U.S. Department of the Interior
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Delineation of Discharge Areas of Two Contaminant Plumes by Use of Diffusion Samplers, Johns Pond, Cape Cod, Massachusetts, 1998

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Water-Resources Investigations Report 00-4017

Prepared in cooperation with the
AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE and the
U.S. ENVIRONMENTAL PROTECTION AGENCY

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By JENNIFER G. SAVOIE, DENIS R. LeBLANC, DANN S. BLACKWOOD, TIMOTHY D. McCOBB, RICHARD R. RENDIGS, U.S. Geological Survey, and SCOTT CLIFFORD, U.S. Environmental Protection Agency

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Northborough, Massachusetts
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:
Chief, Massachusetts-Rhode Island District
U.S. Geological Survey
Water Resources Division
10 Bearfoot Road
Northborough, MA 01532

Copies of this report can be purchased from:
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CONVERSION FACTORS, VERTICAL DATUM, AND CHEMICAL ABBREVIATIONS

CONVERSION FACTORS:

Multiply	By	To obtain
foot (ft)	0.3048	meter
inch (in)	25.40	millimeter

VERTICAL DATUM

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

CHEMICAL ABBREVIATIONS

mL	milliliter
µm	micrometer
µg/L	micrograms per liter
ppb v	parts per billion by volume

Delineation of Discharge Areas of Two Contaminant Plumes by Use of Diffusion Samplers, Johns Pond, Cape Cod, Massachusetts, 1998

By Jennifer G. Savoie, Denis R. LeBlanc, Dann S. Blackwood, Timothy D. McCobb, Richard R. Rendigs, *and* Scott Clifford

Abstract

Diffusion samplers were installed in the bottom of Johns Pond, Cape Cod, Massachusetts, to confirm that volatile organic compounds from the Storm Drain-5 (SD-5) plume emanating from the Massachusetts Military Reservation (MMR) were discharging into the pond. An array of 134 vapor-diffusion samplers was buried by divers about 0.5 feet below the pond bottom in the presumed discharge area of the SD-5 plume and left in place for about 2 weeks to equilibrate.

Two areas of high concentrations of volatile organic compounds (VOCs) were identified. Samples from the first area contained trichloroethene (TCE) and tetrachloroethene with concentrations in vapor as high as 890 and 667 parts per billion by volume, respectively. This discharge area is about 1,000 feet wide, extends from 100 to 350 feet offshore, and is interpreted to be the discharge area of the SD-5 plume. Samples from the second area were located closer to shore than the discharge area of the SD-5 plume and contained unexpectedly high vapor concentrations of TCE (more than 40,000 parts per billion by volume). Ground-water samples collected with a drive-point sampler near the second area had aqueous TCE concentrations as high as 1,100 micrograms per liter. Subsequently, a more closely spaced array of 110 vapor-diffusion samplers was installed to map the area of elevated TCE concentrations. The discharge area detected with the samplers is about 75 feet wide and extends from about 25 to 200 feet offshore. TCE vapor concentrations in this area were as high as 42,800 parts per billion by volume.

TCE concentrations in micrograms per liter in water-diffusion samples from 15 selected sites in the two discharge areas were about 35 times lower than the TCE concentrations in parts per billion by volume in corresponding vapor-diffusion samples. The difference in values is due to the volatile nature of TCE and the different units of measure. TCE was detected in diffusion samplers set in the pond water column above the plume discharge areas, but the TCE concentrations were 20 to 30 times lower than the corresponding levels in diffusion samplers buried in the pond bottom.

INTRODUCTION

A plume of dissolved volatile organic compounds (VOCs) in ground water extends 9,000 ft from the site of a storm drain on the Massachusetts Military Reservation (MMR) to Johns Pond, Mashpee, Mass. (figs. 1 and 2). Johns Pond is a ground-water flow-through glacial kettle pond in a sand and gravel outwash plain. Ground water generally flows into the pond near its western side and discharges back into the ground near the eastern side of the pond, as indicated by the water-table contours in figure 1. This ground-water plume, known as the Storm Drain-5 (SD-5) plume, is composed primarily of trichloroethene (TCE) with concentrations as high as 66 µg/L. Investigations by the MMR's Installation Restoration Program (IRP) suggested that the SD-5 plume was discharging to Johns Pond (Jacobs Engineering Group, Inc., 1997a, 1998a). The MMR IRP sought to confirm that the SD-5 plume was discharging to the pond and to delineate the extent of the discharge area.

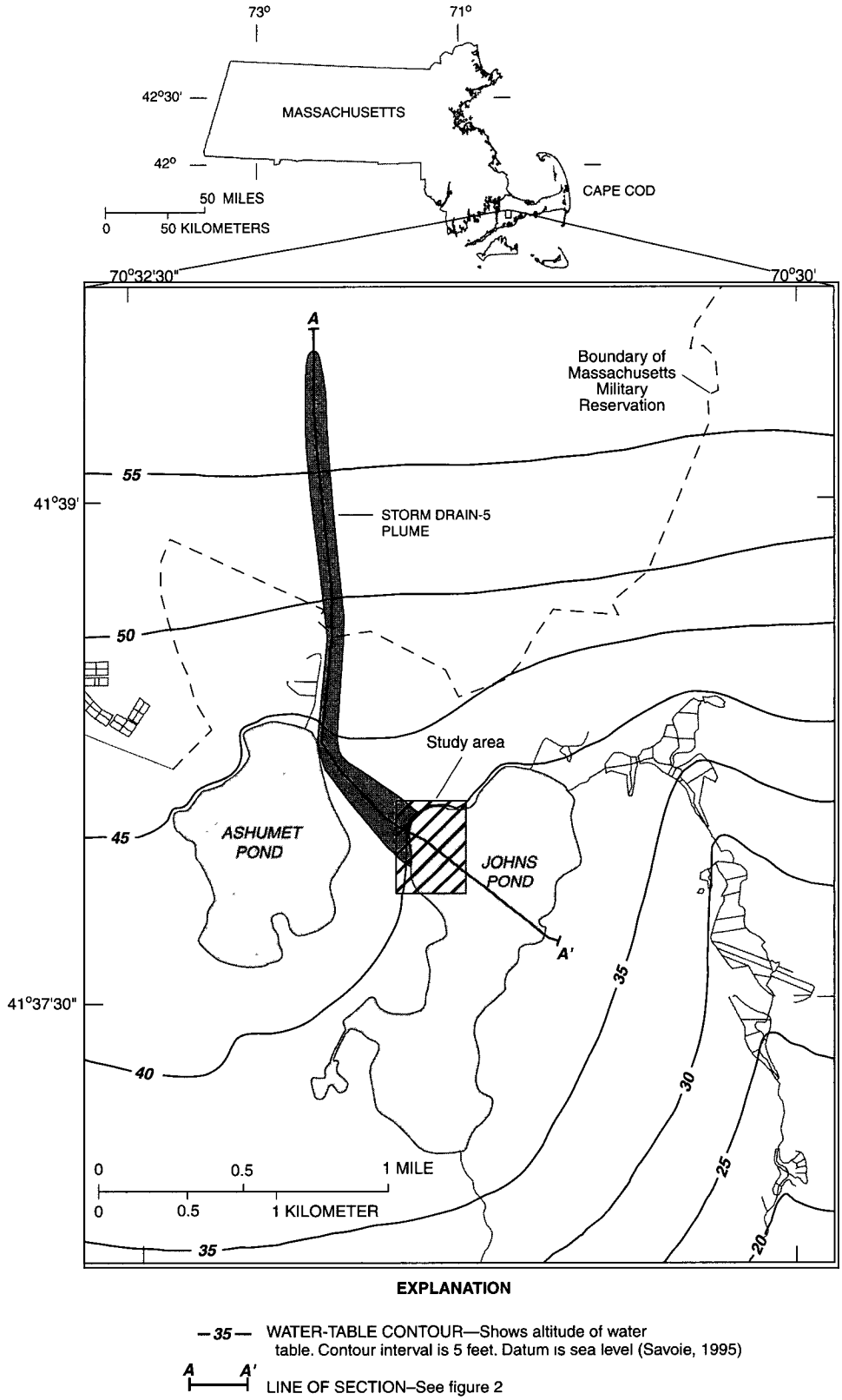

Figure 1. Location of study area, the Storm Drain-5 plume (Jacobs Engineering Group, Inc., 1998a), Johns Pond, and altitude of water table, Cape Cod, Massachusetts.

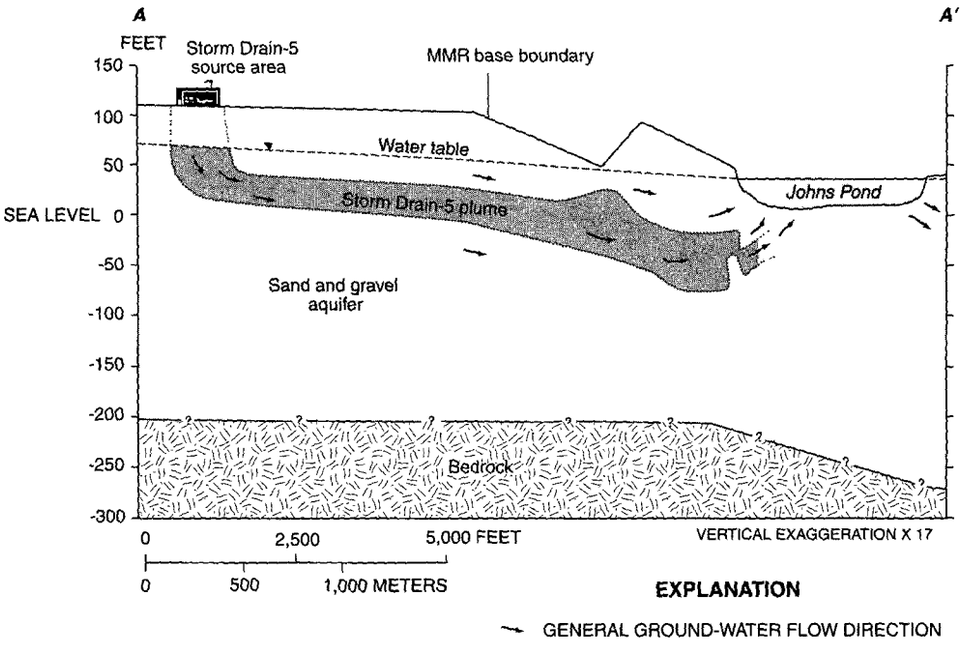

Figure 2. Vertical path of Storm Drain-5 plume in ground water along section *A–A'*, Johns Pond, Cape Cod, Massachusetts (modified from Jacobs Engineering Group, Inc., 1998a). Location of section shown in figure 1.

In 1998, the U.S. Geological Survey (USGS), in cooperation with the Air Force Center for Environmental Excellence and the U.S. Environmental Protection Agency (USEPA), conducted a study in which diffusion samplers were installed in Johns Pond to determine if VOCs from the SD-5 plume were discharging to the pond and to delineate the area of discharge. Diffusion samplers have been used in New England to locate discharge areas of VOCs into other surface-water bodies where wading was possible (Lyford and others, 1998, 1999; Savoie and others, 1999). Johns Pond was the first site at which the samplers were deployed at depths that prohibited wading. The samplers were installed in Johns Pond by divers in water depths ranging from 5 to 30 ft.

Water-to-vapor and water-to-water diffusion samplers (referred to as vapor- and water-diffusion samplers, respectively, in this report) were used to determine the distribution and concentrations of VOCs in the pore waters within the pond-bottom sediments and in pond water near the pond bottom. Vapor-diffusion samplers were chosen for most of the sampling sites because they are easy to construct, install, retrieve, and analyze. Water-diffusion samplers were installed at selected locations to determine aqueous-phase concentrations of VOCs in pore water in the pond-bottom sediments. Vapor-diffusion samplers also were mounted on stands that were placed on the bottom of the pond to determine if VOCs were detectable in the water column just above the pond bottom. Finally, water samples were collected using a drive-point sampler in order to verify results from the diffusion samplers. This report describes how diffusion samplers were constructed and installed in Johns Pond, and describes the locations of the discharge areas of the SD-5 plume and a previously unknown TCE plume that were identified by use of the samplers. Additional information about the SD-5 and TCE ground-water plumes can be obtained from various reports by the Jacobs Engineering Group, Inc. (1998b, 1999).

ACKNOWLEDGMENTS

The authors would like to thank Lee Perry of the Air Force Center for Environmental Excellence, Larry J. Pannell of Jacobs Engineering Group, Inc., and Donald Vroblesky of the U.S. Geological Survey for their support and advice; Joseph Montanaro of the USEPA for his analysis of the water-diffusion samples; Barry J. Irwin and Kenneth F. Parolski of the USGS Geologic Division for their scuba diving efforts;

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STUDY METHODS

Diffusion samplers were used to determine the discharge areas of VOCs entering Johns Pond. Two types of samplers were used—water-to-vapor and water-to-water diffusion samplers. Samplers were deployed three times in 1998 to locate the SD-5 plume and TCE plume discharge areas.

Principles of Operation and Construction of Diffusion Samplers

Diffusion samplers operate on the principle that VOCs will diffuse through a semipermeable membrane, such as polyethylene, until concentrations in air inside the vapor-diffusion samplers or in water inside the water-diffusion samplers reach equilibrium with concentrations in the water outside the sampler. Volatile organic compounds, such as TCE and tetrachloroethene (PCE), have high vapor pressures and readily partition into the vapor phase. Vapor-phase concentrations in this report are given in parts per billion by volume (ppb v), which is a volume per volume measurement. Aqueous-phase concentrations are reported in micrograms per liter (µg/L), which is a weight per volume measurement. In general, elevated vapor concentrations reflect elevated water concentrations. Vapor and water concentrations given in this report cannot be compared directly, however, because of the different units of measure. Conversion of vapor concentrations to equivalent aqueous concentrations would require information on temperature and pressure at each sampling site and compound-specific partitioning data, as described by Henry's Law. Methods of construction and some applications of water- and vapor-diffusion samplers are described by Vroblesky (1998), Vroblesky and Hyde (1997), and Vroblesky and others (1996, 1999).

Vapor-diffusion samplers were chosen as the primary sampling tool because they are easily constructed and deployed. For this reason, many samplers could be installed to delineate the discharge area precisely. Water-diffusion samplers also were installed at selected locations to measure the aqueous-phase concentrations in the pore water of the pond-bottom sediments. Water-diffusion samplers are somewhat more difficult to construct and deploy. Therefore, only a few water-diffusion samplers were deployed in this study. Water-column samplers were deployed at selected locations to determine if contaminants that were entering through the pond bottom were being diluted in the pond water. A water-column sampler was constructed by attaching diffusion samplers to a PVC stand at varying heights above the pond bottom.

A vapor-diffusion sampler is constructed by placing an empty, uncapped, 40-mL glass vial in a polyethylene bag. After most of the air is pushed out of the bag, it is sealed and secured with a cable tie. The vial and bag are then enclosed in a second polyethylene bag to protect the sampler from water and sediment. Self-sealing zipper-lock bags were used in the first two deployments (April and July), while heat-sealed polyethylene tubing was used in the final deployment (November). Finally, the sampler is attached to a surveying pin flag with cable ties.

A water-diffusion sampler is constructed by filling polyethylene tubing with deionized water and sealing both ends by knotting or heating. The water samplers are enclosed in a wire cage that is attached to a surveying pin flag.

Deployment and Retrieval Schedule

Diffusion samplers were deployed three times in 1998 (April, July, and November) to determine if VOC contaminants were discharging into Johns Pond and to define the discharge areas. The study focused on the northwestern corner of Johns Pond where the SD-5 plume intersects the shoreline. The water-table contours (fig. 1) and seepage measurements made in earlier studies (Jacobs Engineering Group, Inc., 1997b) indicated that the northwestern corner is a ground-water discharge area. Samplers were installed within 425 ft of shore because studies by Pfannkuch and Winter (1984) demonstrated that most ground-water discharge to a pond typically occurs near the shore. The initial deployment of diffusion samplers, in April 1998, was conducted to determine if diffusion sampling would be useful for detecting VOCs in the pond bottom. Forty-six vapor-diffusion samplers were

installed at 23 locations along two transects in Johns Pond near where the SD-5 plume intersects the shore. Because the initial deployment was experimental, samplers were installed in duplicate (about 2 to 3 ft apart) to ensure sample recovery and repeatability. Sampling locations 1 through 19 extended from 20 to 365 ft offshore along a line perpendicular to shore, and locations 20 through 23 were about 35 ft offshore along a line parallel to shore (fig. 3). On April 23, 1998, the samplers were retrieved from the pond after being allowed to equilibrate for eight days.

A second deployment of samplers was installed on July 28–29, 1998, to map the areal extent of VOCs discovered in the first deployment. Samplers were emplaced at 134 locations along 9 transect lines that were 350 ft long and spaced 150 ft apart (fig. 4). Samplers were spaced 25 ft apart along the lines. Water-diffusion samplers were installed at eight locations. At two additional locations, water-column samplers were deployed with vapor-diffusion samplers attached to PVC stands at 0.2, 0.6, 1.0, and 2.0 ft above the pond bottom. On August 10–11, 1998, the samplers were retrieved from the pond after being allowed to equilibrate for about two weeks. The two-week equilibration time was believed to be sufficient based on laboratory tests (Donald Vroblesky, written commun., 1998), field experience elsewhere in New England (Lyford and others, 1998, 1999; Savoie and others, 1999), and the permeable sandy pond-bottom sediments. To confirm the higher than expected TCE concentrations detected in August at line 7, water samples were collected at eight locations with a drive-point sampler in September 1998 (fig. 5).

A third deployment of samplers was installed on November 16–17, 1998, to map the areal extent of the higher than expected TCE concentrations found in August at line 7. Samplers were emplaced at 110 locations along 8 transects that were about 200 ft long and spaced 25 to 35 ft apart (fig. 6). Samplers were spaced 10 to 25 ft apart along the lines. Water-diffusion samplers were installed at 18 locations. At two additional locations, water-column samplers were deployed with vapor-diffusion samplers attached to PVC stands at 0.2, 0.6, 1.0, and 2.0 ft above the pond bottom. On one stand, water-diffusion samplers also were installed at 0.2 and 1.0 ft above the pond bottom. On December 1–2, 1998, the samplers were retrieved from the pond after being allowed to equilibrate for two weeks.

Installation and Retrieval Methods

To install the samplers, lines were prepared using fisherman's sinking-pot-warp line with the samplers attached by clips at variable spacing for each deployment. A boat and compass were used to lay the lines on the pond bottom. The line endpoints were located with a sub-meter accuracy global-positioning system (GPS) unit. Scuba divers swam along each line, buried the samplers about 0.5 ft into the pond-bottom sediments by hand or with a trowel, and unclipped them from the line. The samplers were unclipped from the line because there was concern that a fisherman might accidently snag the main line with a fishing hook and pull the samplers out of the sediment.

When samplers were retrieved, divers swam along the lines, clipped the samplers back on the lines, and then pulled them out of the sediment. The lines were hauled into a boat, where the vapor samplers were taken out of the outer bag and and then capped directly over the inner polyethylene bag. The water from the water-diffusion samplers was transferred into 40-mL glass vials, preserved with hydrochloric acid, and chilled until analysis. Vapor samples were analyzed on site in a mobile laboratory by USEPA personnel. Water samples were shipped to the USEPA New England Regional Laboratory in Lexington, Mass., for analysis.

Collection of Water Samples with the Drive-Point Sampler

Ten water samples were collected using a drive-point sampler to confirm the higher than expected TCE concentrations detected at line 7 during the August diffusion sampling (fig. 5). The sampler (K-V Associates, Falmouth, Mass., Macho sampling system) was constructed of 5/8-inch-diameter steel casing lined with 3/16-inch-diameter polypropylene tubing; the casing was attached to a 0.85-ft-long slotted steel screen. The sampler was driven with a sliding hammer about 2 ft into the pond-bottom sediments. Several casing volumes of water were purged from the sampler before specific conductance and dissolved oxygen were measured and the samples were collected. The drive-point sampler was then decontaminated with several casing volumes of distilled water. At sampling site KVDP-9, the drive-point sampler was used to collect a water sample from the pond water just above the pond bottom. Sampling sites were located with GPS.

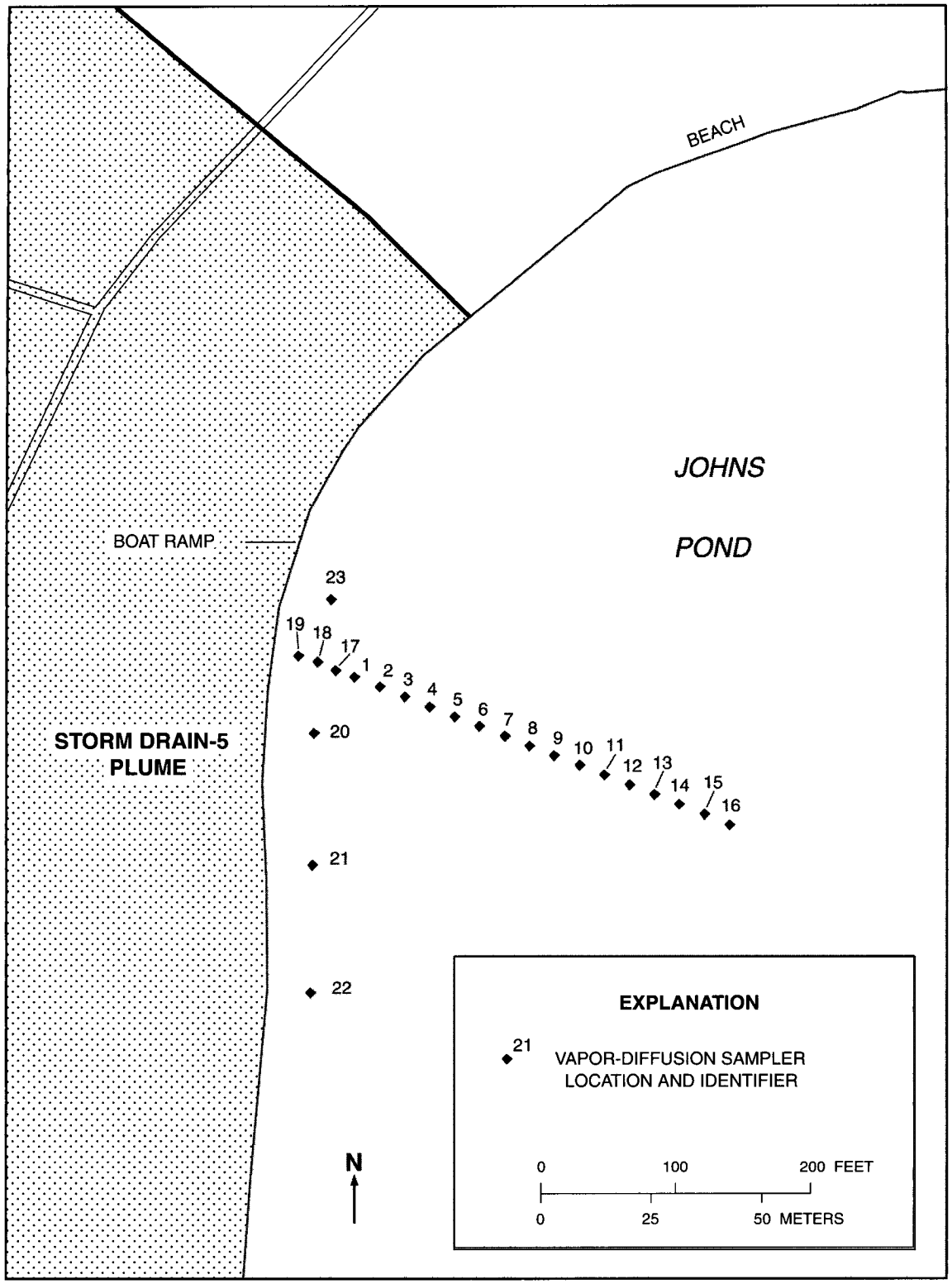


Figure 3. Location of Storm Drain-5 plume (Jacobs Engineering Group, Inc., 1998a) and diffusion samplers collected in April 1998 to delineate the Storm Drain-5 plume discharge area, Johns Pond, Cape Cod, Massachusetts.

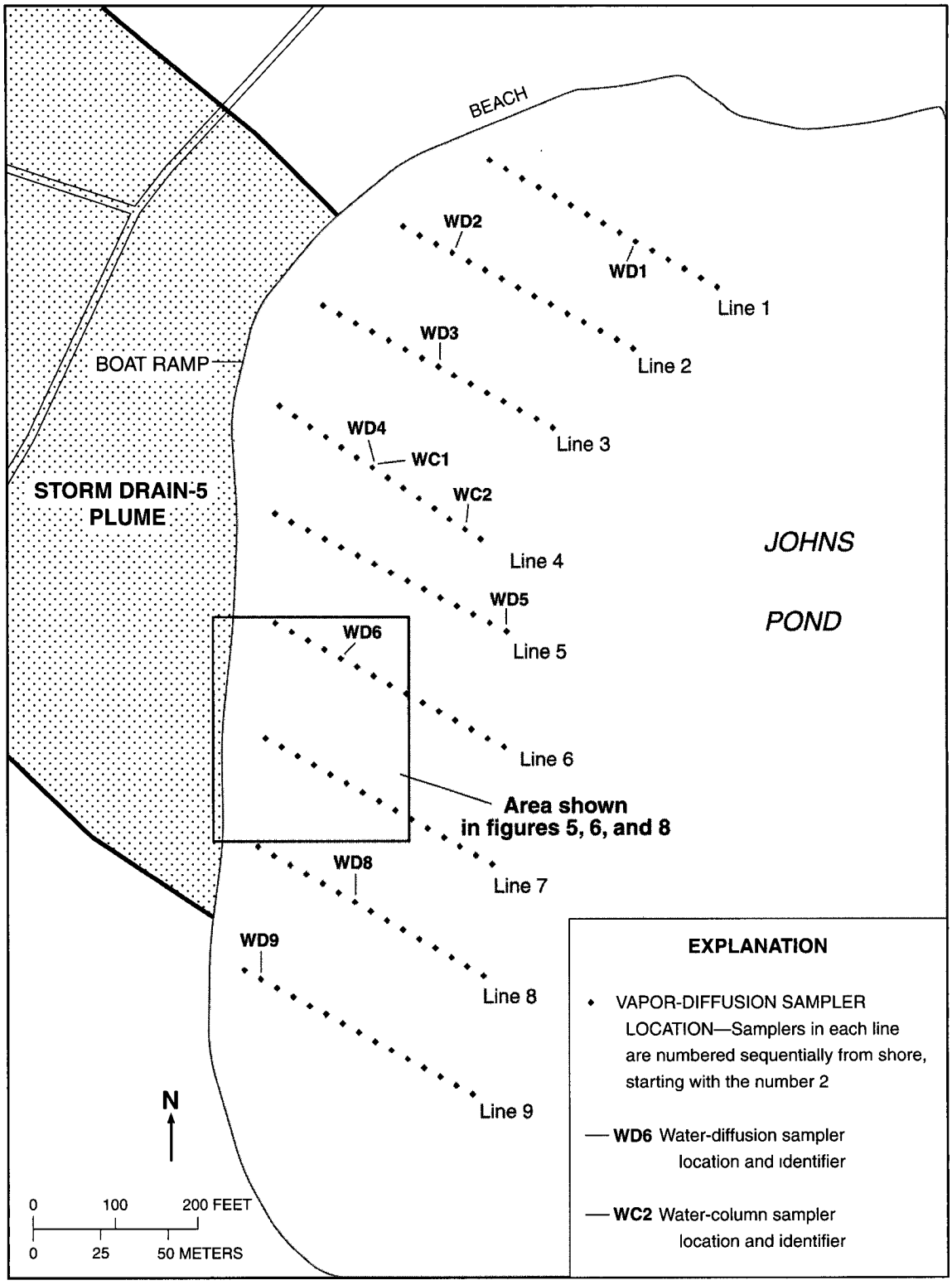
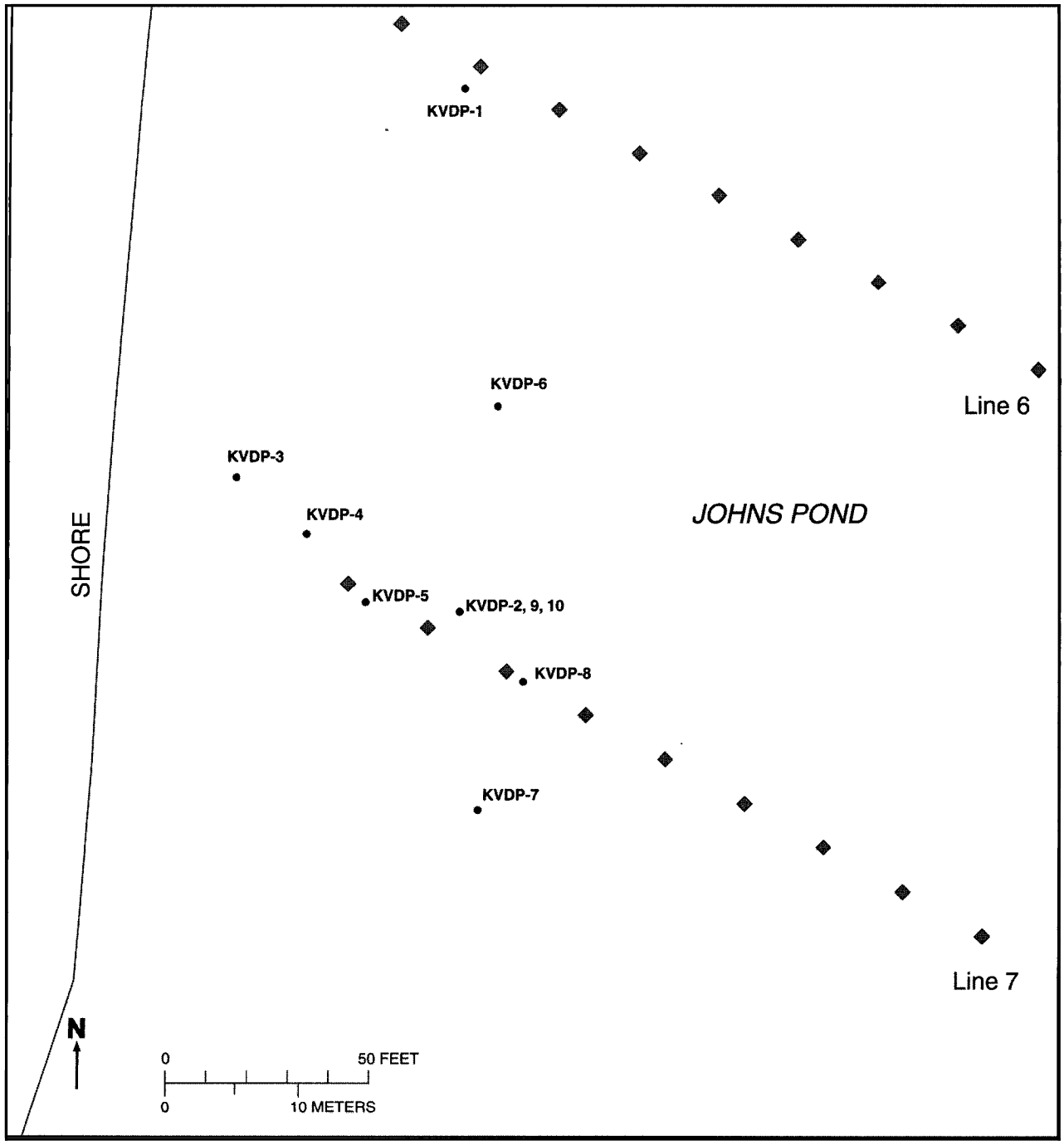


Figure 4. Location of Storm Drain-5 plume (Jacobs Engineering Group, Inc., 1998a) and diffusion samplers collected in August 1998 to delineate the Storm Drain-5 plume discharge area, Johns Pond, Cape Cod, Massachusetts.



EXPLANATION

AUGUST 1998 VAPOR-DIFFUSION SAMPLER LOCATION

KVDP-8 DRIVE-POINT SAMPLER LOCATION AND IDENTIFIER

Figure 5. Location of drive-point water samples collected in September 1998 from discharge area of the previously unidentified trichloroethene plume, Johns Pond, Cape Cod, Massachusetts.

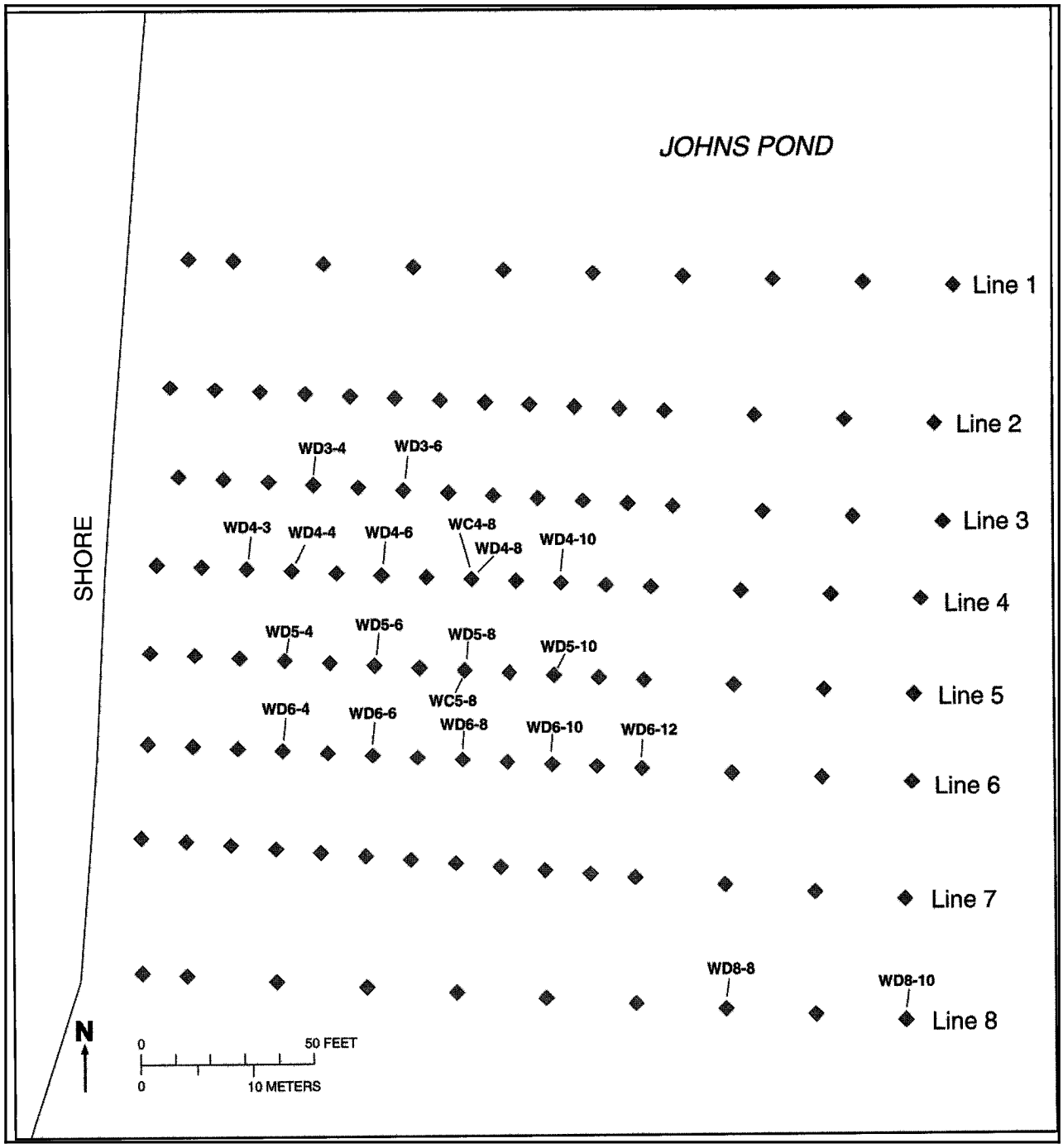


Figure 6. Location of diffusion samplers collected in December 1998 to delineate the discharge area of the trichloroethene plume, Johns Pond, Cape Cod, Massachusetts.

Unfiltered water samples were collected in 40-mL glass septum vials for immediate VOC analysis on site by the USEPA to help direct sample collection; the August sampling lines were no longer in place to orient the sampling locations. Duplicate VOC samples were preserved with hydrochloric acid and chilled for laboratory analysis. Samples for boron and phosphorus analysis were filtered through a 0.45-µm filter and preserved with nitric acid for later analysis. Unfiltered samples for later nitrate plus nitrite analysis were chilled.

Analysis of Vapor and Water Samples

Vapor samples were analyzed on site for VOCs by USEPA personnel by means of the USEPA Region I standard air-screening method (U.S. Environmental Protection Agency, 1998a). Vapor samples were analyzed within 3 to 4 hours of sample collection in order to reduce the possibility of compound degradation. On site analysis equipment included Photovac gas chromatographs equipped with 4-foot by 1/8-inch SE-30 columns and photoionization detectors. Target compounds for the vapor-sample analyses on the Photovac gas chromatographs included TCE and PCE, which were presumed to be present from past site history. Selected water samples from the drive-point sampling were analyzed for VOCs on site with Photovac gas chromatographs by use of the USEPA Region I headspace-analysis method (U.S. Environmental Protection Agency, 1998b). All other aqueous samples were analyzed for VOCs at the USEPA New England Regional Laboratory with a gas chromatograph and mass spectrometer by use of the purge-and-trap USEPA method 8260B (U.S. Environmental Protection Agency, 1996).

Water samples were analyzed for nitrate plus nitrite at the USEPA New England Regional Laboratory by use of USEPA method 300.0 (U.S. Environmental Protection Agency, 1993). Water samples were analyzed for boron and phosphorus by the USGS National Research Program by the method of inductively coupled plasma atomic emission spectroscopy (ICPAES) described by Coston and others (1998).

DISCHARGE AREAS OF TWO CONTAMINANT PLUMES AT JOHNS POND

VOCs were detected in the pore water in the pond-bottom sediments in two distinct zones: the SD-5 plume discharge area and the discharge area of a previously unknown TCE plume. Drive-point water samples confirmed the results from the diffusion samplers in the discharge area of the TCE plume. Low concentrations of VOCs were detected in the water-column samples collected in August over the SD-5 plume discharge area; somewhat higher concentrations of VOCs (particularly TCE) were detected in the water-column samples collected in December over the TCE plume discharge area.

Storm Drain-5 Plume Discharge Area

Results from the initial deployment of diffusion samplers in April 1998 showed the presence of TCE and PCE in pond-bottom sediments from about 100 to 300 ft offshore (table 1). In August 1998, TCE and PCE were detected in the SD-5 plume discharge area with concentrations as high as 890 and 667 ppb v, respectively (table 6, at back of report). Higher concentrations were detected in a separate area near the shore at line 7, with TCE concentrations as high as 47,000 ppb v. It is important to note that the reported vapor-phase concentrations for TCE and PCE (in ppb v) are much higher than the corresponding aqueous-phase concentrations (in µg/L) in the pore water because of the volatile nature of the compounds and the different units of measure. Some vapor samplers had dislodged over the 2-week period and were found floating just above the bottom sediments. Analyses of these samples are included in tables 1 and 6 for completeness, but the reported concentrations may not reflect concentrations in the bottom-sediment pore water because it is not known when the samplers dislodged.

Combined TCE and PCE vapor concentrations greater than 100 ppb v were detected in an area about 1,000 ft wide parallel to the shoreline. The area extends from about 100 to 325 ft offshore at line 3, and becomes narrower to the south, extending from about 300 to 350 ft offshore at line 8 (fig. 7). Lower concentrations of TCE and PCE were measured at scattered locations outside the main discharge area (table 6). Results of drilling by MMR IRP consultants into the

Table 1. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the Storm Drain-5 plume, Johns Pond, Cape Cod, Massachusetts, April 1998

[Analysis by U S. Environmental Protection Agency. Locations of samplers are shown in figure 3. Locations were not surveyed. Detection limits vary No , number; ft, foot; ppb v, parts per billion by volume ; --, sampler lost, <, value is less than method reporting limit; *, sampler found floating above pond bottom, data less reliable, #, 87 ppb v of toluene detected]

Vapor-diffusion sampler No.	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v)	Tetrachloro-ethene (PCE) (ppb v)
SD-5/0498/WVD001a	65	5	<6
SD-5/0498/WVD001b	65	<4	<6
SD-5/0498/WVD002a	85	<4	<6
SD-5/0498/WVD002b	85	<4	<6
SD-5/0498/WVD003a	105	<4	11
SD-5/0498/WVD003b	105	<4	9
SD-5/0498/WVD004a	125	<4	64
SD-5/0498/WVD004b	125	<4	62
SD-5/0498/WVD005a	145	4	65
SD-5/0498/WVD005b	145	--	--
SD-5/0498/WVD006a	165	5	32
SD-5/0498/WVD006b	165	4	32
SD-5/0498/WVD007a	185	11	6
SD-5/0498/WVD007b	185	12	6
SD-5/0498/WVD008a	205	7	<6
SD-5/0498/WVD008b	205	9	<6
SD-5/0498/WVD009a	225	52	<6
SD-5/0498/WVD009b*	225	4	<6
SD-5/0498/WVD010a	245	206	<6
SD-5/0498/WVD010b*	245	9	<6
SD-5/0498/WVD011a	265	204	7
SD-5/0498/WVD011b*	265	5	<6
SD-5/0498/WVD012a*	285	18	<6
SD-5/0498/WVD012b	285	225	<6
SD-5/0498/WVD013a*#	305	29	<6
SD-5/0498/WVD013b*	305	5	<6
SD-5/0498/WVD014a	325	<4	<6
SD-5/0498/WVD014b	325	<4	<6
SD-5/0498/WVD015a	345	4	<6
SD-5/0498/WVD015b*	345	<4	<6
SD-5/0498/WVD016a	365	<4	<6
SD-5/0498/WVD016b	365	<4	<6
SD-5/0498/WVD017a	50	<4	<6
SD-5/0498/WVD017b	50	<4	<6
SD-5/0498/WVD018a	35	<4	<6
SD-5/0498/WVD018b	35	<4	<6
SD-5/0498/WVD019a	20	<4	<6
SD-5/0498/WVD019b	20	<4	<6
SD-5/0498/WVD020a*	35	<4	<6
SD-5/0498/WVD020b	35	5	<6
SD-5/0498/WVD021a	35	<4	<6
SD-5/0498/WVD021b	35	<4	<6
SD-5/0498/WVD022a	35	<4	<6
SD-5/0498/WVD022b	35	<4	<6
SD-5/0498/WVD023a	35	<4	<6
SD-5/0498/WVD023b	35	<4	<6

aquifer beneath the pond between April and June 1998 confirm the location of the SD-5 plume and the area of discharge delineated by the results of the diffusion samplers (Jacobs Engineering Group, 1999).

Trichloroethene Plume Discharge Area

Results of the August sampling detected TCE vapor concentrations as high as 47,000 ppb v at line 7 near the shore (75 to 175 ft offshore, fig. 7). To confirm these high TCE concentrations, water samples were collected in September 1998 directly from the pond-bottom sediments using a drive-point sampler (fig. 5). Because the area was so close to shore, it was thought that the contamination might be derived from local septic-system effluent; therefore, samples also were analyzed for nitrate plus nitrite, boron, and phosphorus, which typically are found in sewage-contaminated ground water. Drive-point sampling results for VOCs and the other species listed above are shown in table 2. The drive-point samples confirmed the high TCE concentrations measured in the diffusion samples. TCE concentrations in these water samples were as high as 1,100 µg/L. The drive-point samples showed concentrations of nitrate plus nitrite and phosphorus at background levels (defined as the levels at KVDP-1 outside the discharge areas); boron concentrations also were at background levels, except for the two measurements from KVDP-3 and -4 that were slightly greater than the background level. Dissolved-oxygen concentrations in the TCE discharge area were greater than 5 milligrams per liter, and specific conductance was 60 to 123 microsiemens per centimeter. These low values suggested that the TCE was not associated with septic-system effluent.

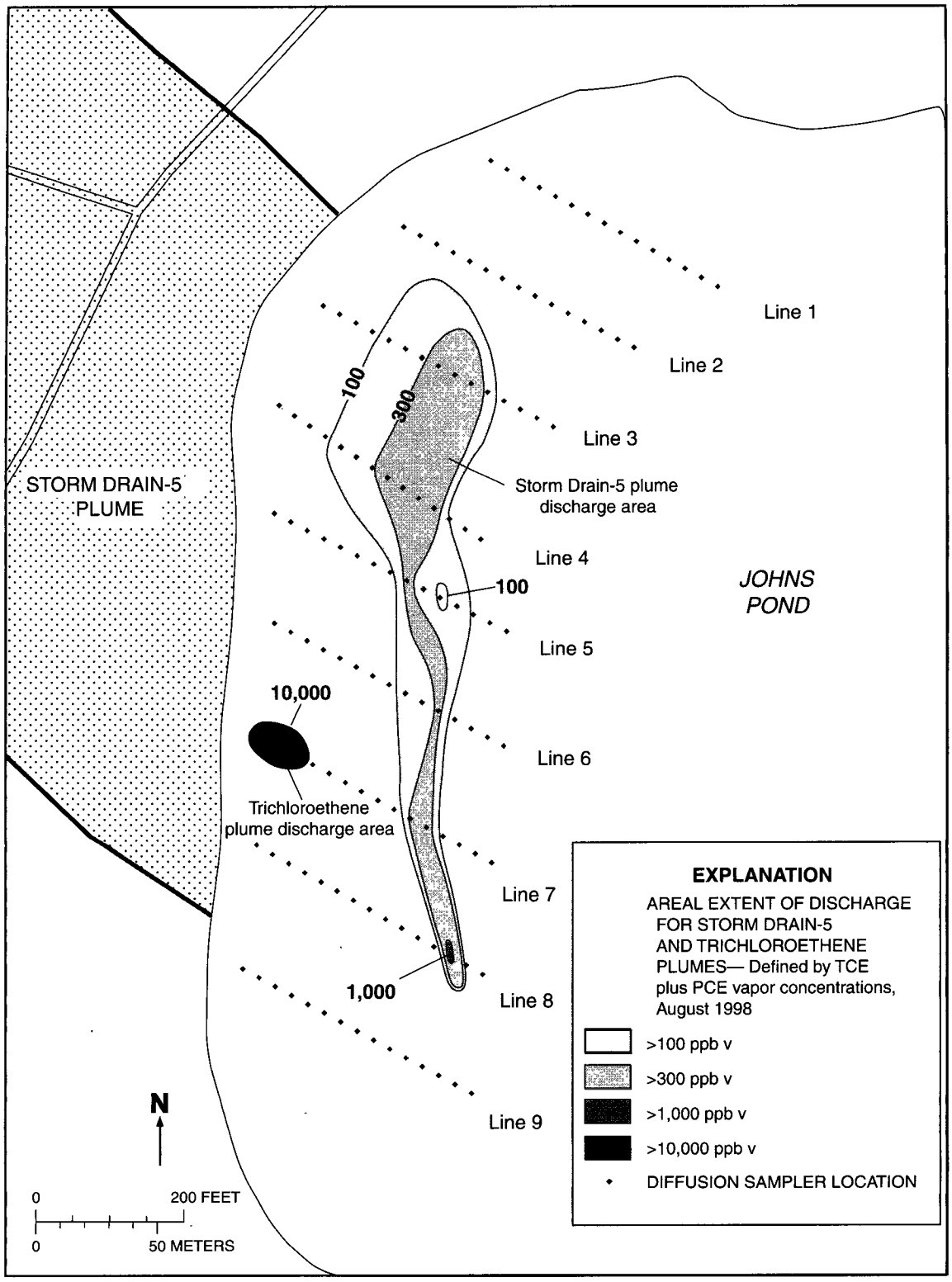


Figure 7. Discharge areas of Storm Drain-5 plume and the previously unidentified trichloroethene plume based on concentrations in vapor-diffusion samples, August 1998, Johns Pond, Cape Cod, Massachusetts (Storm Drain-5 plume path from Jacobs Engineering Group, Inc., 1998a).

Table 2. Results of analyses for volatile organic compounds, specific conductance, dissolved oxygen, and selected inorganic constituents in drive-point water samples collected near the trichloroethene plume, Johns Pond, Cape Cod, Massachusetts, September 1998

[Analysis by U.S. Environmental Protection Agency and Douglas B. Kent, U.S. Geological Survey. Locations of samplers are shown in figure 5. Samples were collected about 2 feet below the pond bottom. No., number; µg/L, microgram per liter; mg/L, milligram per liter; µS/cm, microsiemen per centimeter; <, value is less than method detection limit; --, no analysis; *, sample collected just above pond bottom; **, estimated value is below the calibration range]

Drive-point sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Trichloro-ethene (TCE) (µg/L)	1,2-Dichloro-ethene (cis- and trans-) (DCE) (µg/L)	Specific conduc-tance (µS/cm)	Dissolved oxygen (mg/L)	Nitrate plus nitrite (mg/L as N)	Boron, dissolved (mg/L)	Phos-phorus, dissolved (mg/L)
KVDP-1 (background)	41 37 57.88	70 31 29.44	<5	<5	90	2.7	1.62	0.012	<0.1
KVDP-2	41 37 56.45	70 31 29.48	1,100	<250	119	5.3	--	.006	<.1
KVDP-3	41 37 56.83	70 31 30.28	12	<5	84	10.9	.31	.018	<.1
KVDP-4	41 37 56.67	70 31 30.03	160	<25	75	8	.61	.016	<.1
KVDP-5	41 37 56.48	70 31 29.82	660	<125	113	7	.96	.007	<.1
KVDP-6	41 37 57.01	70 31 29.33	8	<5	83	15	.88	.009	<.1
KVDP-7	41 37 55.91	70 31 29.42	**4	<5	60	6.9	.44	.005	<.1
KVDP-8	41 37 56.26	70 31 29.25	910	<125	123	7.3	1.05	.005	<.1
KVDP-9*	41 37 56.45	70 31 29.48	46	12	--	--	--	--	--
KVDP-10	41 37 56.45	70 31 29.48	1,100	<250	101	7.3	1.05	.004	<.1
Trip Blank	--	--	<5	<5	--	--	--	--	--

In the vapor-diffusion samples collected in December 1998, TCE vapor concentrations as high as 42,800 ppb v were measured (table 3). This concentration is similar to the vapor concentration of 47,000 ppb v measured in the same general area (line 7 near the shore) in August 1998. The discharge area of the presumed TCE plume is only about 75 ft wide, and extends from 25 to 200 ft offshore. The area of greatest TCE concentration is located 40 to 90 ft from shore (fig. 8).

Three features of the TCE plume discharge area suggest that it represents the discharge of a different plume than the SD-5 plume. First, the maximum TCE concentration in the TCE discharge area is about 50 times greater than the maximum TCE concentration measured in the SD-5 plume discharge area. Second, the area of the highest TCE concentrations (greater than 10,000 ppb v) is separated laterally from the SD-5 plume discharge area by about 135 ft (figs. 8 and 9). Third, TCE is the predominant species detected nearshore, whereas both TCE and PCE are detected in the SD-5 plume discharge area (see lines 6–8 at distances greater than 225 ft offshore in table 6). Subsequent drilling by MMR IRP consultants in December 1998 confirmed that the TCE plume is separate from the SD-5 plume and appears to represent a finger of the Chemical Spill-10 plume that originates northwest of Johns and Ashumet Ponds. As it approaches Johns Pond, the TCE plume is 100 ft wide and extends from about 60 to 110 ft below the water table at the shoreline (Jacobs Engineering Group, 1999).

Results from Water-Diffusion Samplers

Water-diffusion samplers were installed in the July and November deployments at selected locations to determine aqueous-phase concentrations of VOCs in pore water in the pond-bottom sediments (figs. 4 and 6). Low concentrations of the compounds TCE, PCE, and 1,2-dichloroethene (DCE) were detected in the two water-diffusion samples (WD3 and WD4, fig. 4) collected from the pond-bottom sediments within the SD-5 plume discharge area in August 1998 (table 4). The other six samplers were not placed within the SD-5 plume discharge area, and VOCs were not detected in any of these samples.

Table 3. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the trichloroethene plume, Johns Pond, Cape Cod, Massachusetts, December 1998

[Analysis by U.S. Environmental Protection Agency. Locations of samplers are shown in figure 6. Detection limits vary. D, duplicate sample; ft, foot; No., number; ppb v, parts per billion by volume; --, no analysis; <, value is less than method reporting limit, *, sampler not in pond-bottom sediments; **, estimated value is below the calibration range; ***, inner bag punctured, data less reliable]

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v	Tetrachloro-ethene (PCE) (ppb v)
TCE/1298/WVD1-1	41 37 57.43	70 31 30.45	12	<5	<10
TCE/1298/WVD1-2	41 37 57.43	70 31 30.28	25	6	<10
TCE/1298/WVD1-3	41 37 57.41	70 31 29.95	50	<5	<10
TCE/1298/WVD1-4	41 37 57.40	70 31 29.62	75	<5	<10
TCE/1298/WVD1-4-D	41 37 57.40	70 31 29.62	75	<5	<10
TCE/1298/WVD1-5	41 37 57.39	70 31 29.29	100	<5	<10
TCE/1298/WVD1-6	41 37 57.38	70 31 28.97	125	<5	<10
TCE/1298/WVD1-7	41 37 57.36	70 31 28.64	150	<5	<10
TCE/1298/WVD1-8	41 37 57.35	70 31 28.31	175	<5	<10
TCE/1298/WVD1-9	41 37 57.34	70 31 27.98	200	<5	<10
TCE/1298/WVD1-10	41 37 57.33	70 31 27.65	225	5	<10
TCE/1298/WVD2-1	41 37 57.08	70 31 30.52	12	<5	<10
TCE/1298/WVD2-2	41 37 57.07	70 31 30.36	25	15	<10
TCE/1298/WVD2-3	41 37 57.07	70 31 30.19	37.5	**4	<10
TCE/1298/WVD2-4	41 37 57.06	70 31 30.03	50	<5	<10
TCE/1298/WVD2-5*	41 37 57.05	70 31 29.86	67.5	21	<10
TCE/1298/WVD2-6	41 37 57.04	70 31 29.70	75	19	<10
TCE/1298/WVD2-7*	41 37 57.04	70 31 29.54	87.5	13	<10
TCE/1298/WVD2-8	41 37 57.03	70 31 29.37	100	<5	<10
TCE/1298/WVD2-9	41 37 57.02	70 31 29.21	112.5	<5	<10
TCE/1298/WVD2-10	41 37 57.01	70 31 29.04	125	<5	<10
TCE/1298/WVD2-11	41 37 57.00	70 31 28.88	137.5	<5	<10
TCE/1298/WVD2-12	41 37 57.00	70 31 28.71	150	<5	<10
TCE/1298/WVD2-13	41 37 56.98	70 31 28.38	175	<5	<10
TCE/1298/WVD2-14***	41 37 56.96	70 31 28.06	200	<5	<10
TCE/1298/WVD2-15	41 37 56.95	70 31 27.73	225	<5	<10
TCE/1298/WVD3-1	41 37 56.84	70 31 30.50	12	<5	<10
TCE/1298/WVD3-2	41 37 56.83	70 31 30.33	25	41	<10
TCE/1298/WVD3-3*	41 37 56.82	70 31 30.17	37.5	69	<10
TCE/1298/WVD3-4	41 37 56.81	70 31 30.01	50	56	<10
TCE/1298/WVD3-5	41 37 56.80	70 31 29.84	67.5	13	<10
TCE/1298/WVD3-6	41 37 56.79	70 31 29.68	75	5	<10
TCE/1298/WVD3-7	41 37 56.78	70 31 29.51	87.5	<5	<10
TCE/1298/WVD3-7-D	41 37 56.78	70 31 29.51	87.5	<5	<10
TCE/1298/WVD3-8	41 37 56.77	70 31 29.35	100	<5	<10
TCE/1298/WVD3-9	41 37 56.76	70 31 29.18	112.5	<5	<10
TCE/1298/WVD3-10	41 37 56.75	70 31 29.02	125	<5	<10
TCE/1298/WVD3-11	41 37 56.74	70 31 28.85	137.5	<5	<10
TCE/1298/WVD3-12	41 37 56.74	70 31 28.69	150	<5	<10
TCE/1298/WVD3-13	41 37 56.72	70 31 28.36	175	50	<10
TCE/1298/WVD3-14	41 37 56.70	70 31 28.03	200	5	<10
TCE/1298/WVD3-15	41 37 56.68	70 31 27.70	225	15	<10

Table 3. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the trichloroethene plume, Johns Pond, Cape Cod, Massachusetts, December 1998—*Continued*

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v	Tetrachloro-ethene (PCE) (ppb v)
TCE/1298/WVD4-1	41 37 56.60	70 31 30.58	12	<5	<10
TCE/1298/WVD4-2	41 37 56.59	70 31 30.42	25	75	<10
TCE/1298/WVD4-3	41 37 56.58	70 31 30.26	37.5	7,680	<200
TCE/1298/WVD4-4	41 37 56.58	70 31 30.09	50	41,300	<200
TCE/1298/WVD4-5	41 37 56.57	70 31 29.93	67.5	37,600	<200
TCE/1298/WVD4-5-D	41 37 56.57	70 31 29.93	67.5	42,800	<200
TCE/1298/WVD4-6	41 37 56.56	70 31 29.76	75	6,310	<200
TCE/1298/WVD4-7	41 37 56.55	70 31 29.60	87.5	1,580	<50
TCE/1298/WVD4-8***	41 37 56.55	70 31 29.43	100	389	<40
TCE/1298/WVD4-9	41 37 56.54	70 31 29.27	112.5	430	<40
TCE/1298/WVD4-10	41 37 56.53	70 31 29.10	125	101	<10
TCE/1298/WVD4-11	41 37 56.52	70 31 28.94	137.5	133	<10
TCE/1298/WVD4-12	41 37 56.52	70 31 28.77	150	7,460	<50
TCE/1298/WVD4-13	41 37 56.50	70 31 28.45	175	220	<10
TCE/1298/WVD4-14	41 37 56.49	70 31 28.12	200	2,170	10**
TCE/1298/WVD4-15*	41 37 56.47	70 31 27.79	225	6	<10
TCE/1298/WVD5-1	41 37 56.36	70 31 30.62	12	7	<10
TCE/1298/WVD5-2	41 37 56.35	70 31 30.45	25	9	<10
TCE/1298/WVD5-3	41 37 56.34	70 31 30.29	37.5	682	<80
TCE/1298/WVD5-4	41 37 56.33	70 31 30.12	50	9,620	<200
TCE/1298/WVD5-5	41 37 56.32	70 31 29.96	67.5	23,400	<200
TCE/1298/WVD5-6	41 37 56.31	70 31 29.79	75	21,200	<200
TCE/1298/WVD5-7	41 37 56.31	70 31 29.63	87.5	13,200	<200
TCE/1298/WVD5-7-D	41 37 56.31	70 31 29.63	87.5	12,800	<200
TCE/1298/WVD5-8	41 37 56.30	70 31 29.46	100	9,470	<200
TCE/1298/WVD5-9	41 37 56.29	70 31 29.30	112.5	4,730	<80
TCE/1298/WVD5-10	41 37 56.28	70 31 29.14	125	738	<80
TCE/1298/WVD5-11	41 37 56.27	70 31 28.97	137.5	11	<10
TCE/1298/WVD5-11-D	41 37 56.27	70 31 28.97	137.5	11	<10
TCE/1298/WVD5-12	41 37 56.26	70 31 28.81	150	<5	<10
TCE/1298/WVD5-13	41 37 56.24	70 31 28.48	175	71	<15
TCE/1298/WVD5-14	41 37 56.23	70 31 28.15	200	5	<10
TCE/1298/WVD5-15*	41 37 56.21	70 31 27.82	225	<5	<10

Table 3. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the trichloroethene plume, Johns Pond, Cape Cod, Massachusetts, December 1998—*Continued*

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v	Tetrachloro-ethene (PCE) (ppb v)
TCE/1298/WVD6-1	41 37 56.11	70 31 30.63	12	<5	<10
TCE/1298/WVD6-2	41 37 56.10	70 31 30.46	25	12	<10
TCE/1298/WVD6-3	41 37 56.09	70 31 30.30	37.5	19	<10
TCE/1298/WVD6-4	41 37 56.08	70 31 30.14	50	118	<10
TCE/1298/WVD6-4-D	41 37 56.08	70 31 30.14	50	277	<10
TCE/1298/WVD6-5	41 37 56.08	70 31 29.97	67.5	353	<40
TCE/1298/WVD6-6	41 37 56.07	70 31 29.81	75	402	<40
TCE/1298/WVD6-7	41 37 56.06	70 31 29.64	87.5	346	<40
TCE/1298/WVD6-8	41 37 56.05	70 31 29.48	100	150	<15
TCE/1298/WVD6-9	41 37 56.04	70 31 29.31	112.5	<5	<10
TCE/1298/WVD6-9-D	41 37 56.04	70 31 29.31	112.5	<5	<10
TCE/1298/WVD6-10	41 37 56.04	70 31 29.15	125	<5	<10
TCE/1298/WVD6-11	41 37 56.03	70 31 28.98	137.5	14	<10
TCE/1298/WVD6-12	41 37 56.02	70 31 28.82	150	5	<10
TCE/1298/WVD6-13	41 37 56.00	70 31 28.49	175	<5	<10
TCE/1298/WVD6-14	41 37 55.99	70 31 28.16	200	<5	<10
TCE/1298/WVD6-15	41 37 55.97	70 31 27.83	225	<5	<10
TCE/1298/WVD7-1	41 37 55.85	70 31 30.66	12	<5	<10
TCE/1298/WVD7-2	41 37 55.84	70 31 30.50	25	17	<10
TCE/1298/WVD7-3	41 37 55.83	70 31 30.33	37.5	38	<10
TCE/1298/WVD7-4*	41 37 55.81	70 31 30.17	50	29	<10
TCE/1298/WVD7-5	41 37 55.80	70 31 30.00	67.5	<5	<10
TCE/1298/WVD7-6	41 37 55.79	70 31 29.84	75	<5	<10
TCE/1298/WVD7-7	41 37 55.78	70 31 29.67	87.5	<5	<10
TCE/1298/WVD7-7-D	41 37 55.78	70 31 29.67	87.5	<5	<10
TCE/1298/WVD7-8	41 37 55.77	70 31 29.51	100	<5	<10
TCE/1298/WVD7-9	41 37 55.75	70 31 29.35	112.5	<5	<10
TCE/1298/WVD7-10	41 37 55.74	70 31 29.18	125	<5	<10
TCE/1298/WVD7-11	41 37 55.73	70 31 29.02	137.5	5	<10
TCE/1298/WVD7-12	41 37 55.72	70 31 28.85	150	6	<10
TCE/1298/WVD7-13	41 37 55.69	70 31 28.52	175	<5	<10
TCE/1298/WVD7-14	41 37 55.67	70 31 28.19	200	<5	<10
TCE/1298/WVD7-15	41 37 55.65	70 31 27.87	225	<5	<10
TCE/1298/WVD8-1	41 37 55.48	70 31 30.67	12	<5	<10
TCE/1298/WVD8-2	41 37 55.47	70 31 30.50	25	9	<10
TCE/1298/WVD8-3	41 37 55.45	70 31 30.17	50	7	<10
TCE/1298/WVD8-4	41 37 55.43	70 31 29.84	75	<5	<10
TCE/1298/WVD8-5	41 37 55.41	70 31 29.51	100	<5	<10
TCE/1298/WVD8-5-D	41 37 55.41	70 31 29.51	100	<5	<10
TCE/1298/WVD8-6	41 37 55.39	70 31 29.19	125	<5	<10
TCE/1298/WVD8-7	41 37 55.37	70 31 28.86	150	5	<10
TCE/1298/WVD8-8	41 37 55.36	70 31 28.53	175	<5	<10
TCE/1298/WVD8-9	41 37 55.34	70 31 28.20	200	<5	<10
TCE/1298/WVD8-10	41 37 55.32	70 31 27.87	225	<5	<10

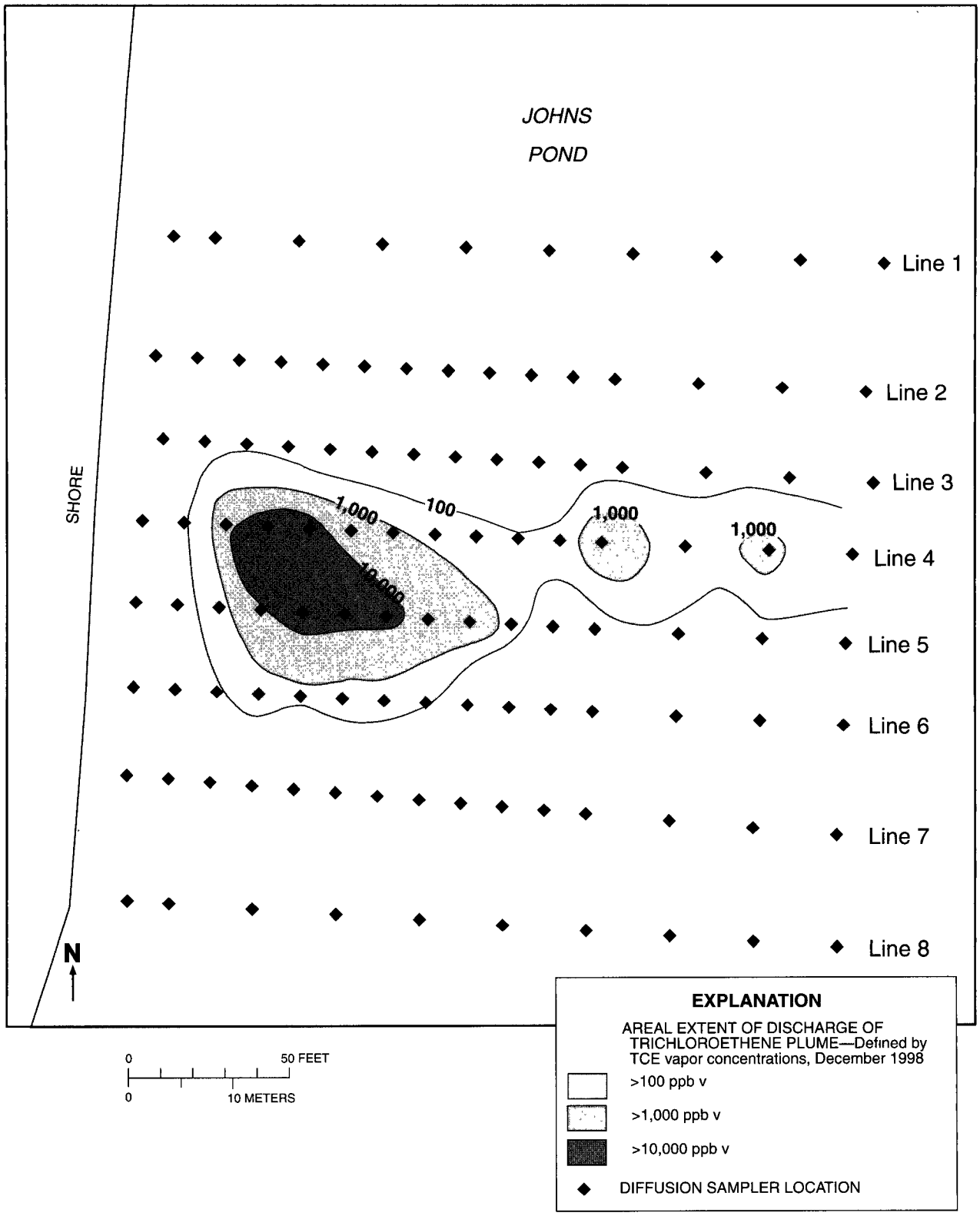


Figure 8. Discharge area of the trichloroethene plume based on concentrations in vapor-diffusion samples, December 1998, Johns Pond, Cape Cod, Massachusetts.

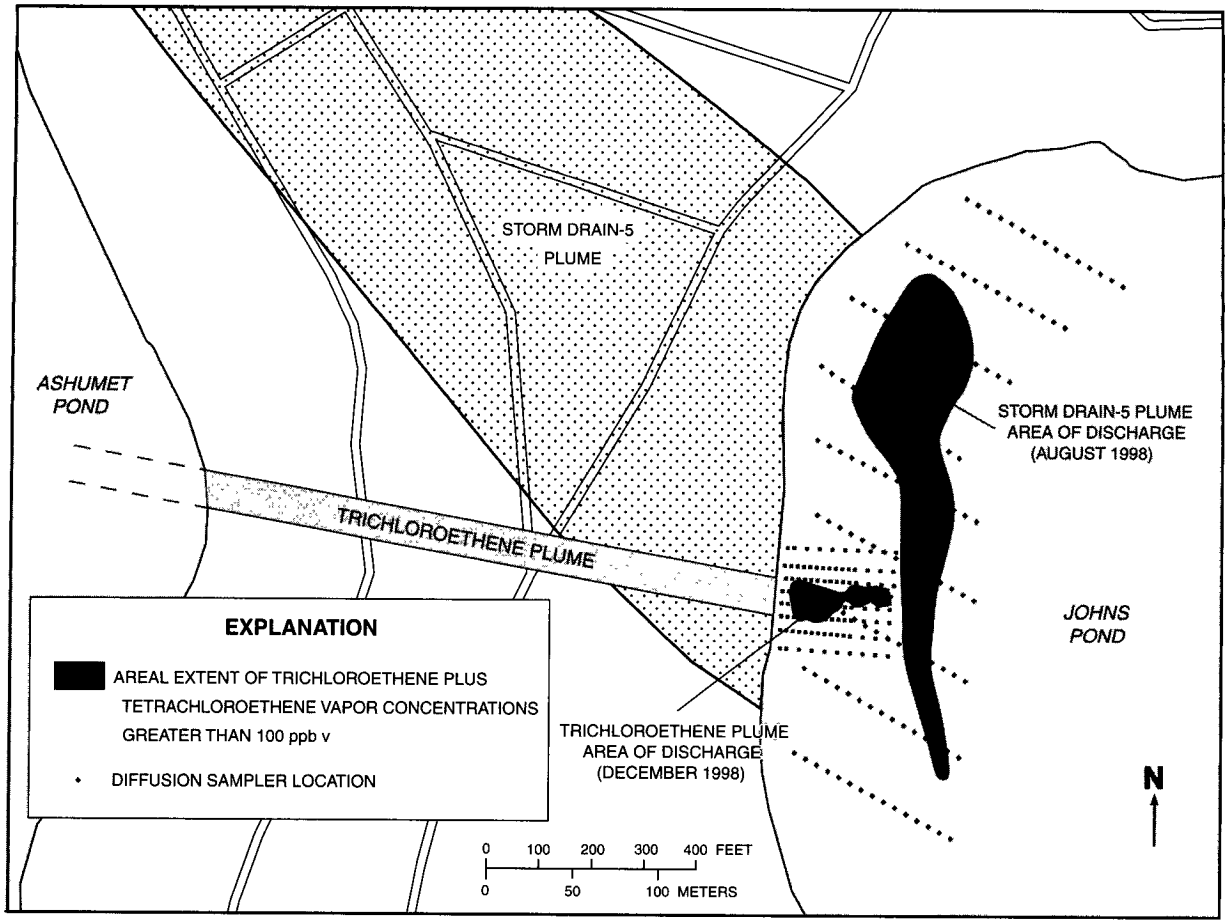


Figure 9. Discharge areas and plume paths of the Storm Drain-5 and trichloroethene plumes, August and December 1998, Johns Pond, Cape Cod, Massachusetts (plume paths from Jacobs Engineering Group, Inc., 1999).

TCE was detected in the 13 water-diffusion samples collected from the pond-bottom sediments within the TCE plume discharge area in December 1998 (fig. 6, table 4). The TCE concentrations in the water-diffusion samples ranged from 2 to 1,200 µg/L. The other five water-diffusion samplers were not placed within the TCE discharge area, and TCE was not detected in any of these samples. The relationship between TCE concentrations measured in the vapor-diffusion samples (in ppb v) and the corresponding water-diffusion samples (in µg/L) for December 1998 is shown in figure 10. The vapor concentrations in ppb v were 19 to 75 times greater than the corresponding water concentrations in µg/L and averaged about 35 times greater. Because the equilibrium partitioning of VOCs between water and vapor varies as a function of temperature and pressure, the relationship cited here may not be applicable to other sites or other sampling events at this site.

Results from Water-Column Samplers

Water-column samplers were installed in the July and November deployments at selected locations to determine if contaminants entering the pond through the pond bottom were being diluted in the pond water. An estimated 11 ppb v of TCE was detected in each of the water-column diffusion samples WC1b, WC1c, and WC1d set above the SD-5 plume discharge area in August 1998 (table 5, fig. 4). At this location the sample from the adjacent vapor-diffusion sampler in the pond-bottom sediments (SD-5/0898/WVD4-8) contained TCE and PCE at 250 and 34 ppb v, respectively. Thus, the TCE concentration in the pond water just above the bottom was about 20 times less than the concentration in the corresponding vapor-diffusion sampler emplaced in the pond-bottom sediments. The WC2 water-column samplers were not installed in the discharge area, and VOCs were not detected in any samples.

Table 4. Results of analyses for volatile organic compounds in water-diffusion and adjacent vapor-diffusion samples collected from pore water in pond-bottom sediments, Johns Pond, Cape Cod, Massachusetts, August and December 1998

[Analysis by U.S. Environmental Protection Agency. Locations of samplers are shown in figures 4 and 6. Coordinates of vapor-diffusion samplers are shown in tables 3 and 6. Detection limits vary. D, duplicate sample; No., number; ppb v, parts per billion by volume; µg/L, micrograms per liter; <, value is less than method reporting limit; *, sampler not in pond-bottom sediments; ***, inner bag punctured]

Water-diffusion sampler No.	Aqueous phase			Adjacent vapor-diffusion sampler No.	Vapor phase	
	Trichloroethene (TCE) (µg/L)	Tetrachloroethene (PCE) (µg/L)	1,2-dichloroethene (DCE) (µg/L)		Trichloroethene (TCE) (ppb v)	Tetrachloroethene (PCE) (ppb v)
Storm Drain-5 Plume, August 1998						
WD1	<1	<1	<1	SD-5/0898/WVD1-11*	<12	<18
WD2	<1	<1	<1	SD-5/0898/WVD2-5	13	20
WD3	5	1	1	SD-5/0898/WVD3-9	680	96
WD4	5	<1	2	SD-5/0898/WVD4-8	250	34
				SD-5/0898/WVD4-8-D	215	38
WD5	<1	<1	<1	SD-5/0898/WVD5-15	<12	<18
WD6	<1	<1	<1	SD-5/0898/WVD6-6	<12	<18
WD8	<1	<1	<1	SD-5/0898/WVD8-8	39	<18
WD9	<1	<1	<1	SD-5/0898/WVD9-3	<12	<18
Trip Blank	<1	<1	<1			
Water Blank	<1	<1	<1			
Trichloroethene Plume, December 1998						
WD3-4	2	<5	<5	TCE/1298/WVD3-4	56	<10
WD3-6	<5	<5	<5	TCE/1298/WVD3-6	5	<10
WD4-3	180	<50	<50	TCE/1298/WVD4-3	7,680	<200
WD4-4	1,200	<200	<200	TCE/1298/WVD4-4	41,300	<200
WD4-6	260	<50	<50	TCE/1298/WVD4-6	6,310	<200
WD4-8	17	<5	<5	TCE/1298/WVD4-8***	389	<40
WD4-10	2	<5	<5	TCE/1298/WVD4-10	101	<10
WD5-4	370	<50	<50	TCE/1298/WVD5-4	9,620	<200
WD5-6	690	<100	<100	TCE/1298/WVD5-6	21,200	<200
WD5-8	260	<50	<50	TCE/1298/WVD5-8	9,470	<200
WD5-10	38	<5	<5	TCE/1298/WVD5-10	738	<80
WD6-4	4	<5	<5	TCE/1298/WVD6-4	118	<10
				TCE/1298/WVD6-4-D	277	<10
WD6-6	13	<5	<5	TCE/1298/WVD6-6	402	<40
WD6-8	2	<5	<5	TCE/1298/WVD6-8	150	<15
WD6-10	<5	<5	<5	TCE/1298/WVD6-10	<5	<10
WD6-12	<5	<5	<5	TCE/1298/WVD6-12	5	<10
WD8-8	<5	<5	<5	TCE/1298/WVD8-8	<5	<10
WD8-10	<5	<5	<5	TCE/1298/WVD8-10	<5	<10
Trip Blank	<5	<5	<5			
Water Blank	<5	<5	<5			

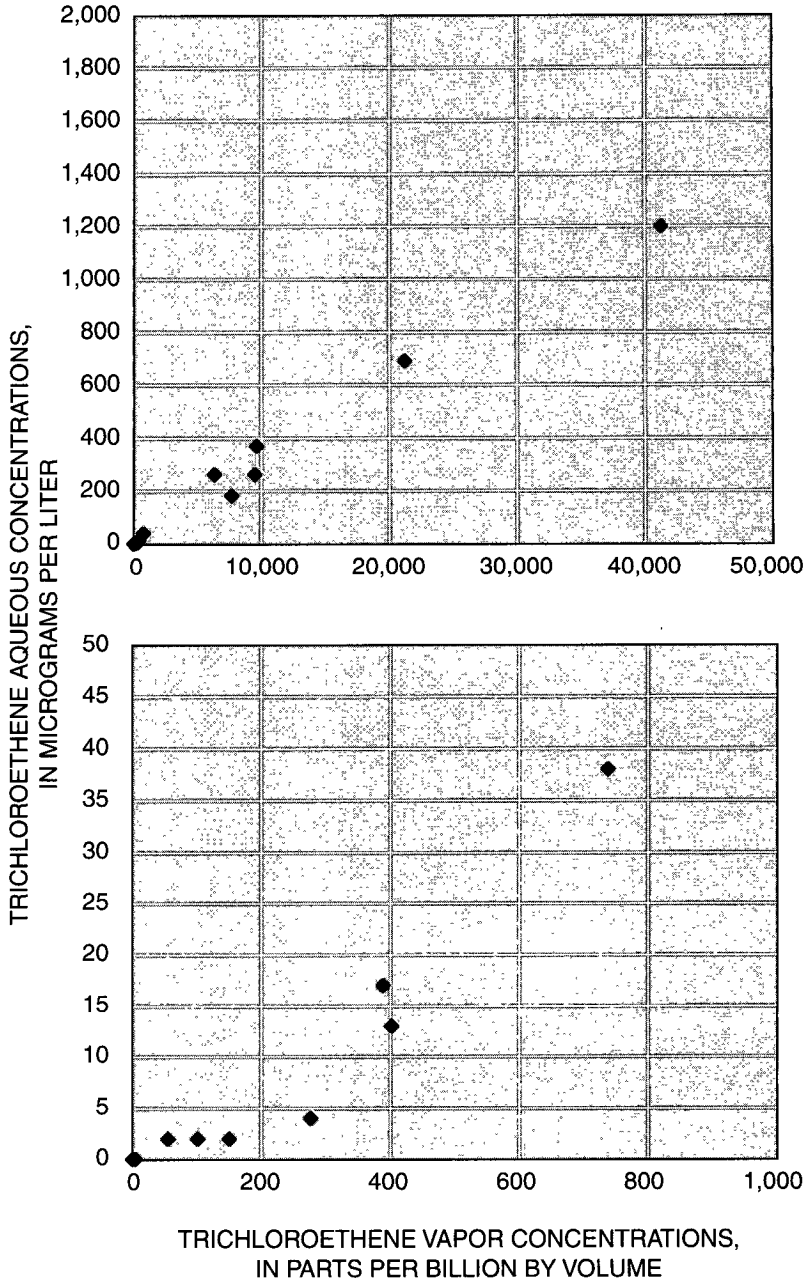


Figure 10. Relation between trichloroethene concentrations in vapor- and water-diffusion samples collected in December 1998, Johns Pond, Cape Cod, Massachusetts.

Table 5. Results of analyses for volatile organic compounds in diffusion samples collected from the pond water column and adjacent pond-bottom sediments, Johns Pond, Cape Cod, Massachusetts, August and December 1998

[Analysis by U.S. Environmental Protection Agency. Locations of samplers are shown in figure 4 and 6. Detection limits vary. No., number; ft, foot; ppb v, parts per billion by volume; µg/L, microgram per liter, --, no analysis; <, value is less than method reporting limit; **, estimated value is below the calibration range; ***, inner bag punctured]

Water column sampler No.	Height above pond bottom (ft)	Vapor phase		Aqueous phase			Adjacent sampler in pond-bottom sediments	Vapor phase	
		Trichloroethene (TCE) (ppb v)	Tetrachloroethene (PCE) (ppb v)	Trichloroethene (TCE) (µg/L)	Tetrachloroethene (PCE) (µg/L)	1,2-dichloroethene (DCE) (µg/L)		Trichloroethene (TCE) (ppb v)	Tetrachloroethene (PCE) (ppb v)
Storm Drain-5, August 1998									
WC1a	0.2	<12	<18	--	--	--	SD-5/0898/WVD4-8	250	34
WC1b	.6	**11	<18	--	--	--	SD-5/0898/WVD4-8	250	34
WC1c	1.0	**11	<18	--	--	--	SD-5/0898/WVD4-8	250	34
WC1d	2.0	**11	<18	--	--	--	SD-5/0898/WVD4-8	250	34
WC2a	.2	<12	<18	--	--	--	SD-5/0898/WVD4-14	16	32
WC2b	.6	<12	<18	--	--	--	SD-5/0898/WVD4-14	16	32
WC2c	1.0	<12	<18	--	--	--	SD-5/0898/WVD4-14	16	32
WC2d	2.0	<12	<18	--	--	--	SD-5/0898/WVD4-14	16	32
Trichloroethene Plume, December 1998									
WC4-8a	.2	321	<40	--	--	--	TCE/1298/WVD4-8***	389	<40
WC4-8b	.6	39	<10	--	--	--	TCE/1298/WVD4-8***	389	<40
WC4-8c	1.0	32	<10	--	--	--	TCE/1298/WVD4-8***	389	<40
WC4-8d	2.0	24	<10	--	--	--	TCE/1298/WVD4-8***	389	<40
WC5-8a	.2	329	<10	8	<5	13	TCE/1298/WVD5-8	9,470	<200
WC5-8b	.6	34	<10	--	--	--	TCE/1298/WVD5-8	9,470	<200
WC5-8c	1.0	30	<10	<5	<5	<5	TCE/1298/WVD5-8	9,470	<200
WC5-8d	2.0	26	<10	--	--	--	TCE/1298/WVD5-8	9,470	<200

More than 300 ppb v of TCE was detected in samples from water-column samplers WC4-8a and WC5-8a set 0.2 ft above the pond bottom (table 5, fig. 6) in the TCE plume discharge area in December 1998. Samples from the other three samplers on the PVC stand at WC4-8 and WC5-8 (set 0.6, 1.0, and 2.0 ft above the pond bottom) had TCE vapor concentrations ranging from 24 to 39 ppb v. The adjacent vapor-diffusion samplers in the pond-bottom sediments (TCE/1298/WVD4-8 and TCE/1298/WVD5-8) also contained TCE. Vapor sampler TCE/1298/WVD4-8 contained TCE at 389 ppb v; however, the inner bag had been punctured and vapors could have escaped before the bottle was capped. Vapor sampler TCE/1298/WVD5-8 contained TCE at 9,470 ppb v. Thus, at site TCE/1298/WVD5-8, the TCE vapor concentration in the pond water just above the bottom was about 30 times less than the concentration in the corresponding vapor-diffusion sampler emplaced in the pond-bottom sediments. Two water-diffusion samplers were installed on the WC5-8 stand at 0.2 and 1.0 ft above the pond bottom. Aqueous-phase TCE and DCE were detected at low concentrations in sample WC5-8a (non-detect to 13 µg/L) at a height of 0.2 ft above the pond bottom. These results indicate that contaminants that enter the pond through the pond bottom are diluted by the pond water just above the pond bottom.

SUMMARY

Volatile organic compounds (VOCs) are present in the Storm Drain-5 (SD-5) ground-water plume, which extends from the Massachusetts Military Reservation (MMR) toward Johns Pond, Mashpee, Massachusetts. The Air Force Center for Environmental Excellence (AFCEE) sought to confirm

that contaminants from the SD-5 plume are discharging into Johns Pond. In 1998, the U.S. Geological Survey, in cooperation with AFCEE and the U.S. Environmental Protection Agency, used diffusion samplers to determine the location and concentrations of VOCs in pore water in the bottom sediments of Johns Pond near the suspected discharge area of the SD-5 plume.

An array of diffusion samplers was buried by divers in the bottom of Johns Pond to delineate the pond-bottom discharge area based on vapor concentrations of trichloroethene (TCE) and tetrachloroethene (PCE). The SD-5 plume discharge area identified from the diffusion-sampler results is about 1,000 ft wide and extends from about 100 to 350 ft from shore. Total vapor concentrations of TCE and PCE in the SD-5 plume discharge area were as great as 1,105 parts per billion by volume.

A previously unidentified area of TCE was found near the shore during the delineation of the SD-5 plume discharge area. TCE vapor concentrations in this area were about 50 times greater than the maximum TCE concentration measured in the SD-5 plume discharge area. TCE concentrations in water samples collected from a drive-point sampler in this area were as high as 1,100 µg/L. A second array of diffusion samplers was used to delineate the TCE discharge area. The area is about 75 ft wide and extends from 25 to 200 ft from shore. Subsequent drilling into the pond bottom and onshore by MMR IRP consultants confirmed that the area of high TCE is associated with a distinct TCE plume that is not related to the SD-5 plume.

TCE concentrations in µg/L in water-diffusion samples from 15 selected sites in the two discharge areas were about 35 times lower than the TCE concentrations in ppb v in corresponding vapor-diffusion samples. The difference in values is due to the volatile nature of TCE and the different units of measure. The relation may not be applicable to other sites because of local differences in temperature and pressure.

TCE was detected in diffusion samplers set in the pond water column above the plume-discharge areas, but the TCE concentrations were 20 to 30 times lower than the corresponding levels in diffusion samplers buried in the pond bottom. The low, but detectable, levels found in the water-column samples indicate that the plume waters become diluted a short distance above the pond bottom.

Diffusion samplers installed by divers in water up to 30 ft deep at two sites in Johns Pond were used successfully to delineate the discharge areas of two plumes, one of which was first detected during this effort. Diffusion samplers proved to be a valuable tool in the investigation of the fate of ground-water contaminant plumes as they discharge into ponds.

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TABLE 6

Table 6. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the Storm Drain-5 plume, Johns Pond, Cape Cod, Massachusetts, August 1998

[Analysis by U.S. Environmental Protection Agency. Locations of samplers are shown in figure 4. Detection limits vary. D, duplicate sample; No., number; ft, feet; ppb v, parts per billion by volume; --, sampler lost; <, value is less than method reporting limit; *, sampler found floating above pond bottom, data less reliable; **, estimated value is below the calibration range]

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v)	Tetrachloro-ethene (PCE) (ppb v)
SD-5/0898/WVD1-2	41 38 04.15	70 31 25.76	75	--	--
SD-5/0898/WVD1-3	41 38 04.03	70 31 25.47	100	--	--
SD-5/0898/WVD1-4	41 38 03.90	70 31 25.19	125	<12	<18
SD-5/0898/WVD1-5	41 38 03.78	70 31 24.90	150	<12	<18
SD-5/0898/WVD1-6	41 38 03.66	70 31 24.62	175	--	--
SD-5/0898/WVD1-7	41 38 03.54	70 31 24.33	200	<12	<18
SD-5/0898/WVD1-8	41 38 03.41	70 31 24.04	225	<12	<18
SD-5/0898/WVD1-9	41 38 03.29	70 31 23.76	250	<12	<18
SD-5/0898/WVD1-9-D	41 38 03.29	70 31 23.76	250	<12	<18
SD-5/0898/WVD1-10	41 38 03.17	70 31 23.47	275	<12	<18
SD-5/0898/WVD1-11*	41 38 03.05	70 31 23.19	300	<12	<18
SD-5/0898/WVD1-12	41 38 02.92	70 31 22.90	325	<12	<18
SD-5/0898/WVD1-13	41 38 02.80	70 31 22.62	350	<12	<18
SD-5/0898/WVD1-14	41 38 02.68	70 31 22.33	375	<12	<18
SD-5/0898/WVD1-15	41 38 02.56	70 31 22.04	400	**7	<18
SD-5/0898/WVD1-16	41 38 02.43	70 31 21.76	425	--	--
SD-5/0898/WVD2-2	41 38 03.28	70 31 27.31	75	14	<18
SD-5/0898/WVD2-3	41 38 03.16	70 31 27.02	100	14	**12
SD-5/0898/WVD2-4	41 38 03.05	70 31 26.73	125	<12	<18
SD-5/0898/WVD2-5	41 38 02.93	70 31 26.44	150	13	20
SD-5/0898/WVD2-6	41 38 02.81	70 31 26.15	175	<12	<18
SD-5/0898/WVD2-7	41 38 02.69	70 31 25.87	200	<12	<18
SD-5/0898/WVD2-8	41 38 02.58	70 31 25.58	225	<12	<18
SD-5/0898/WVD2-9	41 38 02.46	70 31 25.29	250	<12	<18
SD-5/0898/WVD2-10	41 38 02.34	70 31 25.00	275	<12	**9
SD-5/0898/WVD2-11	41 38 02.22	70 31 24.71	300	<12	<18
SD-5/0898/WVD2-12	41 38 02.11	70 31 24.42	325	<12	<18
SD-5/0898/WVD2-13	41 38 01.99	70 31 24.13	350	<12	26
SD-5/0898/WVD2-14	41 38 01.87	70 31 23.84	375	<12	26
SD-5/0898/WVD2-14-D	41 38 01.87	70 31 23.84	375	<12	**17
SD-5/0898/WVD2-15	41 38 01.75	70 31 23.55	400	<12	**9
SD-5/0898/WVD2-16	41 38 01.64	70 31 23.26	425	**7	<18

Table 6. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the Storm Drain-5 plume, Johns Pond, Cape Cod, Massachusetts, August 1998—*Continued*

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v)	Tetrachloro-ethene (PCE) (ppb v)
SD-5/0898/WVD3-2	41 38 02.25	70 31 28.75	75	**10	<18
SD-5/0898/WVD3-3	41 38 02.13	70 31 28.47	100	14	<18
SD-5/0898/WVD3-4	41 38 02.01	70 31 28.18	125	**9	<18
SD-5/0898/WVD3-5	41 38 01.90	70 31 27.89	150	<12	<18
SD-5/0898/WVD3-6	41 38 01.78	70 31 27.60	175	277	16
SD-5/0898/WVD3-7	41 38 01.66	70 31 27.31	200	120	36
SD-5/0898/WVD3-8	41 38 01.54	70 31 27.02	225	109	24
SD-5/0898/WVD3-9	41 38 01.43	70 31 26.73	250	680	96
SD-5/0898/WVD3-10	41 38 01.31	70 31 26.44	275	890	36
SD-5/0898/WVD3-11	41 38 01.19	70 31 26.15	300	347	215
SD-5/0898/WVD3-12	41 38 01.07	70 31 25.86	325	166	78
SD-5/0898/WVD3-12-D	41 38 01.07	70 31 25.86	325	160	72
SD-5/0898/WVD3-13	41 38 00.96	70 31 25.57	350	<12	<18
SD-5/0898/WVD3-14	41 38 00.84	70 31 25.28	375	**10	<18
SD-5/0898/WVD3-15	41 38 00.72	70 31 24.99	400	12	<18
SD-5/0898/WVD3-16*	41 38 00.60	70 31 24.70	425	12	<18
SD-5/0898/WVD4-2	41 38 00.93	70 31 29.56	75	<12	<18
SD-5/0898/WVD4-3	41 38 00.79	70 31 29.28	100	<12	<18
SD-5/0898/WVD4-3-D	41 38 00.79	70 31 29.28	100	**10	<18
SD-5/0898/WVD4-4	41 38 00.65	70 31 29.01	125	<12	38
SD-5/0898/WVD4-5	41 38 00.51	70 31 28.74	150	--	--
SD-5/0898/WVD4-6	41 38 00.38	70 31 28.46	175	<12	134
SD-5/0898/WVD4-7	41 38 00.24	70 31 28.19	200	--	--
SD-5/0898/WVD4-8	41 38 00.10	70 31 27.92	225	250	34
SD-5/0898/WVD4-8-D	41 38 00.10	70 31 27.92	225	215	38
SD-5/0898/WVD4-9	41 37 59.96	70 31 27.65	250	--	--
SD-5/0898/WVD4-10	41 37 59.82	70 31 27.38	275	610	145
SD-5/0898/WVD4-11	41 37 59.68	70 31 27.10	300	748	78
SD-5/0898/WVD4-12	41 37 59.55	70 31 26.83	325	416	84
SD-5/0898/WVD4-13	41 37 59.41	70 31 26.56	350	42	31
SD-5/0898/WVD4-14	41 37 59.27	70 31 26.28	375	16	32
SD-5/0898/WVD4-15	41 37 59.13	70 31 26.01	400	15	<18

Table 6. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the Storm Drain-5 plume, Johns Pond, Cape Cod, Massachusetts, August 1998—*Continued*

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v)	Tetrachloro-ethene (PCE) (ppb v)
SD-5/0898/WVD5-2	41 37 59.50	70 31 29.66	75	--	--
SD-5/0898/WVD5-3	41 37 59.39	70 31 29.37	100	<12	29
SD-5/0898/WVD5-4	41 37 59.28	70 31 29.08	125	<12	19
SD-5/0898/WVD5-5	41 37 59.16	70 31 28.78	150	<12	**8
SD-5/0898/WVD5-6	41 37 59.05	70 31 28.49	175	<12	**12
SD-5/0898/WVD5-6-D	41 37 59.05	70 31 28.49	175	<12	**12
SD-5/0898/WVD5-7	41 37 58.93	70 31 28.20	200	<12	<18
SD-5/0898/WVD5-8	41 37 58.82	70 31 27.91	225	<12	<18
SD-5/0898/WVD5-9	41 37 58.71	70 31 27.62	250	43	19
SD-5/0898/WVD5-10	41 37 58.59	70 31 27.33	275	256	59
SD-5/0898/WVD5-11	41 37 58.48	70 31 27.03	300	100	150
SD-5/0898/WVD5-12	41 37 58.36	70 31 26.74	325	25	46
SD-5/0898/WVD5-13	41 37 58.25	70 31 26.45	350	44	243
SD-5/0898/WVD5-14	41 37 58.14	70 31 26.16	375	21	67
SD-5/0898/WVD5-15	41 37 58.02	70 31 25.87	400	<12	<18
SD-5/0898/WVD5-16	41 37 57.91	70 31 25.57	425	<12	<18
SD-5/0898/WVD6-2*	41 37 58.05	70 31 29.68	75	<12	<18
SD-5/0898/WVD6-3	41 37 57.93	70 31 29.39	100	<12	<18
SD-5/0898/WVD6-4	41 37 57.81	70 31 29.10	125	<12	<18
SD-5/0898/WVD6-5	41 37 57.69	70 31 28.81	150	<12	<18
SD-5/0898/WVD6-6	41 37 57.57	70 31 28.52	175	<12	<18
SD-5/0898/WVD6-7	41 37 57.45	70 31 28.24	200	<12	<18
SD-5/0898/WVD6-8	41 37 57.33	70 31 27.95	225	<12	<18
SD-5/0898/WVD6-9	41 37 57.21	70 31 27.66	250	<12	21
SD-5/0898/WVD6-9-D	41 37 57.21	70 31 27.66	250	<12	21
SD-5/0898/WVD6-10	41 37 57.09	70 31 27.37	275	82	123
SD-5/0898/WVD6-11	41 37 56.97	70 31 27.08	300	19	190
SD-5/0898/WVD6-12	41 37 56.86	70 31 26.80	325	202	112
SD-5/0898/WVD6-13	41 37 56.74	70 31 26.51	350	<12	<18
SD-5/0898/WVD6-14	41 37 56.62	70 31 26.22	375	<12	<18
SD-5/0898/WVD6-15	41 37 56.50	70 31 25.93	400	<12	<18
SD-5/0898/WVD6-16	41 37 56.38	70 31 25.64	425	<12	<18

Table 6. Results of analyses for volatile organic compounds in vapor-diffusion samples collected from pore water in pond-bottom sediments near the Storm Drain-5 plume, Johns Pond, Cape Cod, Massachusetts, August 1998—*Continued*

Vapor-diffusion sampler No.	Latitude ° ′ ″	Longitude ° ′ ″	Distance from shore (ft)	Trichloro-ethene (TCE) (ppb v)	Tetrachloro-ethene (PCE) (ppb v)
SD-5/0898/WVD7-2	41 37 56.53	70 31 29.88	75	23,000	90
SD-5/0898/WVD7-3	41 37 56.41	70 31 29.60	100	43,000	<900
SD-5/0898/WVD7-4	41 37 56.29	70 31 29.31	125	47,000	<900
SD-5/0898/WVD7-5	41 37 56.16	70 31 29.03	150	24	<18
SD-5/0898/WVD7-6	41 37 56.04	70 31 28.74	175	24	<18
SD-5/0898/WVD7-7	41 37 55.92	70 31 28.45	200	<12	<18
SD-5/0898/WVD7-8	41 37 55.80	70 31 28.17	225	<12	<18
SD-5/0898/WVD7-9	41 37 55.67	70 31 27.88	250	<12	<18
SD-5/0898/WVD7-10	41 37 55.55	70 31 27.60	275	<12	<18
SD-5/0898/WVD7-11	41 37 55.43	70 31 27.31	300	166	167
SD-5/0898/WVD7-11-D	41 37 55.43	70 31 27.31	300	166	193
SD-5/0898/WVD7-12	41 37 55.31	70 31 27.02	325	142	316
SD-5/0898/WVD7-13	41 37 55.19	70 31 26.74	350	20	<18
SD-5/0898/WVD7-14	41 37 55.06	70 31 26.45	375	--	--
SD-5/0898/WVD7-15	41 37 54.94	70 31 26.17	400	--	--
SD-5/0898/WVD7-16	41 37 54.82	70 31 25.88	425	--	--
SD-5/0898/WVD8-2*	41 37 55.10	70 31 30.04	75	<12	<18
SD-5/0898/WVD8-3	41 37 54.97	70 31 29.75	100	<12	<18
SD-5/0898/WVD8-4	41 37 54.85	70 31 29.47	125	<12	<18
SD-5/0898/WVD8-5	41 37 54.72	70 31 29.19	150	<12	<18
SD-5/0898/WVD8-6*	41 37 54.60	70 31 28.90	175	<12	<18
SD-5/0898/WVD8-7	41 37 54.47	70 31 28.62	200	<12	<18
SD-5/0898/WVD8-8	41 37 54.35	70 31 28.34	225	39	<18
SD-5/0898/WVD8-9	41 37 54.22	70 31 28.05	250	16	<18
SD-5/0898/WVD8-10	41 37 54.09	70 31 27.77	275	<12	<18
SD-5/0898/WVD8-11	41 37 53.97	70 31 27.48	300	<12	<18
SD-5/0898/WVD8-12	41 37 53.84	70 31 27.20	325	<12	<18
SD-5/0898/WVD8-13	41 37 53.72	70 31 26.92	350	12	<18
SD-5/0898/WVD8-14	41 37 53.59	70 31 26.63	375	438	667
SD-5/0898/WVD8-15	41 37 53.47	70 31 26.35	400	42	**10
SD-5/0898/WVD8-15-D	41 37 53.47	70 31 26.35	400	50	**10
SD-5/0898/WVD8-16	41 37 53.34	70 31 26.06	425	13	**10
SD-5/0898/WVD9-2	41 37 53.46	70 31 30.31	75	<12	<18
SD-5/0898/WVD9-3	41 37 53.34	70 31 30.02	100	<12	<18
SD-5/0898/WVD9-4	41 37 53.21	70 31 29.73	125	<12	<18
SD-5/0898/WVD9-5	41 37 53.09	70 31 29.44	150	<12	<18
SD-5/0898/WVD9-6	41 37 52.97	70 31 29.16	175	<12	<18
SD-5/0898/WVD9-7	41 37 52.85	70 31 28.87	200	<12	<18
SD-5/0898/WVD9-8	41 37 52.73	70 31 28.58	225	<12	<18
SD-5/0898/WVD9-9	41 37 52.61	70 31 28.30	250	<12	<18
SD-5/0898/WVD9-10	41 37 52.49	70 31 28.01	275	<12	<18
SD-5/0898/WVD9-11	41 37 52.37	70 31 27.72	300	<12	<18
SD-5/0898/WVD9-12	41 37 52.25	70 31 27.43	325	<12	<18
SD-5/0898/WVD9-13	41 37 52.13	70 31 27.15	350	<12	<18
SD-5/0898/WVD9-14	41 37 52.01	70 31 26.86	375	<12	<18
SD-5/0898/WVD9-15	41 37 51.89	70 31 26.57	400	<12	<18
SD-5/0898/WVD9-16	41 37 51.77	70 31 26.28	425	<12	<18

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