.48	Andrews & Burgess, Inc. 6/17/08
PAI-45-MW29-D	2	23.1	33.1	187284.392	2099087.798	5.18	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW30-D	2	25	35	187323.614	2099133.512	8.05	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW31-SL	2	10	15	187230.214	2099198.181	5.49	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW31-SU	2	5	10	187232.003	2099195.065	5.57	Andrews & Burgess, Inc. 6/11/08

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/ year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW1	6/25/2007	8–11	187360.27	2099409.50	6.59
PAI-45-USGS-TW2	6/25/2007	7–11	187343.36	2099429.00	6.13
PAI-45-USGS-TW3	6/25/2007	7–11	187326.55	2099422.00	6.03
PAI-45-USGS-TW4	6/25/2007	7–11	187323.50	2099404.50	6.54
PAI-45-USGS-TW5	6/25/2007	6–10.5	187314.65	2099435.85	5.88
PAI-45-USGS-TW6	6/25/2007	7–11	187301.52	2099408.25	6.33
PAI-45-USGS-TW7	6/25/2007	7–11	187279.92	2099428.61	6.35
PAI-45-USGS-TW8	6/25/2007	7.5–11.5	187266.28	2099410.01	6.85
PAI-45-USGS-TW9	6/25/2007	7.5–11.5	187257.22	2099423.55	7.55
PAI-45-USGS-TW10	6/25/2007	0–10	187254.39	2099401.62	7.18
PAI-45-USGS-TW11	6/25/2007	7.75–11.75	187366.61	2099389.75	6.77
PAI-45-USGS-TW12	6/25/2007	7.5–10.5	187348.06	2099387.50	6.93
PAI-45-USGS-TW13	6/25/2007	6–10	187331.98	2099384.50	6.84
PAI-45-USGS-TW14	6/25/2007	6–10	187308.06	2099378.75	6.94
PAI-45-USGS-TW15	6/25/2007	6–10	187282.89	2099371.50	6.93
PAI-45-USGS-TW16	6/25/2007	6–10	187245.86	2099364.08	6.15
PAI-45-USGS-TW17	6/25/2007	6.5–10.5	187232.94	2099363.75	6.54
PAI-45-USGS-TW18	6/25/2007	12–14.5	187258.84	2099423.52	7.43
PAI-45-USGS-TW19	6/25/2007	8–12	187189.27	2099397.75	7.83
PAI-45-USGS-TW20	6/25/2007	8–12	187183.31	2099411.00	8.39
PAI-45-USGS-TW21	6/25/2007	11–15	187185.06	2099411.75	8.49
PAI-45-USGS-TW22	6/25/2007	6–10	187201.98	2099356.50	6.9
PAI-45-USGS-TW23	6/25/2007	6–10	187176.92	2099350.50	6.69
PAI-45-USGS-TW24	6/25/2007	11.5–15.5	187122.83	2099374.50	6.95
PAI-45-USGS-TW25	6/25/2007	11.5–15.5	187139.01	2099328.13	6.14
PAI-45-USGS-TW26	6/25/2007	11.5–15.5	187072.66	2099372.77	5.96
PAI-45-USGS-TW27	6/25/2007	11.5–15.5	187110.40	2099310.81	6.33
PAI-45-USGS-TW28	6/25/2007	11.5–15.5	187113.94	2099298.75	5.94
PAI-45-USGS-TW29	6/27/2007	11.5–15.5	187094.61	2099274.29	6.32
PAI-45-USGS-TW30	6/25/2007	11.5–15.5	187102.36	2099356.75	6.76
PAI-45-USGS-TW31	6/27/2007	11.5–15.5	187127.72	2099232.59	6.95
PAI-45-USGS-TW32	6/27/2007	11.5–15.5	187142.73	2099217.73	6.98
PAI-45-USGS-TW33	6/25/2007	11.5–15.5	187107.59	2099330.16	5.83
PAI-45-USGS-TW34	6/25/2007	11.5–15.5	187093.87	2099328.33	5.78

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/ year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW35	6/25/2007	11.5–15.5	187070.40	2099318.86	5.77
PAI-45-USGS-TW36	6/25/2007	11.5–15.5	187096.98	2099397.75	7.22
PAI-45-USGS-TW37	6/27/2007	11.5–15.5	187167.73	2099175.75	6.47
PAI-45-USGS-TW38	6/27/2007	10–14	187251.48	2099137.50	5.34
PAI-45-USGS-TW39	6/27/2007	10–14	187283.45	2099131.22	5.83
PAI-45-USGS-TW40	6/27/2007	10–14	187234.53	2099123.25	5.29
PAI-45-USGS-TW41	6/27/2007	10–14	187316.97	2099133.25	7.95
PAI-45-USGS-TW42	6/27/2007	10–14	187272.82	2099106.84	5.57
PAI-45-USGS-TW43	6/27/2007	10–14	187202.56	2099108.50	—
PAI-45-USGS-TW44	6/27/2007	10–14	187296.06	2099126.50	7.16
PAI-45-USGS-TW45	6/27/2007	10.5–14.5	187171.89	2099107.00	6.76
PAI-45-USGS-TW46	6/27/2007	10.5–14.5	187218.25	2099078.75	5.86
PAI-45-USGS-TW47	6/27/2007	10.5–14.5	187301.52	2099109.50	7.25
PAI-45-USGS-TW48	6/27/2007	10.5–14.5	187234.42	2099192.59	5.64
PAI-45-USGS-TW49	6/27/2007	10–14	187298.99	2099087.18	6.3
PAI-45-USGS-TW50	6/27/2007	11–15	187276.06	2099198.35	6.47
PAI-45-USGS-TW51	6/27/2007	10.5–14.5	187286.09	2099176.36	6.61
PAI-45-USGS-TW52	6/27/2007	11–15	187210.67	2099246.72	6
PAI-45-USGS-TW53	6/27/2007	11–15	187188.90	2099234.92	6.06
PAI-45-USGS-TW54	6/27/2007	11–15	187169.28	2099226.16	5.97
PAI-45-USGS-TW55	6/28/2007	11–15	187292.91	2099206.75	6.63
PAI-45-USGS-TW56	6/28/2007	11–15	187254.19	2099207.20	5.75
PAI-45-USGS-TW57	6/28/2007	11–15	187206.84	2099183.50	5.97
PAI-45-USGS-TW58	6/28/2007	11–15	187130.32	2099144.04	6.92
PAI-45-USGS-TW59	6/28/2007	11–15	187096.29	2099247.02	6.92
PAI-45-USGS-TW60	6/28/2007	10–14	187283.61	2099230.42	6.82
PAI-45-USGS-TW61	6/28/2007	11–15	187244.46	2099262.61	6.21
PAI-45-USGS-TW62	6/28/2007	11.5–15.5	187224.64	2099306.74	6.26
PAI-45-USGS-TW63	6/28/2007	11.5–15.5	187149.34	2099277.79	6.57
PAI-45-USGS-TW64	6/28/2007	11.5–15.5	187114.10	2099279.61	5.97
PAI-45-USGS-TW65	6/28/2007	11.5–15.5	187135.36	2099411.25	6.53
PAI-45-USGS-TW66	6/28/2007	11.5–15.5	187258.48	2099242.97	—
PAI-45-USGS-TW67	6/28/2007	11–15	187277.23	2099251.25	7
PAI-45-USGS-TW68	6/28/2007	11–15	187287.06	2099253.50	6.94

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/ year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW69	6/28/2007	11–15	187258.16	2099079.12	5.21
PAI-45-USGS-TW70	6/28/2007	11–15	187254.18	2099103.20	5.2
PAI-45-USGS-TW71	8/29/2007	8–12	187211.46	2099416.85	10.04
PAI-45-USGS-TW72	8/29/2007	11–15	187284.76	2099119.48	5.04
PAI-45-USGS-TW73	8/29/2007	11–15	187266.94	2099152.55	5.6
PAI-45-USGS-TW74	8/29/2007	11–15	187249.54	2099172.17	5.56
PAI-45-USGS-TW75	8/29/2007	1–14	187191.45	2099277.80	6.09
PAI-45-USGS-TW76	8/29/2007	11–15	187127.76	2099283.83	6.88
PAI-45-USGS-TW77	3/5/2008	7–11 and 11–15	187311.01	2099116.30	7.33
PAI-45-USGS-TW78	3/5/2008	7–11 and 11–15	187306.62	2099122.83	7.34
PAI-45-USGS-TW79	3/5/2008	11–15	187294.99	2099121.60	6.31
PAI-45-USGS-TW80	3/5/2008	7–11 and 11–15	187291.03	2099106.77	5.54
PAI-45-USGS-TW81	3/5/2008	7–11 and 11–15	187304.55	2099132.91	7.67
PAI-45-USGS-TW82	3/4/2008	11–15	187291.12	2099140.97	6.72
PAI-45-USGS-TW83	3/5/2008	11–15	187273.63	2099135.31	5.38
PAI-45-USGS-TW84	3/5/2008	11–15	187269.15	2099123.28	5.58
PAI-45-USGS-TW85	3/5/2008	11–15	187281.50	2099096.44	5.35
PAI-45-USGS-TW86	3/5/2008	11–15	187279.37	2099108.35	5.32
PAI-45-USGS-TW87	3/4/2008	11–15	187266.53	2099154.00	5.54
PAI-45-USGS-TW88	3/4/2008	11–15	187260.98	2099146.37	5.58
PAI-45-USGS-TW89	3/4/2008	11–15	187263.54	2099179.96	5.6
PAI-45-USGS-TW90	3/4/2008	11–15	187255.87	2099167.90	5.66
PAI-45-USGS-TW91	3/5/2008	11–15	187248.20	2099157.66	5.51
PAI-45-USGS-TW92	3/4/2008	11–15	187247.59	2099194.75	5.72
PAI-45-USGS-TW93	3/4/2008	7–11 and 11–15	187238.34	2099187.03	5.6
PAI-45-USGS-TW94	3/5/2008	7–11 and 11–15	187293.68	2099135.13	6.6
PAI-45-USGS-TW95	3/5/2008	11–15	187320.82	2099118.61	7.52
PAI-45-USGS-TW96	4/30/2008	Core 4–16	187232.55	2099193.41	5.67

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/ year)	1,1-DCE	1,2-DCE	Benzene	CB	cDCE	EB	Napht	PCE	TCE	Tol	tDCE	VC	Xyl
PAI-45-MW03-SL	7/23/2007	<3	750	<3	<2.5	750	<2.5	<2.5	<2.5	54	<2.5	<3	31.5	<2.5
PAI-45-MW03-SL	9/10/2007	<3	1,080	<3	<2.5	1,070	<2.5	<2.5	<2.5	11	<2.5	<3	14.3	<2.5
PAI-45-MW04-D	9/10/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW04-SL	8/25/2005	6.51	1,290	<0.3	0.52J	1,290	0.28J	<0.25	4,460	5,390	2.71	—	155J	—
PAI-45-MW04-SL	3/7/2006	<100	796	<100	<100	796	<100	26.6J	5,370	4,760	<100	<100	135	<100
PAI-45-MW04-SLR	3/7/2006	<100	787	<100	<100	787	<100	32.7J	5,270	4,770	<100	<100	137	<100
PAI-45-MW04-SL	9/26/2006	<6.8	—	<10	<11	830	<10	<16	3,700	5,100	<8.5	12J	200	—
PAI-45-MW04-SL	7/24/2007	<15	701	<15	<12.5	701	<12.5	<12.5	1,290	4,010	<12.5	<15	113	<12.5
PAI-45-MW04-SL	9/10/2007	3.45	808	<0.3	1.13	1,010H	<0.25	<0.25	1,840H	5,860H	1.41	13.2	145H	0.50J
PAI-45-MW04-SL	6/18/2008	3.97	1,070	<0.3	1.2	1,450H	<0.25	<0.25	1,030H	3,440H	1.16	15.4	>100	0.46J
PAI-45-MW04-SL	9/9/2008	<15	2,260	<15	<12.5	2,260	<12.5	<12.5	326	2,280	<12.5	<15	101	<12.5
PAI-45-MW04-SU	7/24/2007	<1.2	45.9	<1.2	<1	45.9	<1	<1	67.4	245	<1	<1.2	10.4	<1
PAI-45-MW04-SU	9/10/2007	<0.3	53.4	<0.3	<0.25	52.6	<0.25	<0.25	80.6	277	<0.25	0.82J	12.5	<0.25
PAI-45-MW05-SL	7/23/2007	<0.3	55	<0.3	<0.25	55	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SL	9/11/2007	<0.3	27.7	<0.3	<0.25	27.7	<0.25	<0.25	<0.25	<0.25	0.311J	<0.3	<0.5	<0.25
PAI-45-MW05-SL	6/19/2008	<0.6	126	<0.6	<0.5	126	<0.5	1.03J	<0.5	<0.5	<0.5	<0.6	<1	<0.5
PAI-45-MW05-SL	9/8/2008	<0.3	63.2	<0.3	<0.25	62.6	<0.25	<0.25	<0.25	0.94J	<0.25	0.6J	0.6J	<0.25
PAI-45-MW05-SU	7/23/2007	<0.3	23.7	<0.3	<0.25	23.7	<0.25	<0.25	<0.25	0.47J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SU	6/19/2008	<0.3	13	<0.3	<0.25	13	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SU	9/8/2008	<0.3	4.04	<0.3	<0.25	4.04	<0.25	<0.25	<0.25	1.44	<0.25	<0.3	<0.5	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/ year)	1,1-DCE	1,2-DCE	Benzene	CB	cDCE	EB	Napht	PCE	TCE	Tol	tDCE	VC	Xyl
PAI-45-MW10-SL	7/23/2007	<3	504	<3	<2.5	504	<2.5	<2.5	<2.5	153	<2.5	<3	<5	<2.5
PAI-45-MW10-SL	9/10/2007	<1.5	525	<1.5	<1.25	563	<1.25	<1.25	<1.25	263	<1.25	2.59J	4.53J	<1.25
PAI-45-MW10-SL	6/18/2008	<0.3	417	<0.3	0.81J	406	<0.25	<0.25	1.3	50.4	<0.25	3.54	8.87	<0.25
PAI-45-MW10-SL	9/9/2008	0.51J	457	<0.3	<0.25	454	<0.25	<0.25	<0.45	13.7	<0.25	2.91	8.32	<0.6
PAI-45-MW10-SU	7/23/2007	0.5J	123	<0.3	<0.25	120	<0.25	<0.25	<0.25	<0.25	<0.25	1.84	9.03	<0.25
PAI-45-MW10-SU	9/10/2007	0.7J	147	<0.3	0.387J	168	<0.25	<0.25	<0.25	<0.25	<0.25	2.07	9.79	<0.25
PAI-45-MW10-SU	6/18/2008	<0.3	59.8	<0.3	<0.25	58.4	<0.25	<0.25	<0.25	<0.25	<0.25	1.34	9.65	<0.25
PAI-45-MW10-SU	9/9/2008	<0.3	66	<0.3	<0.25	64.7	<0.25	0.49J	8.98	2.4	<0.25	1.26	18.3	<0.6
PAI-45-MW13-SL	7/23/2007	<0.6	201	<0.6	3.43	189	<0.5	<0.5	<0.5	<0.5	<0.5	<0.6	4.03	<0.5
PAI-45-MW13-SL	9/11/2007	<1.5	334	<1.5	3.22J	334	<1.25	<1.25	<1.25	<1.25	<1.25	<1.5	<2.5	1.38J
PAI-45-MW13-SL	6/17/2008	<0.3	171	<0.3	3.61	144	<0.25	<0.25	11.5	6.32	<0.25	0.7J	5.52	<0.25
PAI-45-MW13-SL	9/9/2008	<0.6	154	<0.6	4.04	153	<0.5	<0.5	<0.5	<0.5	<0.5	0.7J	3.34	<0.5
PAI-45-MW16-SL	7/24/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW16-SU	7/24/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	7/24/2007	<0.3	1.04	<0.3	<0.25	1.04	<0.25	<0.25	<0.25	0.27J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	9/11/2007	<0.3	0.61J	<0.3	<0.25	0.61J	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	6/17/2008	<0.3	2.48	<0.3	<0.25	2.48	<0.25	<0.25	<0.25	1.67	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	9/8/2008	<0.3	0.35J	<0.3	<0.25	0.35J	<0.25	<0.25	<0.25	0.25J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17SU	6/17/2008	<0.3	9.71	<0.3	<0.25	9.71	<0.25	<0.25	<0.25	8.83	<0.25	<0.3	1.41	<0.25
PAI-45-MW17-SU	7/24/2007	<0.3	5.34	<0.3	<0.25	5.34	<0.25	<0.25	<0.25	5.74	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SU	9/11/2007	<0.3	7.9	<0.3	<0.25	7.9	<0.25	<0.25	<0.25	9.04	<0.25	<0.3	0.87J	<0.25
PAI-45-MW17-SU	9/8/2008	<0.3	7.62	<0.3	<0.25	7.62	<0.25	<0.25	<0.25	4.69	<0.25	<0.3	<0.5	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/ year)	1,1-DCE	1,2-DCE	Benzene	CB	cDCE	EB	Napht	PCE	TCE	Tol	<i>t</i> DCE	VC	Xyl
PAI-45-MW18-SL	9/9/2008	<0.3	3.75	<0.3	<0.25	3.75	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW18-SU	9/9/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW19-SL	7/24/2007	<0.6	141	<0.6	<0.5	141	<0.5	<0.5	<0.5	7.63	<0.5	<0.6	31.7	<0.5
PAI-45-MW19-SLR	7/24/2007	<0.6	136	<0.6	<0.5	135	<0.5	<0.5	<0.5	6.55	<0.5	0.84J	30.2	<0.5
PAI-45-MW19-SL	9/11/2007	<0.3	107	<0.3	<0.25	127	<0.25	<0.25	<0.25	5.46	<0.25	0.97J	23.5	<0.25
PAI-45-MW19-SL	6/19/2008	<0.3	100	<0.3	<0.25	99.8	<0.25	<0.25	<0.25	1.48	<0.25	0.68J	24.8	<0.25
PAI-45-MW19-SL	9/10/2008	<0.3	127	<0.3	<0.25	111	<0.25	<0.25	6.87	2.27	<0.25	1.05	30.3	<0.6
PAI-45-MW20-SL	8/25/2005	3.85	900	<0.3	<0.25	900	<0.25	<0.25	1,100	3,950	1.47	—	<100	—
PAI-45-MW20-SL	3/7/2006	<100	905	<100	<100	905	<100	<100	782	5,840	<100	<100	117	<100
PAI-45-MW20-SL	9/26/2006	<6.8	—	<10	<11	920	<10	<16	430	5,600	<8.5	15J	120	—
PAI-45-MW20-SL	7/24/2007	<15	904	<15	<12.5	904	<12.5	<12.5	731	4,940	<12.5	<15	94.6	<12.5
PAI-45-MW20-SLR	7/24/2007	<15	896	<15	<12.5	896	<12.5	<12.5	740	4,840	<12.5	<15	99.6	<12.5
PAI-45-MW20-SL	9/10/2007	3.2	779	<0.3	0.58J	955H	<0.25	<0.25	661H	5,460H	1.36	12.6	97.7	0.48J
PAI-45-MW20-SL	6/19/2008	2.64	926	<0.3	0.67J	983	<0.25	<0.25	358	3,270	1.11	15.1	92	0.4J
PAI-45-MW20-SL	9/8/2008	4.16	1,700	<0.3	<0.25	2510	<0.25	<0.25	265	3,560	1.06	23.3	81.7	<0.6
PAI-45-MW20-SU	9/26/2006	<6.8	—	<10	<11	340	<10	<16	700	1,500	<8.5	<10	84	—
PAI-45-MW20-SU	7/24/2007	<7.5	993	<7.5	<6.25	993	<6.25	<6.25	1,260	2,350	<6.25	<7.5	188	<6.25
PAI-45-MW20-SU	9/10/2007	<0.3	66.4	<0.3	<0.25	65.5	<0.25	<0.25	32.6B	287H	0.26J	0.95J	19.1	<0.25
PAI-45-MW20-SU	9/8/2008	0.75J	295	<0.3	<0.25	283	<0.25	<0.25	43.3	233	<0.25	2.84	38	<0.25
PAI-45-MW23-SL	7/23/2007	<0.3	26.2	<0.3	<0.25	25.9	<0.25	<0.25	<0.25	0.32J	<0.25	0.37J	2.3	<0.25
PAI-45-MW23-SL	9/11/2007	<0.3	15.1	<0.3	<0.25	15.1	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	0.95J	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/ year)	1,1-DCE	1,2-DCE	Benzene	CB	cDCE	EB	Napht	PCE	TCE	Tol	tDCE	VC	Xyl
PAI-45-MW23-SU	7/23/2007	<6	1,030	<6	<5	1,010	<5	<5	7.26J	276	<5	23.1	183	<5
PAI-45-MW25-SL	9/11/2007	<75	796	<75	<62.5	796	<62.5	<62.5	17,200	4,330	<62.5	<75	<125	<62.5
PAI-45-MW25-SLR	9/11/2007	<75	746	<75	<62.5	746	<62.5	<62.5	17,200	3,960	<62.5	<75	<125	<62.5
PAI-45-MW25-SL	6/19/2008	3.53	413	<0.3	2.22	362	0.72J	<0.25	20,400	4,210	2.02	6.69	46.5	3.14
PAI-45-MW25-SL	9/9/2008	1.51	447	<0.3	2.06	447	0.44J	<0.25	20,600	3,920	1.1	5.93	60.3	2.04
PAI-45-MW26-SL	9/11/2007	<0.3	11.8	<0.3	<0.25	11.8	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW26-SL	6/19/2008	<0.3	3.32	<0.3	<0.25	3.32	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW26-SL	9/9/2008	<0.3	17.5	<0.3	<0.25	17.5	<0.25	<0.25	<0.45	0.501J	<0.25	<0.3	1.62	<0.6
PAI-45-MW27-SL	9/11/2007	<1.5	5.85	6.01	<1.25	5.85	5.14	606	<1.25	<1.25	1.55J	<1.5	<2.5	8.44
PAI-45-MW27-SLR	9/11/2007	<1.5	5.83	5.94	<1.25	5.83	4.94J	555	<1.25	<1.25	1.38J	<1.5	<2.5	8.49
PAI-45-MW27-SL	6/19/2008	<0.3H	5.38H	3.35H	<0.25H	5.38H	2.05H	281	<0.25H	<0.25H	0.34HJ	<0.3H	<0.5H	2.84H
PAI-45-MW27-SL	9/9/2008	<0.3	7.61	4.59	<0.25	7.61	3.27	219	<0.45	<0.25	0.420J	<0.3	<0.5	4.92
PAI-45-MW28D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW29D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW30D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW31-SL	6/18/2008	4.96	1,180	<0.3	1.11	1,350	0.46J	<0.25	7,240	4,380	2.57	20	120	1.98
PAI-45-MW31-SLR	6/18/2008	5.9	1,220	<0.3	1.12	1,310	0.45J	<0.25	7,450	4,560	2.72	22	170	1.99
PAI-45-MW31-SL	9/9/2008	<30	3,270	<30	<25	3,270	<25	<25	7,840	4,670	<25	<30	228	<60
PAI-45-MW31-SLR	9/9/2008	<30	2,810	<30	<25	2,810	<25	<25	8,720	5,560	<25	<30	259	<60
PAI-45-MW31-SU	6/18/2008	2.83	925	<0.3	<0.25	945	<0.25	<0.25	2,060	1,480	1.26	19.5	144	<0.25
PAI-45-MW31-SUR	6/18/2008	3.23	920	<0.3	<0.25	1,010	<0.25	<0.25	2,160	1,550	1.13	18	148	<0.25
PAI-45-MW31-SU	9/9/2008	<7.5	1,150	<7.5	<6.25	1,140	<6.25	<6.25	2,770	1,860	<6.25	12.0J	205	<15
PAI-45-MW31-SUR	9/9/2008	3.69	1,050	<0.3	<0.25	1,230	<0.25	<0.25	3,000	2,090	1.45	13.7	263	<0.6

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[H₂, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H ₂ (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW03-SL	7/23/2007	0.11	—	—	143	<2	4.6J	1.1	—	—	—	423	—	—	—	110	34
PAI-45-MW03-SL	9/10/2007	0.19	—	—	241	<10	20J	—	<0.1	—	—	1,970	—	—	—	111	17
PAI-45-MW04-SL	8/25/2005	—	—	—	185	<2	97	—	—	—	—	1,510	—	—	—	53	—
PAI-45-MW04-SL	9/26/2006	—	—	—	—	<0.4	25	—	—	—	—	440	—	—	—	—	24
PAI-45-MW04-SL	7/24/2007	<0.07	—	—	146	<10	55J	1.1	0.15	—	—	1,410	—	—	—	51	21
PAI-45-MW04-SL	9/10/2007	0.12	—	—	260	<20	84J	—	<0.1	—	—	2,740	—	—	—	64	17
PAI-45-MW04-SL	6/18/2008	—	—	7,550	153	28BJ	45J	—	—	7,920	18.4	2,390B	<0.033	—	122,000	52	20
PAI-45-MW04-SL	9/9/2008	—	—	8,020	157	0.56	43	1.6	—	7,870	16.4	1,800	—	—	124,000	54	21
PAI-45-MW04-SU	7/24/2007	—	—	—	17.9	<4	6.1J	—	—	—	—	358	—	—	—	38	—
PAI-45-MW04-SU	9/10/2007	—	—	—	19.5	<10	10J	—	—	—	—	588	—	—	—	34	—
PAI-45-MW05-SL	7/23/2007	—	—	—	371	<20	<20	—	—	—	—	3,640	—	—	—	13	—
PAI-45-MW05-SL	9/11/2007	—	—	—	379	<40	<40	—	—	—	—	5,170	—	—	—	2.9	—
PAI-45-MW05-SL	6/19/2008	—	—	52,000	418	21J	<20	—	—	22,800	394	685B	—	—	226,000	65	9.8
PAI-45-MW05-SL	9/8/2008	—	< 0.0050	56,000	369	0.06	0.25	—	—	19,700	413	3,300	—	—	178,000	14	7
PAI-45-MW05-SU	7/23/2007	—	—	—	91.3	<2	<2	—	—	—	—	93.6	—	—	—	14	—
PAI-45-MW05-SU	6/19/2008	—	—	—	46.6	3BJ	<2	—	—	—	—	155B	—	—	—	19	12
PAI-45-MW05-SU	9/8/2008	—	< 0.0050	—	16.4	< 0.03	< 0.02	—	—	—	—	11	—	—	—	28	15
PAI-45-MW10-SL	7/23/2007	—	—	—	259	<2	4.J	2.2	—	—	—	190	—	—	—	140	16
PAI-45-MW10-SL	9/10/2007	—	—	—	243	<4	8.2J	—	—	—	—	363	—	—	—	110	—
PAI-45-MW10-SL	6/18/2008	—	—	23,300	223	3BJ	3.7J	—	—	14,000	65.9	164B	—	—	183,000	120	17
PAI-45-MW10-SL	9/9/2008	—	—	24,100	222	0.04	5.3	2.1	—	15,900	63.5	170	—	—	190,000	120	16
PAI-45-MW10-SU	7/23/2007	—	—	—	109	<20	<20	—	—	—	—	942	—	—	—	54	—
PAI-45-MW10-SU	9/10/2007	—	—	—	114	<10	<10	—	—	—	—	958	—	—	—	74	13
PAI-45-MW10-SU	6/18/2008	—	—	—	99.6	<10	<10	—	—	—	—	679B	—	—	—	47	50
PAI-45-MW10-SU	9/9/2008	—	—	—	103	0.1	9.3	—	—	—	—	1100	—	—	—	49	33

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[H₂, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H ₂ (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW13-SL	7/23/2007	0.14	—	—	153	<4	<4	—	0.15	—	—	425	—	—	—	120	15
PAI-45-MW13-SL	9/11/2007	<0.07	—	—	203	<4	<4	—	<0.1	—	—	600	—	—	—	130	14
PAI-45-MW13-SL	6/17/2008	—	—	24,700	140	—	—	—	—	13,700	69.6	—	—	—	143,000	87	16
PAI-45-MW13-SL	9/9/2008	—	—	28,300	131	0.19	1	—	—	15,100	73.9	870	—	—	131,000	100	15
PAI-45-MW16-SL	7/24/2007	—	—	—	24.3	<20	<20	—	—	—	—	3,840	—	—	—	0.7	—
PAI-45-MW16-SU	7/24/2007	—	—	—	4.5	<2	<2	—	—	—	—	36.5	—	—	—	9.4	—
PAI-45-MW17-SL	7/24/2007	—	—	—	1,480	<4	<4	—	—	—	—	294	—	—	—	200	—
PAI-45-MW17-SL	9/11/2007	—	—	—	1,500	<4	<4	—	—	—	—	385	—	—	—	200	—
PAI-45-MW17-SL	6/17/2008	—	—	72,200	1,750	2.8BJ	<2	—	—	128,000	172	269B	—	—	890,000	250	9
PAI-45-MW17-SL	9/8/2008	—	—	46,600	1,160	—	—	—	—	80,900	152	—	—	—	646,000	130	8
PAI-45-MW17SU	6/17/2008	—	—	19,400	86	3.BJ	<2	—	—	7,750	23.2	250B	—	—	87,500	10	54
PAI-45-MW17-SU	7/24/2007	—	—	—	162	<4	<4	—	—	—	—	476	—	—	—	15	—
PAI-45-MW17-SU	9/11/2007	—	—	—	141	<4	<4	—	—	—	—	876	—	—	—	14	—
PAI-45-MW17-SU	9/8/2008	—	—	21,500	68.5	—	—	—	—	8,570	23.8	—	—	—	60,700	7.8	19
PAI-45-MW18-SL	9/9/2008	—	0.013	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PAI-45-MW18-SU	9/9/2008	—	< 0.0050	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PAI-45-MW19-SL	7/24/2007	—	—	—	332	5.1J	<4	—	—	—	—	614	—	—	—	36	31
PAI-45-MW19-SLR	7/24/2007	—	—	—	357	<4	<4	—	—	—	—	569	—	—	—	36	—
PAI-45-MW19-SL	9/11/2007	0.33	—	—	303	<4	<4	—	<0.1	—	—	742	—	—	—	29	33
PAI-45-MW19-SL	6/19/2008	—	—	—	311	<10	<10	—	—	—	—	203B	—	—	—	32	30
PAI-45-MW19-SL	9/10/2008	—	—	—	334	1.8	1.4	—	—	—	—	510	—	—	—	33	33

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[H₂, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H ₂ (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW27-SL	9/11/2007	—	—	—	138	<40	<40	—	—	—	—	7,630	—	—	—	2.9	<5
PAI-45-MW27-SLR	9/11/2007	—	—	—	135	<40	<40	—	—	—	—	7,310	—	—	—	2.6	—
PAI-45-MW27-SL	6/19/2008	—	—	11,000	126	<40	<40	—	—	11,000	61.4	3210B	—	<1	76,200	0.6	6
PAI-45-MW27-SL	9/9/2008	—	—	9,610	120	0.23	0.18	—	—	10,100	57.2	7200	—	—	72,000	0.2J	5
PAI-45-MW28D	6/17/2008	—	—	—	5,520	<2	<2	—	—	—	—	17.3BJ	—	—	—	950	4
PAI-45-MW29D	6/17/2008	—	—	—	4,160	3.1BJ	<2	—	—	—	—	20.6BJ	—	8.1	—	660	4
PAI-45-MW30D	6/17/2008	—	—	—	1,940	3.2BJ	<2	—	—	—	—	29.8B	—	—	—	260	6
PAI-45-MW31-SL	6/18/2008	—	—	13,300	214	14BJ	130	—	—	10,400	54.5	1,650B	<0.033	—	144,000	62	14
PAI-45-MW31-SLR	6/18/2008	—	—	13,400	213	14BJ	140	—	—	10,400	56.1	2,140B	—	—	145,000	62	14
PAI-45-MW31-SL	9/9/2008	—	0.022	22,500	208	2.2	150	31	—	16,500	102	2,700	—	—	227,000	54	12
PAI-45-MW31-SLR	9/9/2008	—	—	18,500	208	2.3	140	—	—	14,200	79.5	2400	—	—	176,000	53	12
PAI-45-MW31-SU	6/18/2008	—	—	3,330	125	65BJ	77J	—	—	3,080	21.2	4,420B	<0.033H	—	122,000	76	29
PAI-45-MW31-SUR	6/18/2008	—	—	3,360	129	51BJ	49J	—	—	3,080	21.9	2,770B	—	—	125,000	72	26
PAI-45-MW31-SU	9/9/2008	—	—	3,270	121	0.59	87	3.4	—	3,190	16.2	4,400	—	—	113,000	63	34
PAI-45-MW31-SUR	9/9/2008	—	—	—	120	0.78	74	—	—	—	—	5,400	—	—	—	63	34

Appendix 5. Concentrations of field-measured constituents in groundwater from monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[Alk, total alkalinity as calcium carbonate; CO₂, carbon dioxide; DO, dissolved oxygen; Fe, ferrous iron; SC, specific conductance; Temp., temperature; <, less than; —, not analyzed; mg/L, milligrams per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; >, greater than]

Site identifier	Date (month/day/year)	Alk (mg/L)	CO ₂ (mg/L)	DO (mg/L)	Fe (mg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Sulfide (mg/L)	Temp. °C
PAI-45-MW03-SL	7/23/2007	—	—	—	—	6.01	1,030	—	23.92
PAI-45-MW03-SL	9/10/2007	55	50	<0.03	—	5.81	985	—	25.00
PAI-45-MW04-D	9/10/2007	200	50	0.05	—	6.35	12,700	<0.05	24.67
PAI-45-MW04-D	9/10/2007	200	50	0.05	—	6.35	12,700	<0.05	—
PAI-45-MW04-SL	8/25/2005	35	150	<0.03	17.5	5.71	1,040	<0.05	25.35
PAI-45-MW04-SL	3/7/2006	—	—	—	—	5.69	710	—	17.76
PAI-45-MW04-SL	9/26/2006	25	180	<0.03	5.55	5.55	784	<0.05	25.15
PAI-45-MW04-SL	7/24/2007	60	175	0.1	5.17	5.58	745	<0.05	24.18
PAI-45-MW04-SL	9/10/2007	35	100	0.05	—	5.83	632	—	25.40
PAI-45-MW04-SL	6/18/2008	20	170	0.15	5.32	5.58	773	<0.2	21.21
PAI-45-MW04-SL	9/9/2008	35	190	<0.03	5.36	5.63	785	<0.2	25.26
PAI-45-MW04-SU	7/24/2007	<10	100	0.1	1.55	4.99	191	<0.05	25.93
PAI-45-MW04-SU	9/10/2007	-10	125	0.02	—	5.16	211	<0.05	26.81
PAI-45-MW05-SL	7/23/2007	—	—	—	—	5.81	1,449	—	26.53
PAI-45-MW05-SL	9/11/2007	>1,000	50	<0.025	—	5.58	1,740	0.1	27.22
PAI-45-MW05-SL	6/19/2008	22	180	0.3	18.2	5.5	1,737	<0.2	25.02
PAI-45-MW05-SL	9/8/2008	45	30	0.1	27	5.76	1,464	0.18	27.57
PAI-45-MW05-SU	7/23/2007	100	70	0.7	2.8	6.31	568	<0.05	27.74
PAI-45-MW05-SU	6/19/2008	120	65	0.6	<0.2	6.41	480	<0.2	26.19
PAI-45-MW05-SU	9/8/2008	70	17	2	1.18	—	509	0.08	29.38
PAI-45-MW10-SL	7/23/2007	—	—	—	—	5.97	1,390	—	27.51
PAI-45-MW10-SL	9/10/2007	55	80	0.1	—	5.61	1,190	—	29.55
PAI-45-MW10-SL	6/18/2008	60	40	0.1	9.59	5.73	1,230	<0.2	25.54
PAI-45-MW10-SL	9/9/2008	70	45	<0.03	9.73	5.67	1,260	<0.2	30.08
PAI-45-MW10-SU	7/23/2007	—	—	—	—	6.3	975	—	29.52
PAI-45-MW10-SU	9/10/2007	150	70	<0.03	—	5.86	981	<0.05	30.80
PAI-45-MW10-SU	6/18/2008	170	35	0.05	13.7	6.23	960	<0.2	27.71
PAI-45-MW10-SU	9/9/2008	225	40	0.05	16.4	6.18	978	<0.2	30.76
PAI-45-MW13-SL	7/23/2007	—	—	—	—	6.08	1,030	—	28.43
PAI-45-MW13-SL	9/11/2007	110	40	0.05	—	—	1,000	<0.05	29.55
PAI-45-MW13-SL	6/17/2008	125	200	0.25	4.66	5.94	992	<0.2	25.11
PAI-45-MW13-SL	9/9/2008	100	200	0.05	4.97	5.96	1,010	<0.2	29.28
PAI-45-MW16-SL	7/24/2007	—	—	—	—	6.2	313	—	25.81
PAI-45-MW16-SU	7/24/2007	—	—	—	—	5.69	103	—	28.54
PAI-45-MW17-SL	7/24/2007	—	—	—	—	5.77	4,960	—	26.84
PAI-45-MW17-SL	9/11/2007	65	50	0.05	—	5.61	5,310	<.05	27.96
PAI-45-MW17-SL	6/17/2008	75	60	0.05	28.8	5.83	5,920	0.2	24.66
PAI-45-MW17-SL	9/8/2008	40	105	0.05	14.3	5.55	4,260	<0.2	27.82
PAI-45-MW17-SU	7/24/2007	—	—	—	—	6.63	942	—	28.15
PAI-45-MW17-SU	9/11/2007	150	35	0.05	—	6.43	874	<0.05	29.29

Appendix 5. Concentrations of field-measured constituents in groundwater from monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[Alk, total alkalinity as calcium carbonate; CO₂, carbon dioxide; DO, dissolved oxygen; Fe, ferrous iron; SC, specific conductance; Temp., temperature; <, less than; —, not analyzed; mg/L, milligrams per liter; S.U., standard units; μS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; >, greater than]

Site identifier	Date (month/day/ year)	Alk (mg/L)	CO ₂ (mg/L)	DO (mg/L)	Fe (mg/L)	pH (S.U.)	SC (μS/cm at 25 °C)	Sulfide (mg/L)	Temp. °C
PAI-45-MW17-SU	6/17/2008	140	25	<0.03	12.8	6.62	622	<0.2	26.81
PAI-45-MW17-SU	9/8/2008	110	80	<0.03	14.2	6.42	631	<0.2	28.51
PAI-45-MW18-SL	9/9/2008	180	25	0.1	2.27	6.67	3,030	<0.2	25.92
PAI-45-MW18-SU	9/9/2008	175	60	0.075	7.47	6.73	437	<0.2	28.01
PAI-45-MW19-SL	7/24/2007	—	—	—	—	5.72	1,560	—	23.02
PAI-45-MW19-SL	9/11/2007	65	45	0.05	—	5.75	1,350	<0.05	25.08
PAI-45-MW19-SL	6/19/2008	65	160	0.07	9.45	5.93	1,360	<0.2	20.87
PAI-45-MW19-SL	9/10/2008	60	170	<0.03	9.21	—	—	<0.2	—
PAI-45-MW20-SL	8/25/2005	50	70	0.15	12.5	5.92	—	<0.05	—
PAI-45-MW20-SL	3/7/2006	—	—	—	2.5	6.07	3,990	—	19.55
PAI-45-MW20-SL	9/26/2006	70	170	0.05	3.95	5.87	4,270	<0.05	25.90
PAI-45-MW20-SL	9/29/2006	—	—	—	—	—	—	—	—
PAI-45-MW20-SL	7/24/2007	90	165	0.1	6.01	5.8	2,250	<0.05	25.38
PAI-45-MW20-SL	9/10/2007	55	50	0.05	—	5.83	1,640	—	26.01
PAI-45-MW20-SL	6/19/2008	50	28	0.1	5.15	6.01	1,950	<0.2	23.10
PAI-45-MW20-SL	9/8/2008	45	155	<0.03	6.9	5.85	2,590	<0.2	26.12
PAI-45-MW20-SU	9/26/2006	37	180	0.1	3	5.5	579	<0.05	26.94
PAI-45-MW20-SU	9/29/2006	50	40	>1	—	6.44	1,540	<0.05	27.49
PAI-45-MW20-SU	7/24/2007	50	160	0.15	2.1	5.59	448	<0.05	27.54
PAI-45-MW20-SU	9/10/2007	50	40	>1	—	6.44	1,540	<0.05	27.49
PAI-45-MW20-SU	9/8/2008	40	160	0.25	2.72	—	—	0.28	—
PAI-45-MW20-SU	6/18/2008	35	50	0.6	4.43	5.58	591	0.47	26.20
PAI-45-MW23-SL	7/23/2007	250	105	<0.025	14.12	6.75	1,070	<0.05	28.23
PAI-45-MW23-SL	9/11/2007	100	40	0.1	—	6.48	1,040	—	28.66
PAI-45-MW25-SL	9/11/2007	35	25	0.2	—	5.58	427	—	—
PAI-45-MW25-SL	6/19/2008	30	30	0.05	—	5.6	751	<0.2	26.24
PAI-45-MW25-SL	9/9/2008	18	180	0.1	3.75	5.51	436	<0.2	29.18
PAI-45-MW26-SL	9/11/2007	200	40	0.1	—	6.35	1,770	—	28.97
PAI-45-MW26-SL	6/19/2008	200	35	0.2	10	6.56	2,010	<0.2	24.34
PAI-45-MW26-SL	9/9/2008	250	120	<0.025	12	6.54	2,790	<0.2	28.23
PAI-45-MW27-SL	9/11/2007	<10	45	0.05	—	5.68	613	—	27.96
PAI-45-MW27-SL	6/19/2008	40	135	<0.025	5.97	5.71	575	<0.2	25.40
PAI-45-MW27-SL	9/9/2008	40	145	<0.025	5.22	5.69	547	<0.2	27.49
PAI-45-MW28-D	6/17/2008	225	250	<0.025	92.2	6.21	17,700	<0.2	26.29
PAI-45-MW29-D	6/17/2008	240	35	0.1	0.94	7	13,900	0.14	26.72
PAI-45-MW30-D	6/17/2008	250	80	0.05	2.41	6.75	7,050	<0.2	25.07
PAI-45-MW31-SL	6/18/2008	18	140	0.075	5.52	5.66	1,000	<0.2	25.89
PAI-45-MW31-SL	9/9/2008	40	45	<0.025	11.8	5.73	1,110	<0.2	30.26
PAI-45-MW31-SU	6/18/2008	<10	200	0.075	4.14	5.1	708	<0.2	28.98
PAI-45-MW31-SU	9/9/2008	<10	70	0.1	5.77	5.27	679	<0.2	31.47

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *tDCE*, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc. and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>tDCE</i> (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp. (°C)
PAI-45-USGS-TW1	6/25/2007	8–11	<0.3	1.3	<0.3	<0.25	1.3	<0.25	<0.25	0.401J	1.5	<0.25	<0.3	<0.5	<0.25	5.73	1,470	29.8
PAI-45-USGS-TW2	6/25/2007	7–11	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.12	1,350	29.78
PAI-45-USGS-TW3	6/25/2007	7–11	<1.5	268	<1.5	<1.25	268	<1.25	<1.25	<1.25	26.2	<1.25	<1.5	5.83	<1.25	6.15	2,010	30.75
PAI-45-USGS-TW4	6/25/2007	7–11	<7.5	1,150	<7.5	<6.25	1,140	<6.25	<6.25	157	2,160	<6.25	13.2J	37.3	<6.25	6.05	823	31.22
PAI-45-USGS-TW5	6/25/2007	6–10.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.31	315	30.48
PAI-45-USGS-TW6	6/25/2007	7–11	<7.5	1,450	<7.5	<6.25	1,420	<6.25	<6.25	114	1,760	<6.25	28.1	189	<6.25	6.08	810	30.11
PAI-45-USGS-TW7	6/25/2007	7–11	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.31	284	29.56
PAI-45-USGS-TW8	6/25/2007	7.5–11.5	<6	1,030	<6	<5	1,010	<5	<5	<5	226	<5	23.4	212	<5	6.04	918	29.59
PAI-45-USGS-TW9	6/25/2007	7.5–11.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.38	303	29.16
PAI-45-USGS-TW10	6/25/2007	0–10	<15	3,000	<15	<12.5	2,960	<12.5	<12.5	<12.5	898	<12.5	41.6J	362	<12.5	6.29	822	30.87
PAI-45-USGS-TW11	6/25/2007	7.75–11.75	<0.3	41.6	<0.3	<0.25	41.6	<0.25	<0.25	<0.25	4.22	<0.25	<0.3	<0.5	<0.25	6.74	1,030	28.26
PAI-45-USGS-TW12	6/25/2007	7.5–10.5	<0.6	144	<0.6	<0.5	142	<0.5	<0.5	31.8	195	<0.5	2.25	4.07	<0.5	5.94	750	28.56
PAI-45-USGS-TW13	6/25/2007	6–10	<15	1,180	<15	<12.5	1,180	<12.5	<12.5	315	2,760	<12.5	<15	<25	<12.5	5.75	1,300	27.98
PAI-45-USGS-TW14	6/25/2007	6–10	<7.5	2,240	<7.5	<6.25	2,190	<6.25	<6.25	149	1,720	<6.25	53.7	356	<6.25	5.72	563	28.65
PAI-45-USGS-TW15	6/25/2007	6–10	<30	8,570	<30	<25	8,380	<25	<25	3,480	8,700	<25	196	2,290	<25	6.82	829	28.93
PAI-45-USGS-TW16	6/25/2007	6–10	<6	1,180	<6	<5	1,160	<5	<5	<5	557	<5	23.7	<10	<5	5.74	9,000	29.06
PAI-45-USGS-TW17	6/25/2007	6.5–10.5	<3	830	<3	<2.5	815	<2.5	<2.5	<2.5	176	<2.5	15.5	<5	<2.5	6.1	2,100	27.46
PAI-45-USGS-TW18	6/25/2007	12–14.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.59	460	27.45
PAI-45-USGS-TW19	6/25/2007	8–12	<0.3	37.5	<0.3	<0.25	37.1	<0.25	<0.25	0.26J	1.94	<0.25	0.42J	0.68J	<0.25	6.06	289	26.05
PAI-45-USGS-TW20	6/25/2007	8–12	<0.3	0.4J	<0.3	<0.25	0.4J	<0.25	0.404J	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.92	232	24.8

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *tDCE*, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc. and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>tDCE</i> (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp. (°C)
PAI-45-USGS-TW21	6/25/2007	11–15	<0.3	5.23	0.95J	<0.25	5.23	<0.25	6.98	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.83	357	24.79
PAI-45-USGS-TW22	6/25/2007	6–10	<1.5	262	<1.5	<1.25	260	<1.25	<1.25	<1.25	38.3	<1.25	2.36J	3.01J	<1.25	5.82	1,350	27.31
PAI-45-USGS-TW23	6/25/2007	6–10	<0.6	176	<0.6	<0.5	174	<0.5	<0.5	<0.5	23.9	<0.5	1.91J	5.48	<0.5	5.84	1,730	27.07
PAI-45-USGS-TW24	6/25/2007	11.5–15.5	<0.3	10.6	<0.3	<0.25	10.6	<0.25	<0.25	<0.25	17.6	<0.25	<0.3	0.75J	<0.25	6.42	777	25.53
PAI-45-USGS-TW25	6/25/2007	11.5–15.5	<1.5	241	<1.5	<1.25	239	<1.25	<1.25	3.45J	231	<1.25	2.17J	<2.5	<1.25	5.84	1,830	27.03
PAI-45-USGS-TW26	6/25/2007	11.5–15.5	<0.3	1.89	1.71	<0.25	1.89	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.02	2,090	27.8
PAI-45-USGS-TW27	6/25/2007	11.5–15.5	<1.5	342	<1.5	<1.25	339	<1.25	<1.25	<1.25	155	<1.25	2.15J	<2.5	<1.25	5.91	1,820	29.35
PAI-45-USGS-TW28	6/25/2007	11.5–15.5	<1.5	214	<1.5	<1.25	214	<1.25	<1.25	<1.25	<1.25	<1.25	<1.5	4.11J	<1.25	—	—	—
PAI-45-USGS-TW29	6/27/2007	11.5–15.5	<0.3	3.71	<0.3	<0.25	3.71	<0.25	<0.25	4.95	1.34	<0.25	<0.3	<0.5	<0.25	6.4	2,490	24.22
PAI-45-USGS-TW30	6/25/2007	11.5–15.5	<0.3	14.1	<0.3	<0.25	14.1	<0.25	<0.25	<0.25	6.95	<0.25	<0.3	0.99J	<0.25	5.99	1,010	26.45
PAI-45-USGS-TW31	6/27/2007	11.5–15.5	<0.3	14.1	<0.3	<0.25	13.8	<0.25	<0.25	2.12	16.4	<0.25	0.36J	6.48	<0.25	6.16	2,540	25.91
PAI-45-USGS-TW32	6/27/2007	11.5–15.5	<0.3	11.9	<0.3	<0.25	11.9	<0.25	<0.25	1.57	19	<0.25	<0.3	6.87	<0.25	6.11	2,160	24.66
PAI-45-USGS-TW33	6/25/2007	11.5–15.5	<0.6	79.3	<0.6	<0.5	79.3	<0.5	1.32J	21.4	177	<0.5	<0.6	<1	<0.5	5.84	1,900	27.22
PAI-45-USGS-TW34	6/25/2007	11.5–15.5	<0.3	5.34	<0.3	<0.25	5.34	<0.25	<0.25	1.49	3.3	<0.25	<0.3	<0.5	<0.25	5.89	1,790	28.2
PAI-45-USGS-TW35	6/25/2007	11.5–15.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.14	2,810	29.49
PAI-45-USGS-TW36	6/25/2007	11.5–15.5	<0.6	7.68	4.17	<0.5	7.68	1.21J	81.9	<0.5	<0.5	<0.5	<0.6	<1	1.97J	6.02	857	27.24
PAI-45-USGS-TW37	6/27/2007	11.5–15.5	<0.3	3.5	<0.3	<0.25	3.5	<0.25	<0.25	1.43	3.27	<0.25	<0.3	1.41	<0.25	5.86	7,200	23.79
PAI-45-USGS-TW37R	6/27/2007	11.5–15.5	<0.3	3.26	<0.3	<0.25	3.26	<0.25	<0.25	1.33	3.17	<0.25	<0.3	1.18	<0.25	—	—	—
PAI-45-USGS-TW38	6/27/2007	10–14	<0.3	9.51	<0.3	<0.25	9.51	<0.25	<0.25	93.9	21.3	<0.25	<0.3	<0.5	<0.25	5.95	4,040	28.4
PAI-45-USGS-TW38R	6/27/2007	10–14	<0.3	10.5	<0.3	<0.25	10.5	<0.25	<0.25	105	23.2	<0.25	<0.3	0.51J	<0.25	—	—	—
PAI-45-USGS-TW39	6/27/2007	10–14	<30	628	<30	<25	628	<25	<25	5,240	7,600	<25	<30	<50	<25	6.16	2,260	26.95
PAI-45-USGS-TW39R	6/27/2007	10–14	<30	604	<30	<25	604	<25	<25	5,050	7,210	<25	<30	<50	<25	—	—	—
PAI-45-USGS-TW40	6/27/2007	10–14	<0.3	14.3	<0.3	<0.25	14.3	<0.25	<0.25	0.26J	6.44	<0.25	<0.3	4.75	<0.25	5.91	3,370	28.84
PAI-45-USGS-TW41	6/27/2007	10–14	<0.3	2.62	<0.3	2.87	2.62	<0.25	<0.25	0.798J	0.36J	<0.25	<0.3	<0.5	<0.25	5.84	483	26.92

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *tDCE*, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc. and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>tDCE</i> (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp. (°C)
PAI-45-USGS-TW42	6/27/2007	10–14	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.7	7,410	28.84
PAI-45-USGS-TW43	6/27/2007	10–14	<0.3	9.28	<0.3	<0.25	8.95	<0.25	<0.25	<0.25	6.72	<0.25	0.32J	3.13	<0.25	5.94	8,240	25.71
PAI-45-USGS-TW44	6/27/2007	10–14	<30	760	<30	<25	760	<25	<25	17,100	6,100	<25	<30	201	<25	6.63	635	27.62
PAI-45-USGS-TW45	6/27/2007	10.5–14.5	<0.3	6.05	<0.3	<0.25	6.05	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.44	3,540	25.59
PAI-45-USGS-TW46	6/27/2007	10.5–14.5	<0.3	0.52J	<0.3	<0.25	0.52J	<0.25	<0.25	1.69	0.26J	<0.25	<0.3	0.58J	<0.25	5.74	14,800	26.1
PAI-45-USGS-TW47	6/27/2007	10.5–14.5	<300	<300	<300	<250	<300	<250	<250	62,400	4,020	<250	<300	<500	<250	6.26	797	27.23
PAI-45-USGS-TW48	6/27/2007	10.5–14.5	<30	2,180	<30	<25	2,180	<25	<25	10,200	7,590	<25	<30	342	<25	6.08	1,330	28.74
PAI-45-USGS-TW49	6/27/2007	10–14	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.22	911	27.42
PAI-45-USGS-TW50	6/27/2007	11–15	<1.2	180	<1.2	1.26J	180	<1	<1	<1	22.2	<1	<1.2	3.72J	<1	5.74	1,040	25.24
PAI-45-USGS-TW51	6/27/2007	10.5–14.5	<12	147	<12	<10	147	<10	<10	315	2,270	<10	<12	<20	<10	5.71	916	24.21
PAI-45-USGS-TW52	6/27/2007	11–15	<30	472	<30	<25	472	<25	<25	<25	5,530	<25	<30	<50	<25	5.87	1,330	27.17
PAI-45-USGS-TW53	6/27/2007	11–15	<30	1,640	<30	<25	1,640	<25	<25	4,780	7,360	<25	<30	377	<25	6	1,890	24.68
PAI-45-USGS-TW54	6/27/2007	11–15	<3	776	<3	<2.5	771	<2.5	<2.5	<2.5	3,59J	<2.5	5.71J	70.8	<2.5	6.04	3,560	23.99
PAI-45-USGS-TW55	6/28/2007	11–15	<0.3	<0.3	<0.3	0.62J	<0.3	<0.25	<0.25	0.27J	0.69J	<0.25	<0.3	<0.5	<0.25	5.69	982	23.65
PAI-45-USGS-TW56	6/28/2007	11–15	<7.5	1,240	<7.5	<6.25	1,240	<6.25	<6.25	526	2,110	<6.25	<7.5	14.4J	<6.25	5.84	862	27.74
PAI-45-USGS-TW57	6/28/2007	11–15	<3	800	<3	<2.5	800	<2.5	<2.5	<2.5	<2.5	<2.5	<3	133	<2.5	6.03	1,170	26.12
PAI-45-USGS-TW58	6/28/2007	11–15	<0.3	9.71	<0.3	<0.25	9.71	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	3.09	<0.25	6.83	3,810	27.58
PAI-45-USGS-TW58R	6/28/2007	11–15	<0.3	9.14	<0.3	<0.25	9.14	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	2.77	<0.25	—	—	—
PAI-45-USGS-TW59	6/28/2007	11–15	<0.3	5.12	<0.3	<0.25	5.12	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	1.29	<0.25	6.61	2,090	24.61
PAI-45-USGS-TW60	6/28/2007	10–14	<0.3	10.2	<0.3	1.16	10.2	<0.25	<0.25	0.359J	5.24	<0.25	<0.3	4.43	0.29J	5.85	888	24.49
PAI-45-USGS-TW61	6/28/2007	11–15	<3	511	<3	<2.5	511	<2.5	<2.5	<2.5	11.9	<2.5	<3	10.3	<2.5	5.95	1,410	27.27
PAI-45-USGS-TW61R	6/28/2007	11.5–15.5	<3	511	<3	<2.5	511	<2.5	<2.5	<2.5	12.7	<2.5	<3	<5	<2.5	—	—	—
PAI-45-USGS-TW62	6/28/2007	11.5–15.5	<0.3	52.8	<0.3	0.82J	52.1	<0.25	<0.25	<0.25	0.75J	<0.25	0.72J	7.31	<0.25	6.36	5,310	29.22
PAI-45-USGS-TW63	6/28/2007	11.5–15.5	<15	783	<15	<12.5	750	<12.5	<12.5	<12.5	4,100	<12.5	32.4J	30J	<12.5	6.27	1,260	25.7
PAI-45-USGS-TW63R	6/28/2007	11.5–15.5	<15	769	<15	<12.5	738	<12.5	<12.5	<12.5	3,960	<12.5	30.5J	<25	<12.5	—	—	—

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *tDCE*, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc. and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>tDCE</i> (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp. (°C)
PAI-45-USGS-TW64	6/28/2007	11.5–15.5	<0.6	110	<0.6	<0.5	110	<0.5	<0.5	<0.5	0.89J	<0.5	<0.6	<1	<0.5	6.38	2,840	28.78
PAI-45-USGS-TW65	6/28/2007	11.5–15.5	<1.5	6.2	5.36	<1.25	6.2	3.81J	397	<1.25	<1.25	<1.25	<1.5	<2.5	6.55	6.83	367	24.5
PAI-45-USGS-TW66	6/28/2007	11.5–15.5	<3	833	<3	<2.5	833	<2.5	<2.5	<2.5	183	<2.5	<3	15	<2.5	5.97	2,040	26.44
PAI-45-USGS-TW67	6/28/2007	11–15	<0.3	8.88	<0.3	2.62	8.88	<0.25	<0.25	<0.25	19.4	<0.25	<0.3	<0.5	<0.25	6	1,000	25.36
PAI-45-USGS-TW68	6/28/2007	11–15	<0.3	<0.3	<0.3	4.76	<0.3	<0.25	<0.25	<0.25	1.04	<0.25	<0.3	<0.5	<0.25	6.01	946	25.18
PAI-45-USGS-TW68R	6/28/2007	11–15	<0.3	<0.3	<0.3	4.76	<0.3	<0.25	<0.25	<0.25	1	<0.25	<0.3	<0.5	<0.25	—	—	—
PAI-45-USGS-TW69	6/28/2007	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.76	28,500	28.43
PAI-45-USGS-TW70	6/28/2007	11–15	<0.3	4.21	<0.3	<0.25	4.21	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.82	10,600	28.66
PAI-45-USGS-TW71	8/29/2007	8–12	<0.3	0.5J	2.66	<0.25	0.5J	<0.25	119	<0.25	<0.25	0.759J	<0.3	<0.5	0.77J	—	—	—
PAI-45-USGS-TW72	8/29/2007	11–15	<6	39.7	<6	<5	39.7	<5	<5	2,380	1,180	<5	<6	<10	<5	—	—	—
PAI-45-USGS-TW74	8/29/2007	11–15	<0.3	16.7	<0.3	<0.25	16.7	<0.25	<0.25	7.73	35.3	<0.25	<0.3	1.35	<0.25	—	—	—
PAI-45-USGS-TW75	8/29/2007	1–14	<3	653	<3	<2.5	653	<2.5	5.94J	<2.5	21.1	<2.5	<3	6.24J	<2.5	—	—	—
PAI-45-USGS-TW76	8/29/2007	11–15	<3	526	<3	<2.5	526	<2.5	7.55J	<2.5	<2.5	<2.5	<3	24.2	<2.5	—	—	—
PAI-45-USGS-TW77	3/5/2008	7–11	<0.3	50.1	<0.3	1.55	47.9	<0.25	<0.25	0.35J	20.5	<12.5	<0.25	<0.3	<0.25	—	523	20.88
PAI-45-USGS-TW77	3/5/2008	11–15	<15	381	<15	<12.5	365	<12.5	<12.5	454	3,470	<0.25	<12.5	<15	<12.5	—	1,650	21.64
PAI-45-USGS-TW77R	3/5/2008	11–15	<15	460	<15	<12.5	440	<12.5	<12.5	408	3,530	<12.5	<12.5	<15	<12.5	—	—	—
PAI-45-USGS-TW78	3/5/2008	7–11	<0.3	118	<0.3	1.97	117	<0.25	<0.25	10.1	45.5	<12.5	<0.25	<0.3	<0.25	—	446	20.63
PAI-45-USGS-TW78	3/5/2008	11–15	<15	795	<15	<12.5	761	<12.5	<12.5	<12.5	3,200	<0.25	<12.5	<15	<12.5	—	1,970	21.48
PAI-45-USGS-TW79	3/5/2008	11–15	14.2	409	<0.3	<0.25	562	0.88J	<0.25	23,000B	7,160	3.63	3.63	2.56	1.34	—	4,910	22.71
PAI-45-USGS-TW80	3/5/2008	7–11	<3	82.6	<3	<2.5	82.6	<2.5	<2.5	366	732	<2.5	<2.5	<3	<2.5	—	444	20.4
PAI-45-USGS-TW80	3/5/2008	11–15	<30	112	<30	<25	112	<25	<25	6,170B	2,160	<2.5	<25	<30	<25	—	6,620	22.15
PAI-45-USGS-TW81	3/5/2008	7–11	<0.3	117	<0.3	2.43	107	<0.25	<0.25	<0.25	19.9	<6.25	<0.25	<0.3	<0.25	—	453	20.72
PAI-45-USGS-TW81	3/5/2008	11–15	<7.5	599	<7.5	<6.25	573	<6.25	<6.25	14.0J	1,510	<0.25	<6.25	<7.5	<6.25	—	1,710	21.15
PAI-45-USGS-TW81R	3/5/2008	11–15	<7.5	583	<7.5	<6.25	558	<6.25	<6.25	12.5J	1,510	<6.25	<6.25	<7.5	<6.25	—	—	—
PAI-45-USGS-TW82	3/4/2008	11–15	<15	411	<15	<12.5	411	<12.5	<12.5	53.7	2720	<12.5	<12.5	<15	<12.5	—	3,710	20.85

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	cDCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	tDCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp. (°C)
PAI-45-USGS-TW83	3/5/2008	11–15	<0.3	57.5	<0.3	<0.25	55	<0.25	<0.25	29.2	415	<0.25	<0.25	<0.3	<0.25	—	3,970	20.03
PAI-45-USGS-TW84	3/5/2008	11–15	<0.3	18.4	<0.3	<0.25	17.6	<0.25	<0.25	361	63.3	<0.25	<0.25	<0.3	<0.25	—	4,700	19.73
PAI-45-USGS-TW85	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	1.88B	0.97J	<0.25	<0.25	<0.3	<0.25	—	12,200	22.51
PAI-45-USGS-TW86	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	7.29B	2.12	<0.25	<0.25	<0.3	<0.25	—	9,040	21.8
PAI-45-USGS-TW87	3/4/2008	11–15	<0.3	146	<0.3	<0.25	158	<0.25	<0.25	17.2	420	<0.25	<0.25	1	<0.25	—	2,870	21.31
PAI-45-USGS-TW88	3/4/2008	11–15	<0.3	20.8	<0.3	<0.25	19.9	<0.25	<0.25	18.5	56.7	<0.25	<0.25	<0.3	<0.25	—	3,560	21.29
PAI-45-USGS-TW89	3/4/2008	11–15	<0.3	268	<0.3	<0.25	257	<0.25	<0.25	83.6	406	<0.25	<0.25	1.24	<0.25	—	2,180	21.42
PAI-45-USGS-TW90	3/4/2008	11–15	<0.3	154	<0.3	<0.25	164	<0.25	<0.25	37	342	<0.25	<0.25	0.72J	<0.25	—	2,860	21.85
PAI-45-USGS-TW91	3/5/2008	11–15	<0.3	20.2	<0.3	<0.25	19.3	<0.25	<0.25	24.7	47.4	<0.25	<0.25	<0.3	<0.25	—	3,630	18.9
PAI-45-USGS-TW92	3/4/2008	11–15	<6	1,330	<6	<5	1,270	<5	<5	201	796	<5	<5	<6	<5	—	2,340	22.64
PAI-45-USGS-TW93	3/4/2008	4.5–8	<0.3	88.3	<0.3	<0.25	83.3	<0.25	<0.25	34.7	67.7	<0.25	0.28J	1.29	<0.25	—	—	—
PAI-45-USGS-TW93	3/4/2008	11–15	<0.3	97.5	<0.3	<0.25	93.3	<0.25	<0.25	22.8	191	0.28J	<0.25	<0.3	<0.25	—	4,120	23.15
PAI-45-USGS-TW94	3/5/2008	7–11	<0.3	213	<0.3	1.69	254	<0.25	<0.25	331	863	1.05	<0.25	<0.3	<0.25	—	424	20.43
PAI-45-USGS-TW94	3/5/2008	11–15	3.51	323	<0.3	<0.25	413	<0.25	<0.25	754B	5,020	<0.25	1.05	2.07	<0.25	—	4,960	21.59
PAI-45-USGS-TW95	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.25	—	915	22.05

Appendix 7. Concentrations of selected volatile organic compounds in soil borings from temporary well PAI-45-USGS-TW7, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; cDCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; J, estimated concentration; µg/kg, micrograms per kilogram; all data are dry-weight corrected]

Site identifier	Date (month/day/year)	Depth (ft BLS)	Percent moisture	1,1-DCE (µg/kg)	1,2-DCE (µg/kg)	Benzene (µg/kg)	CB (µg/kg)	cDCE (µg/kg)	EB (µg/kg)	Napht (µg/kg)	PCE (µg/kg)	TCE (µg/kg)	Tol (µg/kg)	tDCE (µg/kg)	VC (µg/kg)	Xyl (µg/kg)
PAI-45-USGS-TW96	4/30/2008	10-12	25.5	0.75J	211	<0.65	<0.39	411	<0.39	<0.39	1,990	4,640	0.59J	3.22	15.1	1.08J
PAI-45-USGS-TW96R	4/30/2008	10-12	24.3	1.1J	248	<0.38	<0.23	330	0.30J	<0.23	1,750	3,560	1.01J	4.09	22.3	1.14J
PAI-45-USGS-TW96	4/30/2008	15-16	27.6	<0.27	<0.27	<0.27	<0.18	<0.27	<0.18	<0.18	0.46J	<0.22	<0.26	<0.27	<0.45	0.5J

Appendix 8. Concentrations of total organic carbon in soil borings, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; mg/kg, milligrams per kilogram]

Site identifier	Date (month/day/year)	Depth (ft BLS)	Total organic carbon (mg/kg)	Lithology
PAI-45-MW26-SL	6/27/2008	10–15	128	Fine-grained sand
PAI-45-MW28-D	8/26/2008	18	155,000	Organic-rich clay
PAI-45-USGS-TW96	4/30/2008	8–10	440	Grayish-tan, fine-grained heaving sand
PAI-45-USGS-TW96	4/30/2008	12–13	2,120	Black fine-grained sand

Appendix 9. Concentrations of selected volatile organic compounds in surface water near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; J, estimated concentration; µg/L, micrograms per liter]

Site identifier	Date (month/day/year)	Time (minutes before low tide)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	<i>c</i> DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	<i>t</i> DCE (µg/L)	VC (µg/L)	Xyl (µg/L)
PAI-SW1	6/16/2008	30	<0.3	1.6	<0.3	<0.25	1.6	<0.25	0.33J	0.44J	1.29	<0.25	<0.3	<0.5	<0.25
PAI-SW1-R	6/16/2008	30	<0.3	1.7	<0.3	<0.25	1.7	<0.25	<0.25	0.48J	1.34	<0.25	<0.3	<0.5	<0.25
PAI-SW2	6/16/2008	5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-SW3	6/16/2008	6	<0.3	0.7J	<0.3	<0.25	0.73J	<0.25	<0.25	<0.25	0.6J	<0.25	<0.3	<0.5	<0.25
PAI-SW4	6/16/2008	22	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25

Appendix 10. Concentrations of selected volatile organic compounds in sediment near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; mg/kg, milligrams per kilogram; <, less than; J, estimated concentration; all data are reported as dry-weight corrected]

Site identifier	Date (month/day/year)	Depth below sediment/water interface (feet)	Moisture (percent)	1,1-DCE (mg/kg)	Benzene (mg/kg)	CB (mg/kg)	<i>c</i> DCE (mg/kg)	EB (mg/kg)	PCE (mg/kg)	TCE (mg/kg)	Tol (mg/kg)	<i>t</i> DCE (mg/kg)	VC (mg/kg)	Xyl (mg/kg)
PAI-SWSED1	6/17/2008	0.5	68.5	<0.68	<0.75	<0.45	<0.68	<0.45	<0.45	<0.57	0.67J	<0.68	<1.13	<0.45
PAI-SWSED1	6/17/2008	1	57.2	<49	<54	<32	<49	<32	<32	<41	<47	<49	<81	<32
PAI-SWSED2	6/17/2008	0.5	57.7	<0.57	<0.63	<0.38	<0.57	<0.38	<0.38	<0.48	<0.55	<0.57	<0.95	<0.38
PAI-SWSED2	6/17/2008	1	58	<0.45	<0.5	<0.30	<0.45	<0.3	<0.30	<0.38	<0.44	<0.45	<0.75	<0.3
PA-ISWSED3	6/17/2008	0.5	73.3	<0.86	<0.95	<0.58	<0.86	<0.58	<0.58	<0.72	<0.83	<0.86	<1.44	<0.58
PAI-SWSED3	6/17/2008	1	71	<0.59	<0.65	<0.4	<0.59	0.75J	<0.4	<0.49	3.96	<0.59	<0.99	<0.4
PAI-SWSED4	6/17/2008	0.5	60.2	<0.74	<0.81	<0.49	<0.74	<0.49	<0.49	<0.62	<0.71	<0.74	<1.23	<0.49
PAI-SWSED4	6/17/2008	1	61.6	<0.54	<0.6	<0.36	<0.54	<0.36	<0.36	<0.45	<0.52	<0.54	<0.9	<0.36

Appendix 11. Synoptic water-level measurements at approximately low tide in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[MP, measuring point altitude in feet relative to North American Vertical Datum of 1988; —, data not collected; all top-of-casing altitudes were determined by Andrews and Burgess, Inc., in 2008; *, Datum was changed on these wells. Prior to July 3, 2008, the datum was 5.33 feet for well PAI-45-MW26-SL and 6.405 feet for well PAI-45-MW27-SL]

Well identifier	MP	Water-level altitude, in feet relative to North American Vertical Datum of 1988					
		April 30, 2007	August 7, 2007	August 29, 2007	June 16, 2008	June 27, 2008	July 25, 2008
PAI-45-MW01-D	6.60	1.72	—	2.03	1.31	1.20	1.83
PAI-45-MW01-SL	6.52	3.15	—	3.54	3.60	3.46	—
PAI-45-MW01-SU	6.54	3.12	—	3.57	3.57	3.45	—
PAI-45-MW02-SL	6.22	2.96	4.34	3.39	3.17	3.01	—
PAI-45-MW02-SU	6.12	2.67	4.31	3.12	2.66	2.73	—
PAI-45-MW03-SL	6.54	2.75	3.97	3.12	2.87	2.70	—
PAI-45-MW03-SU	6.59	2.52	4.39	3.12	2.57	2.58	—
PAI-45-MW04-D	5.78	1.59	—	1.92	1.21	1.09	1.71
PAI-45-MW04-SL	5.91	2.45	3.57	2.73	2.45	2.32	—
PAI-45-MW04-SU	5.93	2.45	3.59	2.74	2.47	2.34	—
PAI-45-MW05-D	7.63	1.61	—	1.93	1.19	1.07	1.69
PAI-45-MW05-SL	7.24	2.45	3.36	2.84	2.45	2.32	—
PAI-45-MW05-SU	7.59	2.42	3.33	2.71	2.42	2.29	—
PAI-45-MW06-D	6.44	1.64	—	1.96	1.23	1.09	1.74
PAI-45-MW06-SL	6.48	2.73	3.91	3.11	2.87	2.70	—
PAI-45-MW06-SU	6.52	2.87	3.44	3.12	2.90	2.85	—
PAI-45-MW07-D	6.63	1.66	—	1.97	1.25	1.12	1.75
PAI-45-MW07-SL	6.68	2.80	4.04	3.17	2.97	2.82	—
PAI-45-MW07-SU	6.63	2.79	4.04	3.15	2.95	2.80	—
PAI-45-MW08-SL	6.50	2.90	4.16	3.30	4.19	3.05	—
PAI-45-MW08-SU	6.57	2.81	4.15	3.29	3.17	3.02	—
PAI-45-MW09-D	6.24	1.60	—	1.89	1.15	1.04	1.67
PAI-45-MW10-D	6.25	—	—	—	—	1.18	1.81
PAI-45-MW10-SL	5.85	2.69	3.98	3.03	2.76	2.62	—
PAI-45-MW10-SU	5.90	2.67	3.86	3.02	2.78	2.61	—
PAI-45-MW11-D	5.43	1.36	—	1.37	1.67	-0.13	0.77
PAI-45-MW13-SL	6.39	2.57	3.68	2.87	2.61	2.46	—
PAI-45-MW13-SU	6.48	2.53	4.01	2.87	2.62	2.43	—
PAI-45-MW14-SL	5.76	2.73	3.67	3.08	2.84	2.71	—
PAI-45-MW14-SU	5.84	2.59	3.41	2.83	2.60	2.50	—

70 Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, SC

Appendix 11. Synoptic water-level measurements at approximately low tide in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.—Continued

[MP, measuring point altitude in feet relative to North American Vertical Datum of 1988; —, data not collected; all top-of-casing altitudes were determined by Andrews and Burgess, Inc., in 2008; *, Datum was changed on these wells. Prior to July 3, 2008, the datum was 5.33 feet for well PAI-45-MW26-SL and 6.405 feet for well PAI-45-MW27-SL]

Well identifier	MP	Water-level altitude, in feet relative to North American Vertical Datum of 1988					
		April 30, 2007	August 7, 2007	August 29, 2007	June 16, 2008	June 27, 2008	July 25, 2008
PAI-45-MW15-SL	8.13	2.72	3.72	3.03	2.68	2.56	—
PAI-45-MW15-SU	8.32	2.71	3.70	2.99	2.66	2.53	—
PAI-45-MW16-SL	9.17	2.44	3.35	2.75	2.38	2.29	—
PAI-45-MW16-SU	9.14	2.35	3.28	2.64	2.29	2.18	—
PAI-45-MW17-SL	5.96	2.68	3.11	2.32	2.10	1.97	—
PAI-45-MW17-SU	6.17	2.25	3.12	2.35	2.12	1.98	—
PAI-45-MW18-SL	6.98	2.53	3.53	2.71	2.43	2.30	—
PAI-45-MW18-SU	6.99	3.01	3.77	3.06	2.84	2.72	—
PAI-45-MW19-SL	5.64	2.68	3.82	2.98	2.71	2.55	—
PAI-45-MW19-SU	5.64	2.60	3.77	2.91	2.62	2.48	—
PAI-45-MW20-SL	6.67	2.23	3.29	2.49	2.21	2.11	—
PAI-45-MW20-SU	6.72	2.25	3.29	2.46	2.22	2.11	—
PAI-45-MW21-D	6.27	1.67	—	1.98	1.24	1.15	1.77
PAI-45-MW21-SL	6.27	2.88	—	3.28	3.06	2.93	—
PAI-45-MW21-SU	6.37	2.86	4.30	3.28	3.05	2.90	—
PAI-45-MW22-SL	6.43	2.99	4.37	3.42	3.30	3.17	—
PAI-45-MW22-SU	6.51	3.65	4.28	3.37	3.23	3.09	—
PAI-45-MW23-SL	6.28	2.64	3.43	3.05	2.64	2.67	—
PAI-45-MW23-SU	6.37	2.65	3.59	2.98	2.72	2.62	—
PAI-45-MW24-SU	6.62	2.93	3.91	3.30	3.11	2.97	—
PAI-45-MW25-SL	6.64	—	—	—	3.40	3.22	—
PAI-45-MW26-SL*	5.61	—	—	—	2.14	2.05	—
PAI-45-MW27-SL*	6.58	—	—	—	2.24	2.10	—
PAI-45-MW28-D	5.48	—	—	—	1.24	1.14	1.78
PAI-45-MW29-D	5.18	—	—	—	1.22	1.14	1.81
PAI-45-MW30-D	8.05	—	—	—	1.23	1.14	1.77
PAI-45-MW31-SL	5.49	—	—	—	2.91	2.74	—
PAI-45-MW31-SU	5.57	—	—	—	2.93	2.76	—

Appendix 12. Lithologic logs for permanent wells at site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey]

Permanent well PAI-45-MW28-D

Date: June 2–4, 2008

Method: Hollow-stem auger to 19 ft BLS, Mud-rotary below 19 ft.

Driller: EarthCon

Core Description: Don Vroblesky, USGS

Split spoons

June 2, 2008

Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
2–4	2	2.0–2.6	Silty clay, black
		2.6–4.0	Sand, fine-grained, brown
4–6	2	4.0–5.3	Silty sand, fine-grained, gray with patches of brown silty sand, possibly burrow fills
		5.3–6.0	Silty sand, fine-grained, fewer brown patches than above
6–8	1.5	6.0–6.5	Sand, fine-grained, gray with patches of brown fine-grained sand
		6.5–7.5	Sand, fine-grained, gray, loose
		7.5–8.0	Missing
8–10	2	8.0–10.0	Sand, fine-grained, very loose, very wet, grayish-tan
10–12	2	10.0–11.4	Sand, fine-grained, very loose, very wet, grayish-tan
		11.4–12.0	Silty sand, fine-grained, dark gray
12–14	2	12.0–14.0	Silty sand, fine-grained, dark gray
		16–18	2
16–18	2	17.8–18.0	Clay, organic-rich, dark gray
		18–19	1
18–19	1	18.8–19.0	Sandy clay, dark gray

Stopped at 19 ft to set outer casing. Grouted from 18.6 ft BLS to land surface

General description from mud-rotary cuttings

June 4, 2008

Interval (ft BLS)	Description
19–21.5	Clay
21.5–32	Sand, fine-grained
32–33.5	Shelly material in fine-grained sand
33.5–34	Hard drilling, still looks like shelly material

Set screen 23.7 to 33.7 ft BLS. Grouted from 18.5 ft BLS to land surface.

Permanent well PAI-45-MW29-D

Date: June 3, 2008

Method: Hollow-stem auger to 19 ft BLS, Mud-rotary below 19 ft.

Driller: EarthCon

Core Description: Don Vroblesky, USGS

Split spoons

June 2, 2008

Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
15–17	2	15–17	Sand, very loose, fine-grained, gray, wet
17–18.8	1.8	17–18.8	Same as above
18.8–19	0.2	18.8–19	Silt, organic rich

Stopped at 19 ft BLS to set outer casing. Final casing set at 19.6 ft BLS. Grouted 19.6 ft to land surface.

72 Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, SC

Appendix 12. Lithologic logs for permanent wells at site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.—Continued

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey]

Permanent well PAI-45-MW29-D—Continued	
General description from mud-rotary cuttings	
June 4, 2008	
Interval (ft BLS)	Description
20(?)–21	Sand, fine-grained, gray
21–28.5	Clay
28.5–29	Shelly material in fine-grained to silty sand
30–33	Sand, fine-grained to silty, with shells
Set screen 23.1 to 33.1 ft BLS. Grouted from 17 ft BLS to land surface.	

Permanent well PAI-45-MW30-D			
Date: June 4–5, 2008			
Method: Hollow-stem auger to 20 ft BLS, Mud-rotary below 20 ft.			
Driller: EarthCon			
Core Description: Don Vroblesky, USGS			
Split spoons			
June 4, 2008			
Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
0–15			No split spoons
15–17	2	15.0–17.0	Silty sand, fine-grained
17–19	2	17.0–17.8	Silty sand, fine-grained
		17.8–18.7	Clay, loose, with thin (0.05 inch) of fine-grained gray sand
		18.7–18.9	Clay, gray with abundant shell fragments
		18.9–19.0	Organic-rich clay, sharp upper contact
19–20	1	19.0–19.9	Organic-rich clay
		19.9–20.0	Organic-rich clay, very tight
Stopped at 20 ft BLS to set outer casing. Grouted from 20 ft BLS to land surface.			

General description from mud-rotary cuttings

June 5, 2008

Interval (ft BLS)	Description
20.5–22	Sand
22–23	Hard drilling
23–23.5	Silty sand, wood that does not appear to be from the auger plug
23.5–27	Sand, fine-grained
27–30	Silty sand
30–34	Clay
34–35	Hard drilling, shelly material in silty sand
Set screen 25–35 ft BLS. Grouted from 20 ft BLS to land surface.	

Appendix 13. Lithologic log for temporary well PAI-45-USGS-TW96, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, April 30, 2008.

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey; ppm, parts per million; <, less than; >, greater than]

Date: April 30, 2008

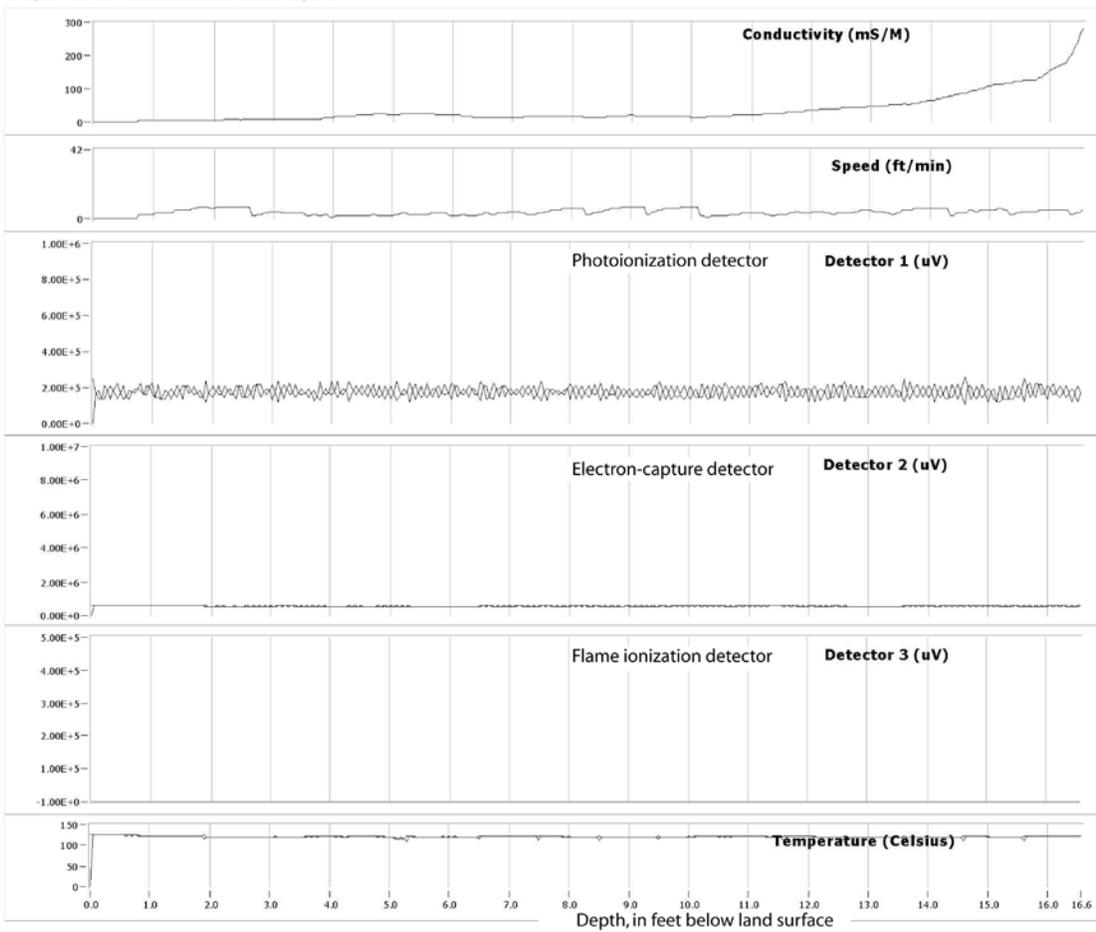
Method: Geoprobe

Driller: James Landmeyer, USGS

Core Description: Don Vroblesky, USGS

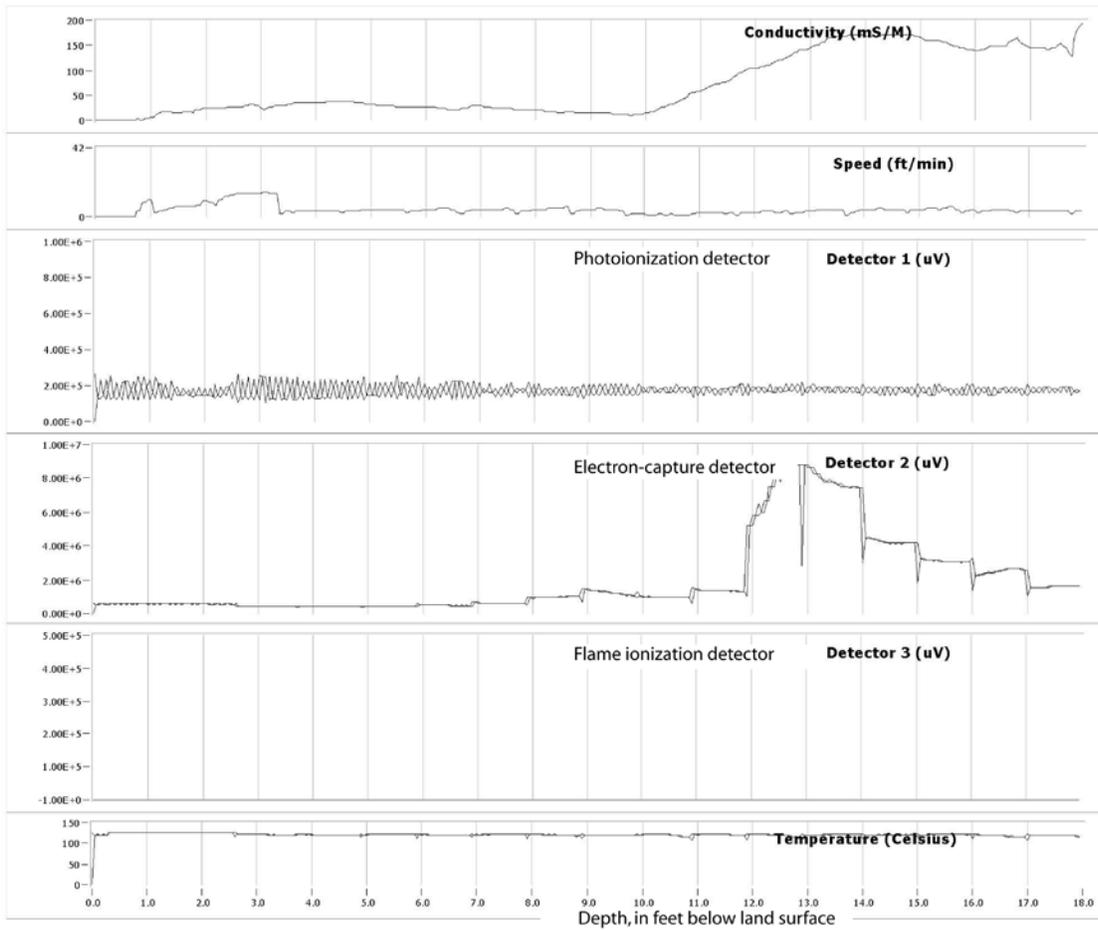
Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description	Reading on ColorTek vapor analyzer (ppm)
4–5	0.85	4.0–4.8	Silty sand, fine-grained, gray. Exact depth uncertain.	<0.2
6–8	1.8	6.0–6.9	Sandy clay, gray	2
		6.9–7.2	Clayey sand, gray	
		7.2–7.8	Silty sand, fine-grained, brown	
		7.8–8.0	Silty sand, fine-grained, gray	
8–10	1.2	8.0–10.0	Sand, fine-grained, heaving, grayish tan	>25
10–12	1.6	10.4–10.8	Sand, fine-grained, grayish tan	30
		10.8–12	Sand, fine-grained, black	
12–14	1.7	12.3–12.8	Sand, fine-grained, black	40
		12.8–14.0	Sand, fine- to very fine-grained, grayish-brown	10
14–16	2	14.0–14.8	Sand, fine-grained, gray	<0.2
		14.8–15.2	Sand, medium-grained, gray	
		15.2–16.0	Silt, with brownish material that appears to be plant matter	<0.2

Log: C:\Documents and Settings\



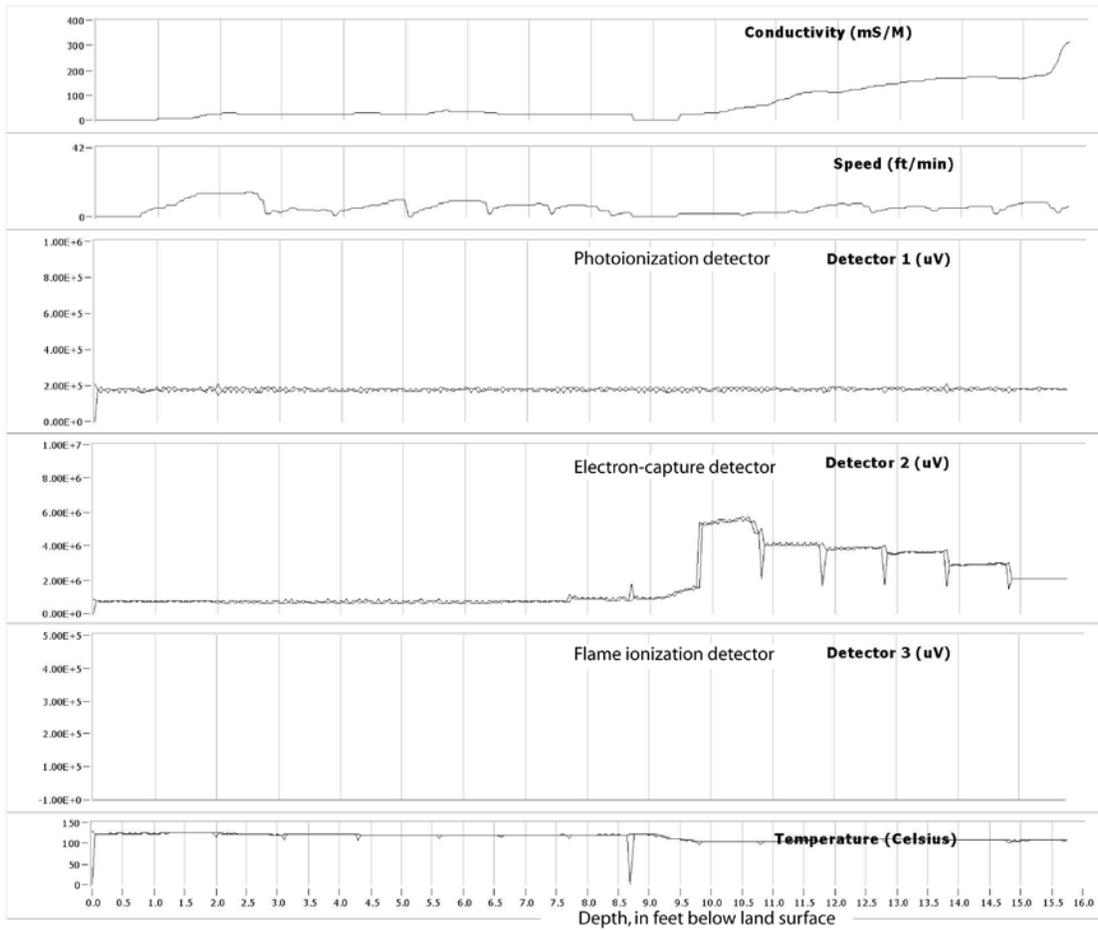
Appendix 14-1. Membrane Interface Probe (MIP) logs for boring MIP1, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



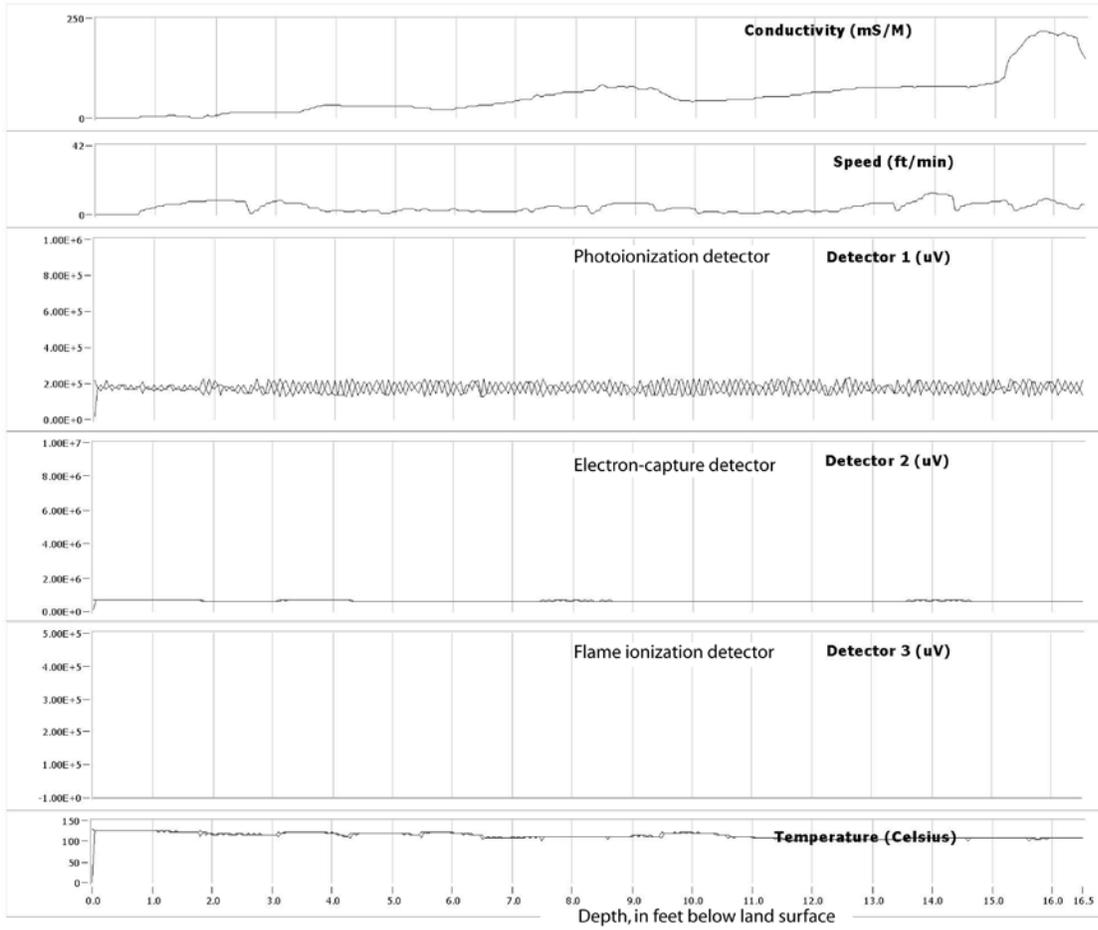
Appendix 14-2. Membrane Interface Probe (MIP) logs for boring MIP2, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



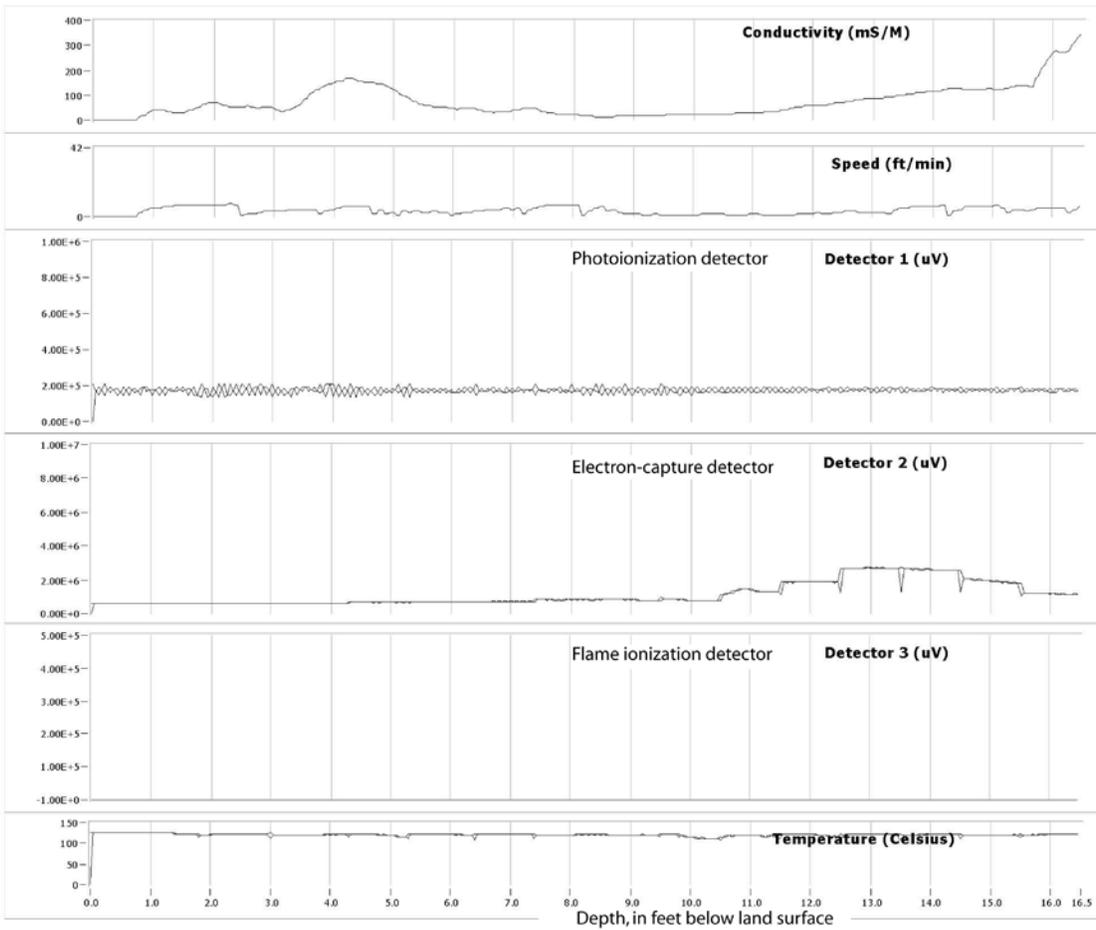
Appendix 14-3. Membrane Interface Probe (MIP) logs for boring MIP3, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



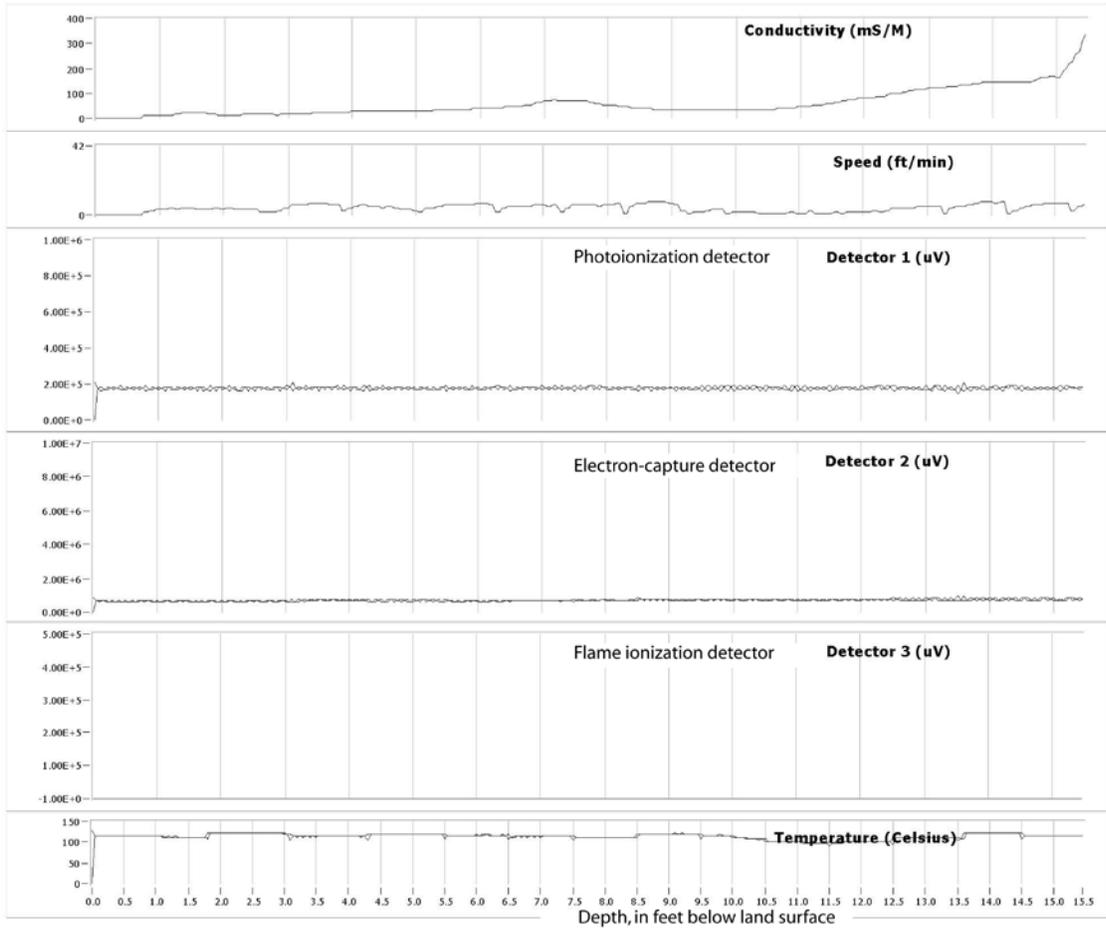
Appendix 14-4. Membrane Interface Probe (MIP) logs for boring MIP4, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



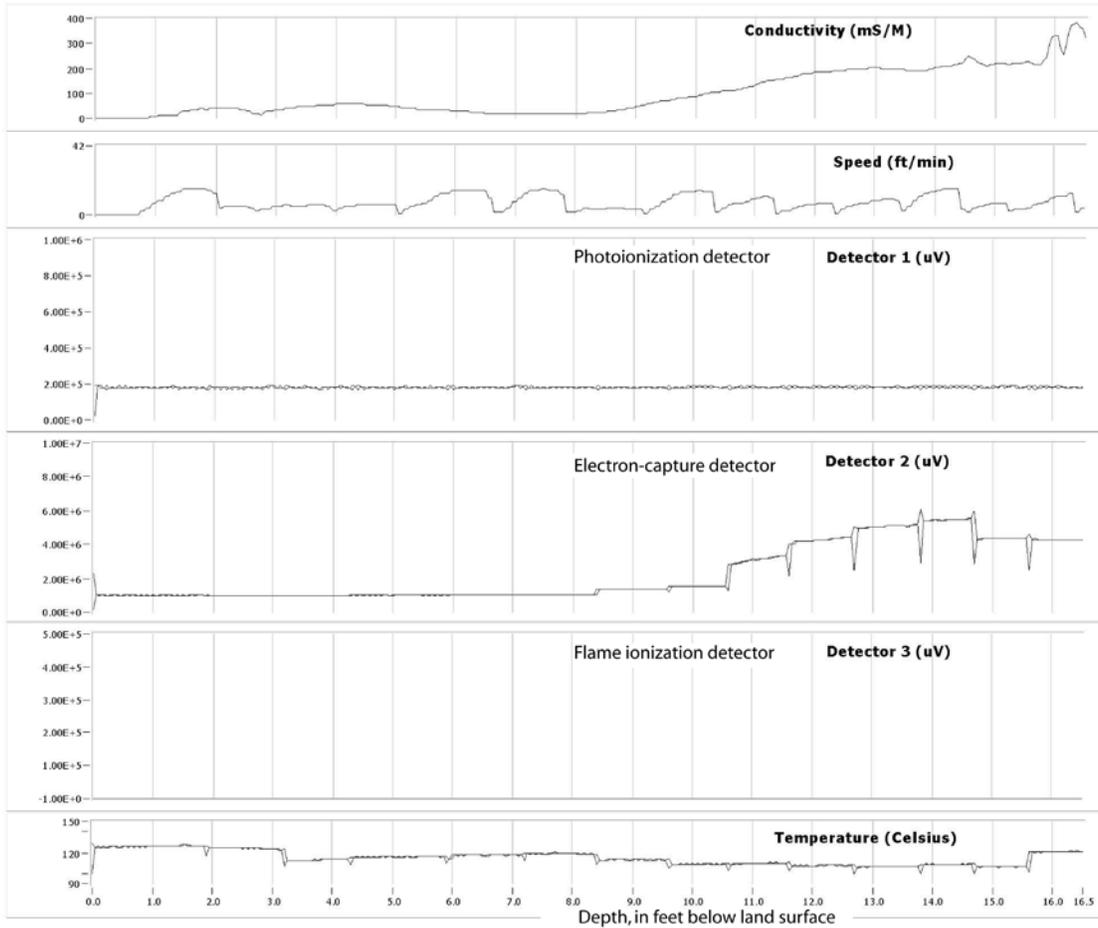
Appendix 14-5. Membrane Interface Probe (MIP) logs for boring MIP5, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



Appendix 14-6. Membrane Interface Probe (MIP) logs for boring MIP6, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Log: C:\Documents and Settings\



Appendix 14-7. Membrane Interface Probe (MIP) logs for boring MIP7, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Prepared by:

USGS Publishing Network
 Raleigh Publishing Service Center
 3916 Sunset Ridge Road
 Raleigh, NC 27607

For additional information regarding this publication, contact:

Don A. Vroblesky, Hydrologist
 USGS South Carolina Water Science Center
 Stephenson Center, Suite 129
 720 Gracern Road
 Columbia, SC 29210
 email: vroblesk@usgs.gov

Or visit the USGS South Carolina Water Science Center Web site at:

<http://sc.water.usgs.gov/>

