

User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells

Part 2: Field Tests

By Don A. Vroblesky, editor

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Evaluation of a Diffusion Sampling Method for Determining Concentrations of Volatile Organic Compounds in Ground Water, Hanscom Air Force Base, Bedford, Massachusetts

By Peter E. Church

Abstract

Ground-water samples were collected in May 1999 at the Hanscom Air Force Base, Bedford, Massachusetts, with a method involving water diffusion samplers and a conventional low-flow sampling method to evaluate the use of diffusion samplers as an inexpensive and reliable alternative method for monitoring volatile organic compounds at the base. The principal compounds detected by both sampling methods were 1,2-dichloroethylene isomers, which ranged in concentration from not detected to nearly 7,000 micrograms per liter, and trichloroethylene, which ranged in concentration from not detected to nearly 5,000 micrograms per liter. A Sign test, applicable to these highly skewed concentrations, indicates that with a probability of 95 percent, it is equally likely to have diffusion sample concentrations of 1,2-dichloroethylene isomers and trichloroethylene greater than low-flow sample concentrations as it is to have diffusion sample concentrations of these compounds less than low-flow sample concentrations.

Analysis of the distribution of 1,2-dichloroethylene isomers and trichloroethylene concentrations in samples from long-screen wells (screen length 10 feet or greater) with multiple-diffusion samplers indicates that vertical concentration

variations within well screens differ substantially from sampled wells at the base. These concentration variations can be attributed to concentration stratification in the aquifer adjacent to the well screen; however, data from borehole-flowmeter logs from selected long-screen wells suggest that wellbore flow also may be a factor affecting concentration variations. Where water quality varies vertically along a well screen, water sampled with multiple diffusion samplers may better characterize water quality in the well than low-flow samples.

INTRODUCTION

Volatile organic compounds (VOCs) are present in ground water at Hanscom Air Force Base (AFB), Massachusetts. These VOCs include chlorinated solvents, petroleum hydrocarbons, and their biodegradation products. Remediation efforts to remove VOCs from ground water have been ongoing at the base since 1991. Considerable amounts of time and money are spent each year to collect water samples from monitoring wells using conventional low-flow techniques as part of a remediation-monitoring programs at sites such as this. An alternative, lower-cost sampling method that will save time and yield reliable results would be advantageous to all services and agencies involved in such activities.

Vroblesky and Hyde (1997) describe an inexpensive and effective sampling method that uses water-to-water polyethylene-membrane diffusion samplers (referred to as diffusion samplers in this report) placed in wells. Although this passive method has yielded promising results in some settings (Vroblesky and Hyde, 1997), additional testing is needed to evaluate its suitability as a long-term monitoring tool at Hanscom AFB. Also of concern at the base are the vertical distribution of VOCs in long-screen wells (screen length 10 ft or greater) and possible redistribution of VOCs caused by vertical flow in these wells.

The U.S. Geological Survey (USGS), in cooperation with the Air Force Center for Environmental Excellence (AFCEE), Brooks Air Force Base, San Antonio, Texas, and in consultation with the Restoration Program Manager at Hanscom AFB, designed a ground-water-sampling and borehole-logging program to compare VOC concentrations in water samples collected with the diffusion sampling method and a low-flow sampling method. To support interpretation of the water-quality data, multiple diffusion samplers were placed in long-screen wells and an open borehole in bedrock to examine the vertical distribution of VOC concentrations and to evaluate possible effects of flow in well screens on the vertical distribution of VOCs in selected wells.

The USGS installed diffusion samplers in wells during April 1999; samplers were retrieved in May 1999. The IT Corporation, Hopkinton, Mass., under contract to the Hanscom AFB, collected ground-water samples with the low-flow sampling method in May 1999, soon after retrieval of diffusion samplers. Vertical flow was measured by the USGS in four long-screen wells with a borehole flowmeter in June 1999.

The diffusion sampling method was chosen for testing as a possible alternative method over the current low-flow method used at the Hanscom AFB because diffusion samplers were expected to require less overall time for sampling, and lower costs for equipment and labor. Low-flow sampling methods, designed for collection of ground-water samples adjacent to well screens, while minimizing disturbance to the aquifer and drawdowns in the well casings (Puls and Barcelona, 1995), require purging the well-screen water until various water-quality parameters stabilize, collection and disposal of the purged water, and decontamination of the downhole sampling equipment before collection of a sample from another well. The diffusion sampling method eliminates the monitoring of water-quality

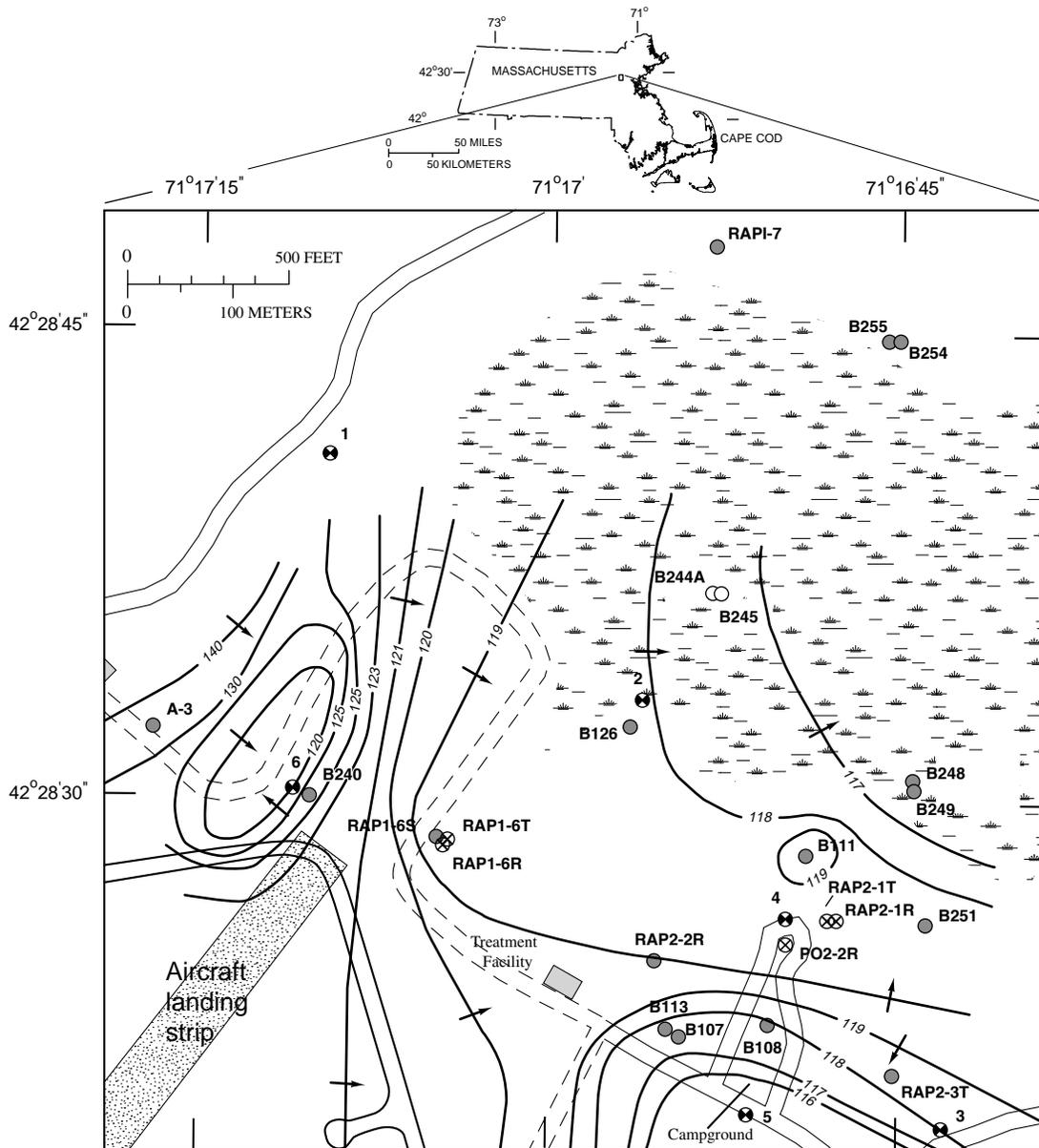
parameters and generates little to no waste water for disposal. Therefore, assuming that the quality of water in the well screen is representative of the water quality in the adjacent aquifer, the diffusion sampling method may prove to be a reliable alternative to the low-flow method.

This report compares a diffusion sampling method to a low-flow sampling method for monitoring of VOCs in ground water at the Hanscom AFB. The report also describes the possible effects of vertical variations of VOCs and borehole flow in long-screen wells on sampling with diffusion and low-flow methods.

The author thanks personnel of the Air Force Center for Environmental Excellence, Brooks AFB, San Antonio, Texas and Tom Best, Restoration Program Manager, Hanscom AFB, for their cooperation in developing the study program. Tom Best provided pertinent site information and assistance in the field, and personnel of IT Corporation, Hopkinton, Mass., collected the low-flow samples. The helpful comments throughout this study from Richard Willey, Office of Site Remediation and Restoration, U.S. Environmental Protection Agency, Region I, Boston, Mass., and the reviews of the report by Richard Willey and Javier Santillan, Air Force Center for Environmental Excellence, are greatly appreciated. William J. Andrade, Analytical Specialist and Joe Montanaro, Analyst, U.S. Environmental Protection Agency, Region I, Lexington, Mass., also are acknowledged for analyzing both the diffusion and low-flow samples and for providing guidance on quality-assurance procedures during the collection of water samples.

DESCRIPTION OF STUDY AREA

The study area is in the northeastern part of the Hanscom AFB in Bedford, Mass. (fig. 1). Physical, hydrogeological, and hydraulic characteristics of this area have been described by Haley & Aldrich, Inc. (1996, 1998). The land surface ranges in altitude from about 110 to 125 ft in most of the study area. In the west-central part of the study area, near well A-3, land-surface altitude increases to greater than 145 ft. Swamps occupy the north-central and eastern part of the study area. Surface drainage at the Hanscom AFB is controlled by storm culverts and swales that drain to the northwest, northeast, and east.



Base from the U.S. Geological Survey 7.5 x 15 minute quadrangle topographic map
 Maynard, Massachusetts base map, 1:25,000, 1987
 Based on Massachusetts coordinate system

EXPLANATION

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|--|--|
|  SWAMP |  RAP1-6T WELLS SAMPLED BY WATER DIFFUSION AND LOW-FLOW METHOD AND IDENTIFIER; VERTICAL FLOW MEASURED |
|  117 WATER-TABLE CONTOURS—Shows altitude of water table in May 1998 (Haley and Aldrich, Inc., 1998). Contour interval is variable. Datum is sea level. |  2 RESTORATION WELLS AND IDENTIFIER |
|  B245 WELLS SAMPLED BY WATER DIFFUSION METHOD AND IDENTIFIER |  DIRECTION OF FLOW |
|  B249 WELLS SAMPLED BY WATER DIFFUSION AND LOW-FLOW METHOD AND IDENTIFIER | |

Figure 1. Location of study area, altitude of water table in May 1998, location of wells sampled with diffusion and low-flow sampling methods, wells logged with a borehole flowmeter, and restoration wells, Hanscom Air Force Base, Bedford, Massachusetts.

VOCs are present in surficial aquifers, a shallow aquifer that is unconfined, a deep confined aquifer, and the underlying fractured bedrock aquifer that also is confined. The shallow aquifer consists of fine sand and silt of glacial outwash deposits. The deep confined aquifer consists of a wide range of particle sizes from silt to boulders [previously described as glacial till by Haley & Aldrich, Inc. (1996), and hereafter referred to as till] below a confining layer of lacustrine silt. The bedrock is composed primarily of granitic gneiss and schists. The bedrock surface slopes from a depth of about 20 to 30 ft below land surface in the northern part of the study area to a depth of about 100 to 120 ft below land surface in the southern part of the study area. The outwash deposits at the surface range in thickness from about 8 to 28 ft and grade downward from silty, fine to medium sand to silty, fine to coarse sand. The lacustrine deposit ranges in thickness from less than 1 ft to about 48 ft and grades downward from fine sand and silt to clayey silt. Lacustrine sediments are not present in the west-central part of the study near well A-3 where the outwash is directly underlain by the sandy and gravelly till, which ranges in thickness from about 8 to 60 ft. In this report, the outwash deposits are referred to as the surficial aquifer, the confined till deposit as the till aquifer, and the fractured bedrock as the bedrock aquifer.

Water-level measurements in May 1998 (Haley & Aldrich, Inc., 1998) indicate that the water table within the study area ranged in altitude from about 116 to 140 ft (fig. 1). The water table is primarily in the surficial aquifer at depths of 0 to about 12 ft below land surface. Ground-water flow in the surficial aquifer is generally from the southwest to the northeast. In the west-central part of the site, where the lacustrine deposit is not present and the till is directly overlain by the outwash deposits, a cone of depression in the water table is formed by the continuous pumping of the bedrock aquifer by Restoration Well No. 6 (fig. 1). The water table in the southeastern part of the site appears to be affected by continuous pumping from Restoration Well No. 5 in the till aquifer. Pumping from Restoration Wells Nos. 1, 2, 3, and 4 (fig. 1) have formed a depression in potentiometric surfaces in the till and bedrock aquifers from the southeastern to the northwestern parts of the site (potentiometric surfaces in the till and bedrock aquifer are not shown

on fig. 1). Aquifer-test data from selected wells indicate horizontal hydraulic conductivities range from about 5 to 65 ft/d in the till aquifer and from about 0.1 to 0.6 ft/d in the bedrock aquifer (Haley & Aldrich, Inc., 1996).

SAMPLING METHODS

Water-quality samples were collected with the diffusion sampling method and a low-flow sampling method. Duplicate samples, and equipment and trip blank samples, were collected for each sampling method to assess the quality of the data collected. Vertical flow was measured in selected long-screen wells with a borehole flowmeter.

Diffusion Samplers

Diffusion samplers were constructed based on the method described by Vroblesky and Hyde (1997). Polyethylene sleeves, 2-inch wide by 18-inch long, and 4 mil thick, were heat sealed at one end, filled with about 300 mL of deionized water, and then closed by heat sealing the other end after the elimination of any air space. The water-filled polyethylene tubes were slid into 24-inch long, 1.5-inch diameter polyethylene-mesh tubing and secured to plastic-covered cords at both ends with plastic cable ties. The diffusion samplers then were lowered into wells with weights attached to the cords, either to depths within well screens or to an open borehole in bedrock. The depths were measured from the midpoint of the samplers to the top of the well casing. The samplers remained in the wells for about 3 weeks before recovery to allow time for VOCs diffusing into the samplers to equilibrate with VOCs in the aquifer.

Upon retrieval, the polyethylene mesh was partially cut open, a small slit was made at the top of a sampler, and the water samples were decanted into 40-milliliter glass vials. Hydrochloric acid (about 0.1 mL) was added to the vials to preserve the sample. Once capped, the vials were packed in ice. Samples were hand delivered to the nearby U.S. Environmental Protection Agency (USEPA) laboratory in Lexington,

Mass., at the end of each day for analysis of VOCs by USEPA method 8260 (U.S. Environmental Protection Agency, 1996).

Seventy diffusion samplers were placed in 23 wells on April 21 and 22, 1999. Fourteen of these wells had screens that were at least 10 ft long or longer and multiple diffusion samplers were placed in these wells. Five wells with 10-foot screens each contained three diffusion samplers; in each well, one sampler was placed about 1 ft above the bottom of the screen, one at the middle of the screen, and one about 1 ft below the top of the screen. Eight wells with screens longer than 10 ft each contained five diffusion samplers that were equally spaced from about 1 ft above the bottom of the screen to about 1 ft below the top of the screen. Five samplers also were placed in the open bedrock well; these were equally spaced as in the long-screen wells.

Each of the eight remaining wells, which had screens 10 ft long or shorter, contained a single diffusion sampler placed at the midpoint of the screen. In the case where the water level was below the top of the screen, the diffusion sampler was placed at the midpoint between the water level and the bottom of the screen. At well RAP1-6S, a long-screen well open to the water table, only two diffusion samplers were installed in the 6 ft of water within the 14.5-foot long screen.

Diffusion samplers were retrieved during May 10–13, 1999, generally in order of increasing VOC concentration as determined from results of previous sampling (Haley & Aldrich, Inc., 1998). The comparison between the diffusion and the low-flow sampling methods was made using the midpoint diffusion sampler in wells where multiple samplers were installed. Because a diffusion sampler was not placed at the midpoint between the water level and the bottom of the screen in well RAP1-6S, the depth at which the low-flow sample was obtained, concentrations from this well were not used in the comparison of diffusion and low-flow sampling method. Relevant diffusion sampling information are summarized in Church and Lyford (2000).

Low-Flow Sampling

A bladder pump was used by IT Corporation, Hopkinton, Mass., to collect water samples with the low-flow sampling method. The pump intake was placed at the midpoint of each well screen. In the case where the water level was below the top of the screen, the pump intake was placed at the midpoint between the water level and the bottom of the screen. Purge rates were adjusted from about 0.1 to 1.0 L/min (0.26 gal/min) according to the rate of inflow to each well to minimize drawdown. Drawdowns measured during sampling ranged from negligible to 1.42 ft, however, drawdowns in 86 percent of the wells sampled were less than 0.5 ft. Water-quality field parameters, water temperature, specific conductance, pH, and turbidity were monitored at 5-minute intervals, and a sample was collected after these field parameters stabilized. The stabilization criteria for these field parameters are: water temperature, ± 1 degree Celsius; specific conductance, ± 5 percent microsiemens per centimeter; pH, ± 0.1 pH unit; turbidity, ± 10 nephelometric units. Samples were processed and analyzed using the same procedures that were used with the diffusion samples.

Samples were collected from 21 wells with the low-flow sampling method May 10–14, 1999, after the diffusion samplers were retrieved. The wells B244A and B245, from which diffusion samples were obtained, were not sampled by the low-flow method because of the difficulty in transporting sampling equipment to these wetland locations. Low-flow water samples generally were collected within one day after the diffusion samples were collected and in the same order that the samplers were retrieved from the wells. Relevant low-flow sampling information are summarized in Church and Lyford (2000).

Borehole Flowmeter

Vertical flow in wells was measured using a borehole flowmeter, which consists of a downhole probe with heat sensors located equidistant above and below a heat source at the bottom of the probe (Keyes, 1990). The heat source is a thin metal mesh through which water flows. A pulse of electricity causes this mesh to increase in temperature, thereby increasing the temperature of a small parcel of water. Travel time of the heated water is measured as it passes either of the

heat sensors, and vertical direction is determined by the sensor that detected the heated water. The annular space between the probe's heat source and the well screen or casing must be sealed to direct vertical flow, if any, through the metal mesh. Travel times are calibrated to well diameter, and flow rates are expressed in gallons per minute. If the annular space between the heat source and the well screen has been properly sealed and the water-level changes caused by introducing the probe have stabilized, accuracies of ± 5 percent can be obtained for vertical-flow measurements under static conditions. The minimum flow rate that can be detected by the borehole flowmeter used at this site is reported as 0.03 gal/min by the manufacturer (Mount Sopris Instruments, Golden, Colo.). Field experience with this flowmeter indicates that flow rates as low as 0.01 gal/min can be detected before the measurement is affected by thermal convection (B.P. Hansen, U.S. Geological Survey, oral commun., 1999)

Borehole-flowmeter logging was conducted under ambient (unstressed) and pumping (stressed) conditions in five wells at the base; two screened in the till aquifer, two screened in bedrock aquifer, and one in the open borehole in bedrock aquifer. Reliable flowmeter measurements under unstressed conditions were not obtained from the two wells screened in bedrock because the water levels in the well casing had not stabilized 2 hours after water was displaced by lowering the logging probe. In the open borehole in bedrock, the annular space between the probe and the bedrock wall could not be sealed, and reliable data under unstressed and stressed conditions could not be obtained.

EVALUATION OF SAMPLING METHODS

The principal VOCs detected with both sampling methods were 1,2-dichloroethylene isomers (1,2-DCE) and trichloroethylene (TCE). Concentrations of 1,2-DCE in diffusion samples ranged from below the minimum reporting limit of 5 micrograms per liter ($\mu\text{g/L}$) to 6,800 $\mu\text{g/L}$ for 1,2-DCE and to 4,900 $\mu\text{g/L}$ for TCE. Concentrations in water samples collected with the low-flow method ranged from below the minimum reporting limit of 5 $\mu\text{g/L}$ to 6,400 $\mu\text{g/L}$ for 1,2-DCE and 4,900 $\mu\text{g/L}$ for TCE (table 1). Other VOCs detected, but generally at lower concentrations, include

acetone, vinyl chloride, 1,1-dichloroethylene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA) (Church and Lyford, 2000).

Samples were collected at the midpoint of well screens (and at the midpoint of the open hole in bedrock) in 20 wells with both methods. Because VOCs were not detected in all wells, and many of the VOCs detected had concentrations outside of the calibration ranges of analytical instruments, the number of wells with paired samples for comparison of sampling methods was reduced to 10 for concentration of 1,2-DCE and 16 for concentration of TCE (table 2, figs. 2 and 3). Concentrations of vinyl chloride were detected within analytical instrument calibration ranges in samples at the midpoint of well screens with both methods from only two wells, and 1,1-DCA from only one well. Acetone, commonly detected in laboratory blank samples (Church and Lyford, 2000), and 1,1-DCE were not detected in any samples from the midpoint of well screens with either sampling method. Therefore, only 1,2-DCE and TCE concentrations are used to evaluate the diffusion sampling method as an alternative to the low-flow sampling method. Concentrations of 1,2-DCE used in this comparison of methods ranged from 8.2 to 2,500 $\mu\text{g/L}$ in diffusion samples and 5.9 to 2,600 $\mu\text{g/L}$ in low-flow samples. Concentrations of TCE ranged from 12 to 4,900 $\mu\text{g/L}$ in diffusion samples and 11 to 4,900 $\mu\text{g/L}$ in low-flow samples (table 2).

Quality Assurance for Sampling Methods

Quality assurance for water samples collected with diffusion samplers included an equipment blank, daily trip blanks, and duplicate samples for about 7 percent of the samples collected. The equipment blank was the deionized water contained in a diffusion sampler exposed to air for about one week. Quality assurance for water samples collected with low-flow method included daily equipment blanks, a trip blank, and duplicate samples for about 14 percent of the samples. The USEPA Laboratory quality-assurance procedures included matrix spike samples made from selected diffusion samples and low-flow samples, and lab blanks (Church and Lyford, 2000).

Table 1. Concentrations of volatile organic compounds in ground-water samples collected with diffusion and low-flow sampling methods from wells at Hanscom Air Force Base, Bedford, Massachusetts, May 10–14, 1999

[Blank spaces indicate that only one low-flow sample was collected per well; samples were not collected from wells B244A and B245 with the low-flow sampling method. B, analyte found in lab blank; E, estimated value exceeds calibration range; L, estimated value is below calibration range; µg/L, micrograms per liter; --(5), not detected at reporting limit of 5 µg/L]

Well name	Water diffusion sampler name	Diffusion sampler depth, in feet below land surface	Low-flow sample depth, in feet below land surface	1,2-Dichloroethylene isomers (µg/L)		Trichloroethylene (µg/L)	
				Diffusion sample	Low-flow sample	Diffusion sample	Low-flow sample
A-3	A-3	48.0	48.0	--(5)	--(5)	--(5)	--(5)
RAP1-6S	RAP1-6S-A	8.1	11.0	37	12	9.2	2.8(L)
RAP1-6S	RAP1-6S-B	12.1		59		16	
B107	B107	13.3	13.5	--(5)	--(5)	--(5)	--(5)
B255	B255	99.5	99.5	--(5)	--(5)	--(5)	--(5)
B254	B254	64.5	64.5	1.4(L)	--(5)	7.6	2.6(L)
RAP1-7	RAP1-7-A	39.0		5.1		56	
RAP1-7	RAP1-7-B	44.75		--(100)		280	
RAP1-7	RAP1-7-C	50.5	50.5	--(50)	8.2(L)	180	180
RAP1-7	RAP1-7-D	56.25		--(50)		220	
RAP1-7	RAP1-7-E	62.0		9.7(L)		190	
B126	B126-A	52.7		8.4		15	
B126	B126-B	56.7	56.5	14	11	22	19
B126	B126-C	60.7		11		20	
B111	B111-A	58.0		7.8		65	
B111	B111-B	61.8	62.0	8.2	5.9	85	47
B111	B111-C	65.6		9.1		77	
B244A	B244A-A	42.0		63		8.1	
B244A	B244A-B	46.5		65		5	
B244A	B244A-C	51.0		55		47	
B244A	B244A-D	55.5		61		46	
B244A	B244A-E	60.0		82		19	

Table 1. Concentrations of volatile organic compounds in ground-water samples collected with diffusion and low-flow sampling methods from wells at Hanscom Air Force Base, Bedford, Massachusetts, May 10–14, 1999 —*Continued*

Well name	Water diffusion sampler name	Diffusion sampler depth, in feet below land surface	Low-flow sample depth, in feet below land surface	1,2-Dichloroethylene isomers (µg/L)		Trichloroethylene (µg/L)	
				Diffusion sample	Low-flow sample	Diffusion sample	Low-flow sample
B245	B245	17.5		15		7.4	
B251	B251	72.5	72.5	1(L)	4.3(L)	18	22
B249	B249	95.0	95.0	2.9(L)	--(5)	35	18
B248	B248	59.5	59.5	170	130	470	260
B113	B113-A	54.7		98		32	
B113	B113-B	58.7	58.5	100	51	30	11
B113	B113-C	62.7		99		34	
PO2-2R	PO2-2R-A	103.5		10		43	
PO2-2R	PO2-2R-B	110.5		12		48	
PO2-2R	PO2-2R-C	117.5	117.5	16	25	56	68
PO2-2R	PO2-2R-D	124.5		140		350	
PO2-2R	PO2-2R-E	131.0		140		320	
RAP2-3T	RAP2-3T-A	67.6		170		160	
RAP2-3T	RAP2-3T-B	70.8		14(L)		86	
RAP2-3T	RAP2-3T-C	74.0	74.0	35	77	200	170
RAP2-3T	RAP2-3T-D	77.2		28		160	
RAP2-3T	RAP2-3T-E	80.4		13(L)		71	
B108	B108-A	69.0		22		21	
B108	B108-B	73.0	73.0	25	7.4	12	16
B108	B108-C	77.0		26		14	
RAP2-1R	RAP2-1R-A	107.0		340		840	
RAP2-1R	RAP2-1R-B	110.5		300		890	
RAP2-1R	RAP2-1R-C	114.1	114.1	270	470	780	750
RAP2-1R	RAP2-1R-D	117.7		280		540	
RAP2-1R	RAP2-1R-E	121.2		260		490	
RAP2-1T	RAP2-1T-A	59.3		--(25)		55	
RAP2-1T	RAP2-1T-B	63.5		15(L)		230	
RAP2-1T	RAP2-1T-C	67.7	67.5	95	--(250)	900	880
RAP2-1T	RAP2-1T-D	71.8		82		1300	
RAP2-1T	RAP2-1T-E	76.0		97		990	

Table 1. Concentrations of volatile organic compounds in ground-water samples collected with diffusion and low-flow sampling methods from wells at Hanscom Air Force Base, Bedford, Massachusetts, May 10–14, 1999 —*Continued*

Well name	Water diffusion sampler name	Diffusion sampler depth, in feet below land surface	Low-flow sample depth, in feet below land surface	1,2-Dichloroethylene isomers (µg/L)		Trichloroethylene (µg/L)	
				Diffusion sample	Low-flow sample	Diffusion sample	Low-flow sample
RAP2-2R	RAP2-2R-A	82.9		1400		320	
RAP2-2R	RAP2-2R-B	87.5		1800		300	
RAP2-2R	RAP2-2R-C	92.0	92.0	1800	2,200	280	190
RAP2-2R	RAP2-2R-D	96.2		1800		270	
RAP2-2R	RAP2-2R-E	101.2		1900		350	
RAP1-6T	RAP1-6T-A	30.6		2400		410	
RAP1-6T	RAP1-6T-B	33.9		6800		1600	
RAP1-6T	RAP1-6T-C	37.0	37.0	6800(E)	6,200(E)	1600	1,500
RAP1-6T	RAP1-6T-D	40.4		6600(E)		1800	
RAP1-6T	RAP1-6T-E	43.7		6200(E)		1600	
RAP1-6R	RAP1-6R-A	52.5		5100(E)		1000	
RAP1-6R	RAP1-6R-B	57.0		5400(E)		1100	
RAP1-6R	RAP1-6R-C	61.6	61.5	6400(E)	6,400(E)	1400	1,200
RAP1-6R	RAP1-6R-D	66.2		6300(E)		1300	
RAP1-6R	RAP1-6R-E	70.7		5400		1100	
B240	B240-A	57.0		2200(B)		4400	
B240	B240-B	61.0	61.0	2500	2,600	4900	4,900
B240	B240-C	65.0		2500		4600	

Table 2. Concentrations, differences in concentrations, and estimated error in concentrations due to sampling and analytical processes of volatile organic compounds in ground-water samples collected with diffusion and low-flow sampling methods at Hanscom Air Force Base, Bedford, Massachusetts, May 10–14, 1999

[Comparison of range or error between sampling methods: >, range of error in diffusion sample is greater than the range of error in the low-flow sample; =, range of error in diffusion sample overlaps range of error in low-flow samples; <, range of error in diffusion sample is less than range of error in low-flow sample. Wells are listed in order of increasing low-flow sample concentration. µg/L, micrograms per liter]

Well	Concentration			Relative percent difference (RPD)	Concentration				Comparison of range of error between sampling methods
	Diffusion sample	Low-flow sample	Diffusion sample minus low-flow sample		Range of error due to sampling and analytical processes (±10 percent)				
					Diffusion sample		Low-flow sample		
					Low	High	Low	High	
1,2-dichloroethylene isomers (µg/L)									
B111	8.2	5.9	2.3	33	7.38	9.02	5.31	6.49	>
B108	25	7.4	17.6	109	22.5	27.5	6.66	8.14	>
B126	14	11	3	24	12.6	15.4	9.9	12.1	>
PO2-2R	16	25	-9	44	14.4	17.6	22.5	27.5	<
B113	100	51	49	65	90	110	45.9	56.1	>
RAP2-3T	35	77	-42	75	31.5	38.5	69.3	84.7	<
B248	170	130	40	27	153	187	117	143	>
RAP2-1R	270	470	-200	54	243	297	423	517	<
RAP2-2R	1,800	2,200	-400	20	1,620	1,980	1,980	2,420	<
B240	2,500	2,600	-100	4	2,250	2,750	2,340	2,860	=
Average.....				45					
Trichloroethylene (µg/L)									
B113	30	11	19	93	27	33	9.9	12.1	>
B108	12	16	-4	29	10.8	13.2	14.4	17.6	<
B249	35	18	17	64	31.5	38.5	16.2	19.8	>
B126	22	19	3	15	19.8	24.2	17.1	20.9	=
B251	18	22	-4	20	16.2	19.8	19.8	24.2	<
B111	85	47	38	58	76.5	93.5	42.3	51.7	>
PO2-2R	56	68	-12	19	50.4	61.6	61.2	74.8	=
RAP2-3T	200	170	30	16	180	220	153	187	=
RAP1-7	180	180	0	0	162	198	162	198	=
RAP2-2R	280	190	90	38	252	308	171	209	>
B248	470	260	210	58	423	517	234	286	>
RAP2-1R	780	750	30	4	702	858	675	825	=
RAP2-1T	900	880	20	2	810	990	792	968	=
RAP1-6R	1,400	1,200	200	15	1,260	1,540	1,080	1,320	=
RAP1-6T	1,600	1,500	100	6	1,440	1,760	1,350	1,650	=
B240	4,900	4,900	0	0	4,410	5,390	4,410	5,390	=
Average.....				27					

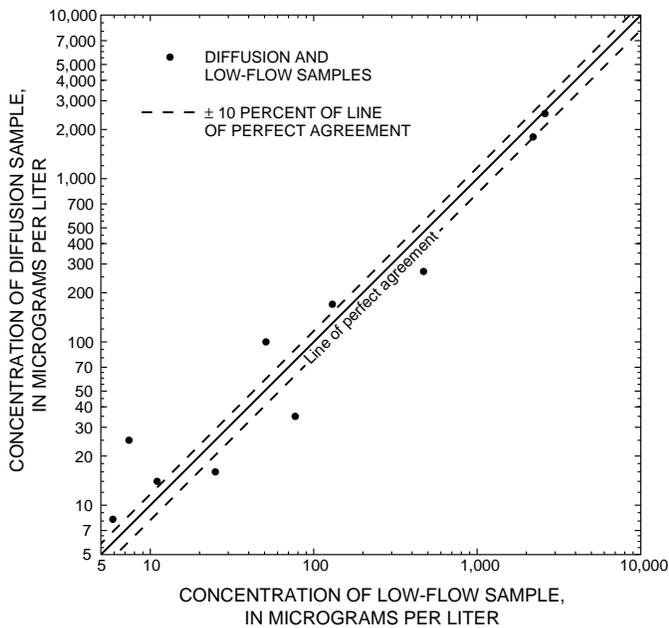


Figure 2. Comparison of 1,2-dichloroethylene isomers in ground water collected with diffusion and low-flow sampling methods, Hanscom Air Force Base, Bedford, Massachusetts, May 1999.

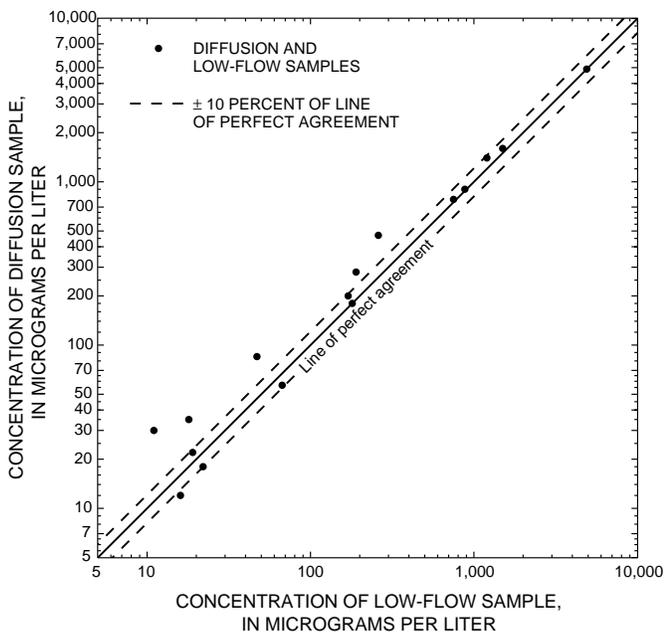


Figure 3. Comparison of trichloroethylene in ground water collected with diffusion and low-flow sampling methods, Hanscom Air Force Base, Bedford, Massachusetts, May 1999.

The VOCs 1,2-DCE and TCE were not detected above reporting limits in the diffusion and low-flow trip blank samples. They also were not detected above reporting limits in the diffusion sampling equipment blank sample and in most of the low-flow sampling equipment blank samples. Concentrations of 1,2-DCE (12 $\mu\text{g/L}$) and TCE (56 $\mu\text{g/L}$) were detected in the low-flow equipment blank sample on the last day of sampling when wells with the highest 1,2-DCE and TCE concentrations were sampled. Assuming the equipment blank concentrations were derived from the first well sampled on this day (RAP2-2R), concentrations of the second sample collected, and perhaps the two additional samples collected on this day, may be affected by contamination of the low-flow sampling equipment. In this case, the 1,2-DCE concentration of the equipment blank would be about 0.2 percent of the concentrations in the low-flow samples from wells RAP1-6T and RAP1-6R (6,200 $\mu\text{g/L}$ and 6,400 $\mu\text{g/L}$), and about 0.5 percent of the concentration in the sample from well B240 (2,600 $\mu\text{g/L}$). Although the 1,2-DCE concentrations in samples from wells RAP1-6T and RAP1-6R exceed the calibration range of the analytical instrument, and as such are qualitative estimates, they demonstrate, as does the concentration in the sample from well B240, that the contaminated equipment blank has minimal effect on the 1,2-DCE concentrations in samples from these wells. The TCE concentration of the equipment blank, however, may account for about 4 percent of the TCE concentration in the sample from well RAP1-6T (1,500 $\mu\text{g/L}$), 5 percent of the sample from well RAP1-6R (1,200 $\mu\text{g/L}$), and 1 percent of the sample well B240 (4,900 $\mu\text{g/L}$).

Thirteen laboratory blank samples were analyzed during the period that diffusion and low-flow samples were analyzed. The VOCs 1,2-DCE and TCE, as well as vinyl chloride, 1,1-DCA, and 1,1-DCE, were not detected in any of the laboratory blank samples.

Duplicate samples for 1,2-DCE and TCE concentrations were obtained with the diffusion sampling method in four wells (B111, B113, RAP2-1R, and RAP1-6R) that also were sampled with the low-flow method. Concentrations of 1,2-DCE in the original and duplicate samples in well RAP1-6R were reported as estimated values because the concentrations exceeded

the calibration range of analytical instrument. Concentrations 1,2-DCE from this well, therefore, are not included in the duplicate sample analysis for 1,2-DCE, nor in any other quantitative analyses. Relative percent differences (RPDs) in 1,2-DCE concentrations between the original and duplicate samples from the three remaining wells ranged from 7.7 to 8.3 percent, with an average of 8.1 percent. Concentration of 1,2-DCE in two of these duplicate samples are less than the concentrations in the original samples, and one is greater. RPDs for the original and duplicate sample concentrations of TCE from the four wells ranged from 1.2 to 15.4 percent, with an average of 6.1 percent. The RPD of 15.4 percent (from well RAP1-6R) appears anomalous compared to the other three RPDs, which ranged from 1.2 to 6.5 percent with an average of 3 percent. Concentration of TCE in two of these duplicate samples are less than those in the original samples, and two are greater. There appears to be no positive or negative bias in duplicate sample concentrations sampled with the diffusion method.

Duplicate samples were obtained with the low-flow sampling method in three wells (B254, B240, and RAP1-6R). Concentrations of 1,2-DCE in the original and duplicate samples from well RAP1-6R exceeded the calibration range, concentrations of 1,2-DCE in well B254 were not detected in original and duplicate samples, and concentrations of TCE in well B254 were estimated below the calibration range. As a result, low-flow duplicate sample analysis of 1,2-DCE concentrations is represented by samples from one well (B240), and in this case, the original and duplicate sample concentrations are the same (2,600 µg/L). TCE duplicate analysis is represented by concentrations from two wells (B240 and RAP1-6R); RPDs are 2.1 and 8.0 percent, with an average of about 5 percent. Concentration of TCE in one duplicate sample is less than that in the original sample, and TCE concentrations in the other duplicate sample is greater than that in the original sample.

The error in sample concentrations attributable to sampling methods and analytical processes is estimated as within ± 10 percent for both sampling methods, based on analyses of trip, equipment, and laboratory blank samples and duplicate samples. Concentrations of TCE in low-flow samples from wells RAP1-6T, RAP1-6R, and B240, however, contain additional

error, as much as 5 percent, due to the TCE detected in the equipment blank sample that represents the day that samples were collected from these wells.

Comparison of Concentrations of 1,2-DCE and TCE in Diffusion and Low-flow Samples

Concentrations of 1,2-DCE and TCE in samples collected with diffusion and low-flow methods, differences in concentrations, relative percent differences in concentrations, and ranges of error due to sampling and analytical processes are provided in table 2. These data show a wide range of concentrations, and a wide range of differences in concentrations of 1,2-DCE and TCE sampled with the diffusion and low-flow methods. Average RPD for 1,2-DCE concentrations from samples collected with both methods is about 45 percent, whereas the average RPD for TCE concentrations is about 27 percent (table 2), indicating substantially smaller differences between TCE concentration from diffusion and low-flow samples than differences between 1,2-DCE concentrations from both methods. With the estimated error attributable to sampling and analytical processes of ± 10 percent applied to each sample, and sample concentrations from both methods are considered to be the same if their ranges of error overlap, concentrations of 1,2-DCE in diffusion samples are greater than those in low-flow samples in 5 wells, are the same in one well, and are less in 4 wells. TCE concentrations in diffusion samples are greater than those low-flow samples in 5 wells, are the same in 9 wells, and are less in 2 wells (table 2).

Because the 1,2-DCE and TCE concentrations determined from both methods are highly skewed, even with a log₁₀ transformation, a Sign test, a non-parametric statistical test that can be applied to paired, non-normally distributed data sets with non-normally distributed differences (Helsel and Hirsch, 1992), was used to compare the concentrations from each method. The concentration data applied to this test include the estimated error of ± 10 percent for each diffusion and low-flow sample. Results of these statistical tests indicate, at a probability of 95 percent, that it is equally likely to have diffusion sample concentrations of 1,2-DCE and TCE greater than low-flow sample

concentrations as it is to have diffusion sample concentrations of 1,2-DCE and TCE less than low-flow sample concentrations. Therefore, results from evaluation of the diffusion sampling method indicate that use of diffusion samplers for collection of VOCs containing 1,2-DCE and TCE, and thus other VOCs, may be a viable alternative to the low-flow sampling method currently being used at this base.

It is useful to note, however, that the highest concentrations of 1,2-DCE and TCE in long-screen wells, which were determined from samples collected with multiple diffusion samplers placed in these wells, are not necessarily at the midpoint of well screens where low-flow samples were obtained (table 1). A non-midpoint sample concentration is considered to be higher than the midpoint sample concentration if the ranges of uncertainty (± 10 percent) in concentrations for each sample do not overlap. The highest concentrations of 1,2-DCE were detected in diffusion samples either above or below the midpoint sample in 36 percent of the long-screen wells. The highest concentrations of TCE were detected in samples either above or below the midpoint sample in 43 percent of the long-screen wells. This result demonstrates that, if the goal is to determine the highest concentrations of VOCs in a long-screen well, even if only to select where along the well screen a sample should be collected with another sampling method, use of diffusion samplers can be very effective in monitoring, or assisting in monitoring of VOCs in ground water.

DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN LONG-SCREEN WELLS

Analysis of concentrations of water samples obtained with multiple diffusion samplers in long-screen wells (screen length 10 ft or greater) indicate that vertical variations of concentrations of 1,2-DCE and TCE within well screens differ considerably in samples from well to well at this site. Because concentrations of 1,2-DCE and TCE also range widely at this site, standard deviations of 1,2-DCE and TCE concentrations within each well, normalized by their respective average concentrations, were calculated as indicators of the relative variations of concentrations among these wells. These normalized standard deviations

(NSDs) are shown in figure 4, ordered first by aquifer, second by increasing screen length, and third by increasing NSD for TCE concentrations. A low NSD indicates a small variation in concentrations in a well screen. An NSD was not calculated for 1,2-DCE concentrations in wells RAP2-3T, RAP2-1T, and RAP1-7 because 1,2-DCE was not detected above reporting limits in some of the diffusion samples in these wells.

Comparison between NSDs in these wells suggests increasing variations in concentrations of 1,2-DCE and TCE with increasing screen length (fig. 4). Vertical variations in concentrations among well screens of similar screen length and similar variations in concentrations within well screens of different length, however, also are apparent. The variations of 1,2-DCE and TCE concentrations in these wells may reflect the distribution of these concentrations in the aquifer adjacent to the wells. Wellbore flow also may have an appreciable effect on the distribution of contaminant concentrations in the long-screen wells at this site. Explanations of these variations in 1,2-DCE and TCE concentrations are discussed below for wells from which borehole-flowmeter data were obtained.

Till Aquifer

At well RAP1-6T (15.1 ft screen), 1,2-DCE and TCE concentrations in the upper diffusion sample are appreciably less than those in lower four samples (1,2-DCE concentrations in the bottom three samples are estimated above calibration range) (fig. 5). This difference in concentrations is likely due to the upper part of the screens placed in the fine-grained lacustrine deposit. Borehole-flowmeter data under unstressed conditions indicate a uniform upward flow of about 0.025 gal/min within the till, and then decreases to less than 0.01 gal/min in the overlying lacustrine deposit (fig. 5). Under pumping conditions, borehole flowmeter data indicate that most of the water pumped to the surface is from the lower third of the well screen (near the middle of the till deposit) and that little, if any, flow is contributed from the lacustrine deposit. The flowmeter data are consistent with the lithologic data in indicating that the till is more hydraulically conductive than the overlying lacustrine deposit.

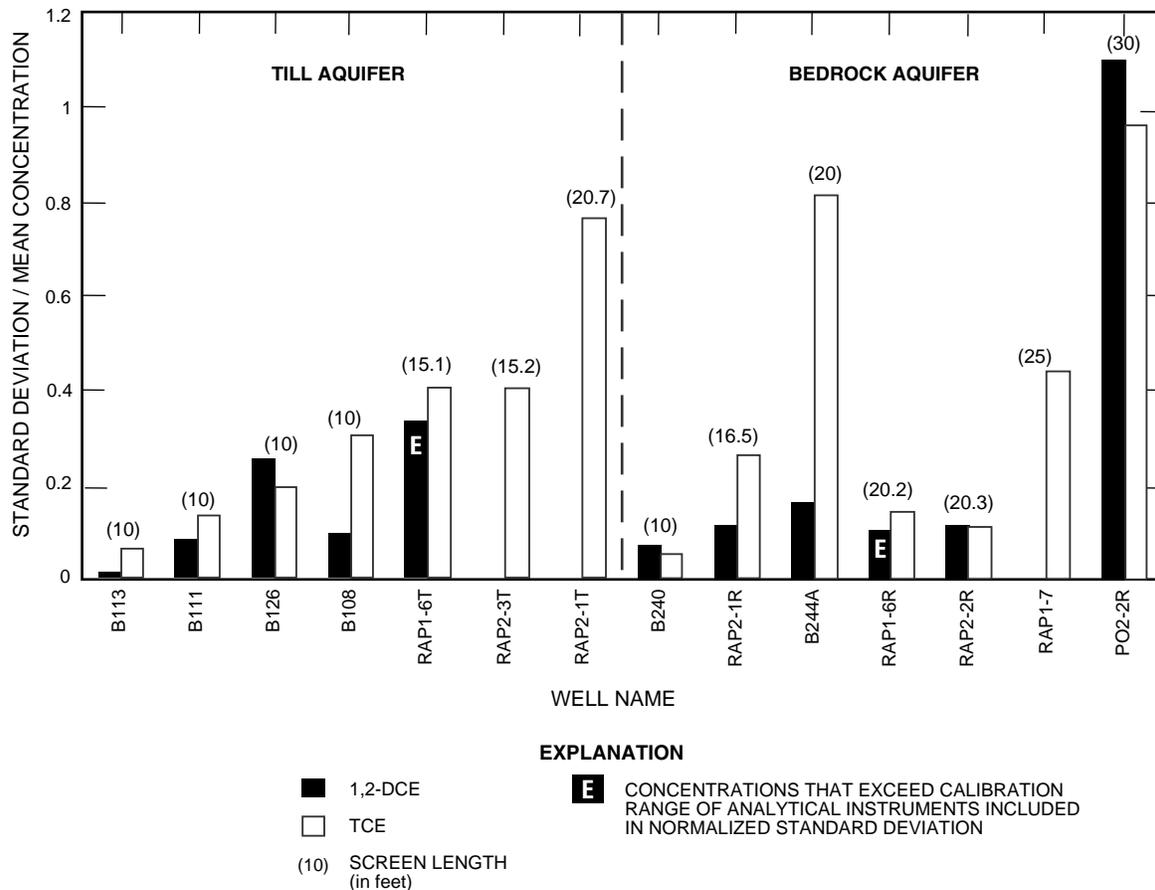


Figure 4. Normalized standard deviations of variations of 1,2-dichloroethylene isomers (1,2-DCE) and trichloroethylene (TCE) concentrations from multiple diffusion samples in long-screen wells, Hanscom Air Force Base, Bedford, Massachusetts.

Although the apparent uniform distribution of VOC concentrations with depth in the till also may be similar in the aquifer, it also is likely due to the upward unstressed flow in the well homogenizing the concentration in the part of the well screened in the till (fig. 5). The lower concentrations observed in the well screen opposite the lacustrine deposit probably indicates that most of the upward moving waters containing VOCs exit the well screen below the lacustrine deposit.

Concentrations of TCE in the midpoint diffusion sample and the low-flow samples are similar (fig. 5). The relative percent differences of these concentrations resulting from application of both methods are about 6 percent. These similar concentrations suggest that the same waters are sampled with both methods, but the source of water, whether from the aquifer adjacent to the sampling devices in the screen or from lower in the aquifer because of wellbore flow, is uncertain.

The vertical distribution of TCE concentrations at well RAP2-1T (fig. 6), where the upper 4 ft of the 20.7-foot well screen is in the lacustrine deposit, are similar to those observed at well RAP1-6T. Concentrations of TCE in the bottom four diffusion samples, where the well screen is in the till, are substantially higher than in the upper sample where the well is screened in the lacustrine deposit. Borehole flowmeter data indicate downward flow in the till under non-pumping (unstressed) conditions with a maximum flow of about 0.06 gal/min near the middle of the screen (fig. 6), indicating that the horizontal hydraulic conductivity of the till may be higher in this zone than in the overlying and underlying till. Although measurements of flow under unstressed conditions were not made in the upper part of the screen in the lacustrine deposit, the first measurement in the till, near the contact with the lacustrine deposit, was about 0.01 gal/min, indicating that little to no flow occurred in the lacustrine

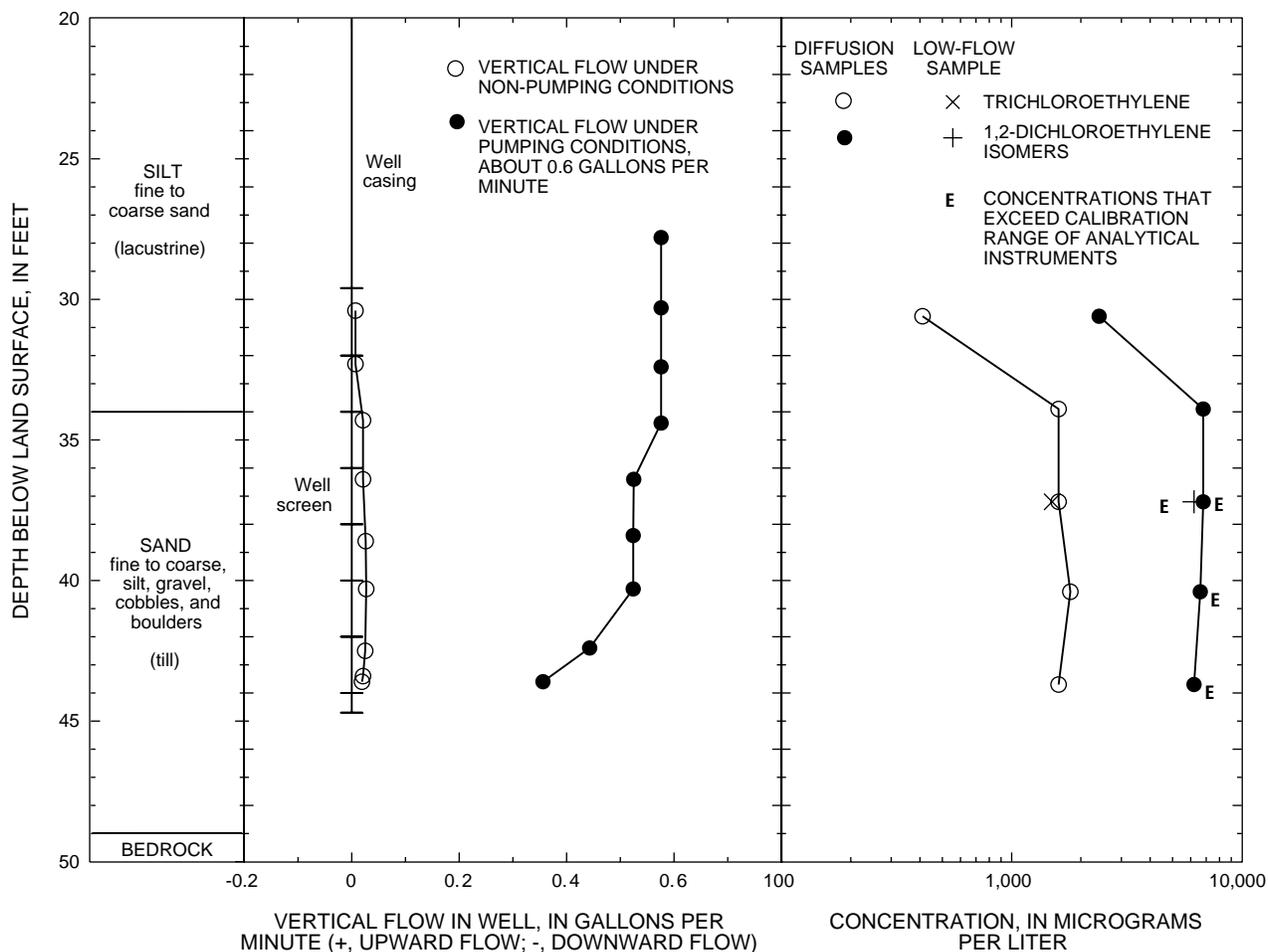


Figure 5. Lithology, well casing and screen, borehole-flowmeter data, and concentrations of 1,2-dichloroethylene isomers and trichloroethylene in multiple diffusion samples and in the low-flow sample at well RAP1-6T in the till aquifer at Hanscom Air Force Base, Bedford, Massachusetts.

deposit. Flow under pumping (stressed) conditions exhibits a nearly uniform increase in volume of water contributed to the well with decreasing depth in the till. The flow rate measured at the top of the till approximates the rate at which water was being pumped from the well, indicating that very little water, if any, was contributed from the lacustrine deposit.

The flowmeter data from this well are consistent with the lithologic data that indicate the point of contact between the lacustrine and till deposits. The unstressed flow data suggest that contaminants would flow preferentially within a zone near the middle of the part of the well screened in the till. Therefore, the relatively uniform TCE concentrations observed below this zone probably reflect the downward flow in the well screen. As in well RAP1-6T, the relatively lower concentration of TCE measured in the lacustrine deposit

could be the result of lower concentrations in this unit or insufficient time for the well water to equilibrate with the aquifer water after installing the diffusion samplers in the slower moving water of the lacustrine deposit.

The concentrations of TCE from the midpoint diffusion sample and the low-flow sample show little variation (fig. 6). The relative difference is about 2 percent. Because different dilution factors were used in these analyses, concentrations of 1,2-DCE were detected above the reporting limit of 25 µg/L in the diffusion sample and was not detected above the reporting limit of 250 µg/L in the low-flow sample (fig. 6), and, therefore, cannot be compared directly. The close correlation between TCE concentrations from both methods suggests that waters from the same source are being sampled, and flowmeter data suggest that much

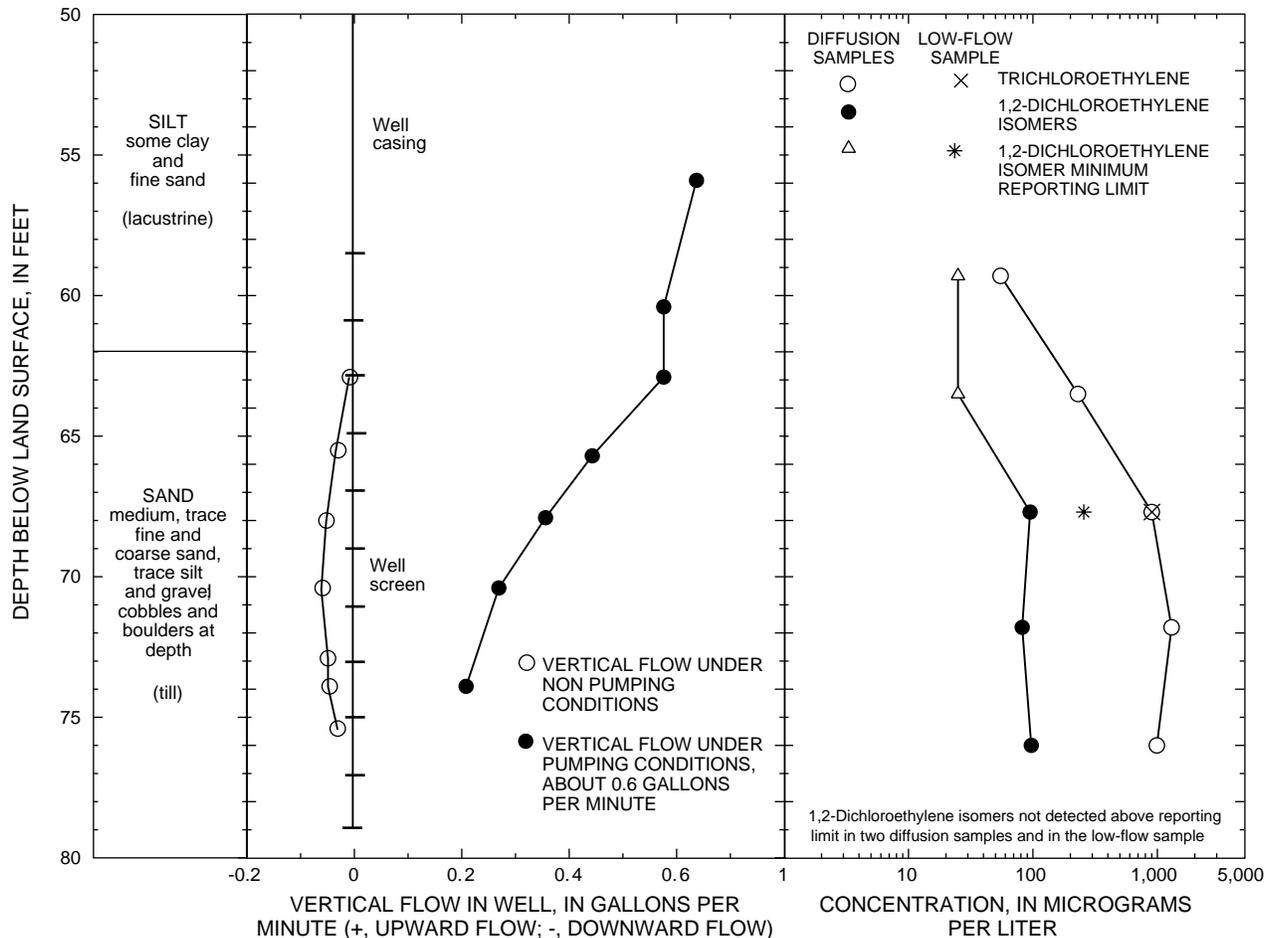


Figure 6. Lithology, well casing and screen, borehole-flowmeter data, and concentrations of 1,2-dichloroethylene isomers and trichloroethylene in multiple diffusion samples and in the low-flow sample at well RAP2-1T in the till aquifer at Hanscom Air Force Base, Bedford, Massachusetts.

of this water is from the aquifer adjacent to a midpoint zone in the screen. Downward flow in the screen of lower concentration water from the upper part of the till aquifer, and possibly from the lacustrine deposit, however, could dilute concentrations in water in the mid-section of the screen, and result in lower concentrations than in the adjacent aquifer.

Bedrock Aquifer

Variations in concentrations of 1,2-DCE and TCE at well RAP1-6R (20.2-ft well screen) are relatively small (fig. 7) (1,2-DCE concentrations in the upper four samples are estimated above calibration range) and are comparable to those in 10-foot screens in the till. Unstressed flow was not measured in this

well because the water level in the well casing had not stabilized after 2 hours since placing the flowmeter probe in the well. Vertical flow in the well screen, however, is suggested as a possible cause for the nearly uniform distribution of 1,2-DCE and TCE concentrations. Borehole flowmeter data under pumping conditions indicate that most of the water pumped was contributed from the bottom 6 ft of the screen; especially from a thin zone about 4 to 6 ft from the bottom (fig. 7). This contribution would be consistent with a fracture, or fracture zone in the bedrock in this vicinity. Although the driller's log describes the bedrock as highly fractured, the flowmeter data indicate that the only substantial water-bearing fractures are near the bottom of the well screen. The nearly uniform distribution of concentrations with depth in the well screen could be the result of downward flow of contaminants

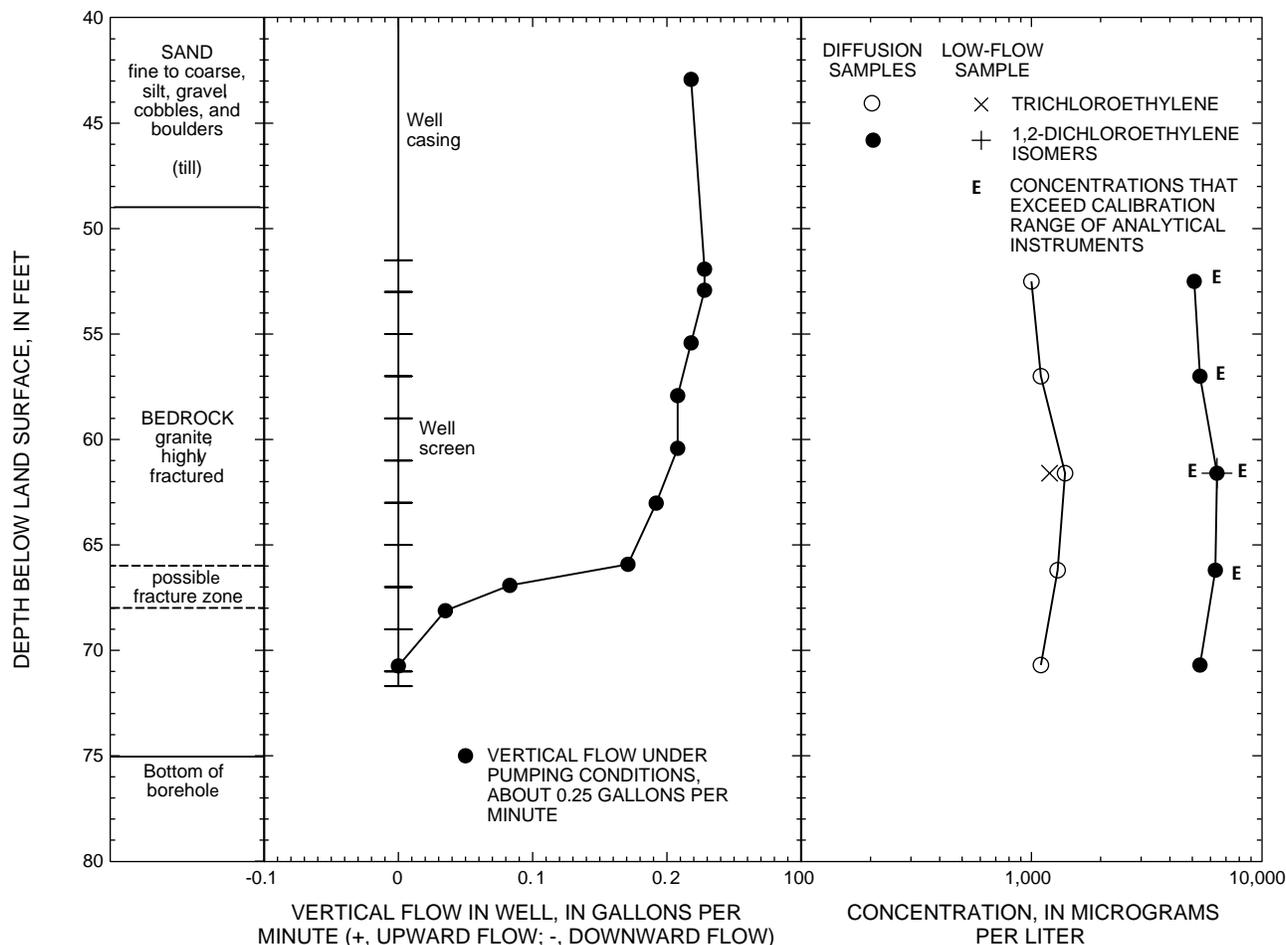


Figure 7. Lithology, well casing and screen, borehole-flowmeter data, and concentrations of 1,2-dichloroethylene isomers and trichloroethylene in multiple diffusion samples and in the low-flow sample at well RAP1-6R in the bedrock aquifer at Hanscom Air Force Base, Bedford, Massachusetts.

entering the upper part of the screen from a source in the upper bedrock or lower part of the till, or upward flow originating from the fracture identified or from fractures at depths below the well screen. It also is possible that this nearly uniform distribution of concentrations with depth in the screen reflects the distribution in the formation.

Concentrations of 1,2-DCE in the low-flow sample (also estimated above the calibration range) and in the midpoint diffusion sample appear to be the same, and the TCE concentrations from both methods are similar (fig. 7). The respective relative percent difference for concentrations of TCE is 15 percent. Although the entry point, or zone, of these waters is uncertain, both the diffusion and low-flow samples appear to be from the same source.

At well PO2-2R (30-ft well screen) (fig. 8), the large relative variations in concentrations of 1,2-DCE and TCE compared to those in samples from the other wells examined at this base (fig. 4) appear to result from the well screen intersecting a fracture or fracture zone. Although reliable ambient flow data were not obtained, borehole flowmeter data under pumping conditions indicate that most of the water pumped to the surface is contributed from a zone at and below a previously defined fracture (Tom Best, Restoration Program Manager, Hanscom Air Force Base, written commun., 1999). The depth to the top of this fracture, or fracture zone, was reported as 116 ft below land surface, but its downward extent was not provided in the drillers log. No flow was measured in the bottom 8 ft of the well screen, and little to

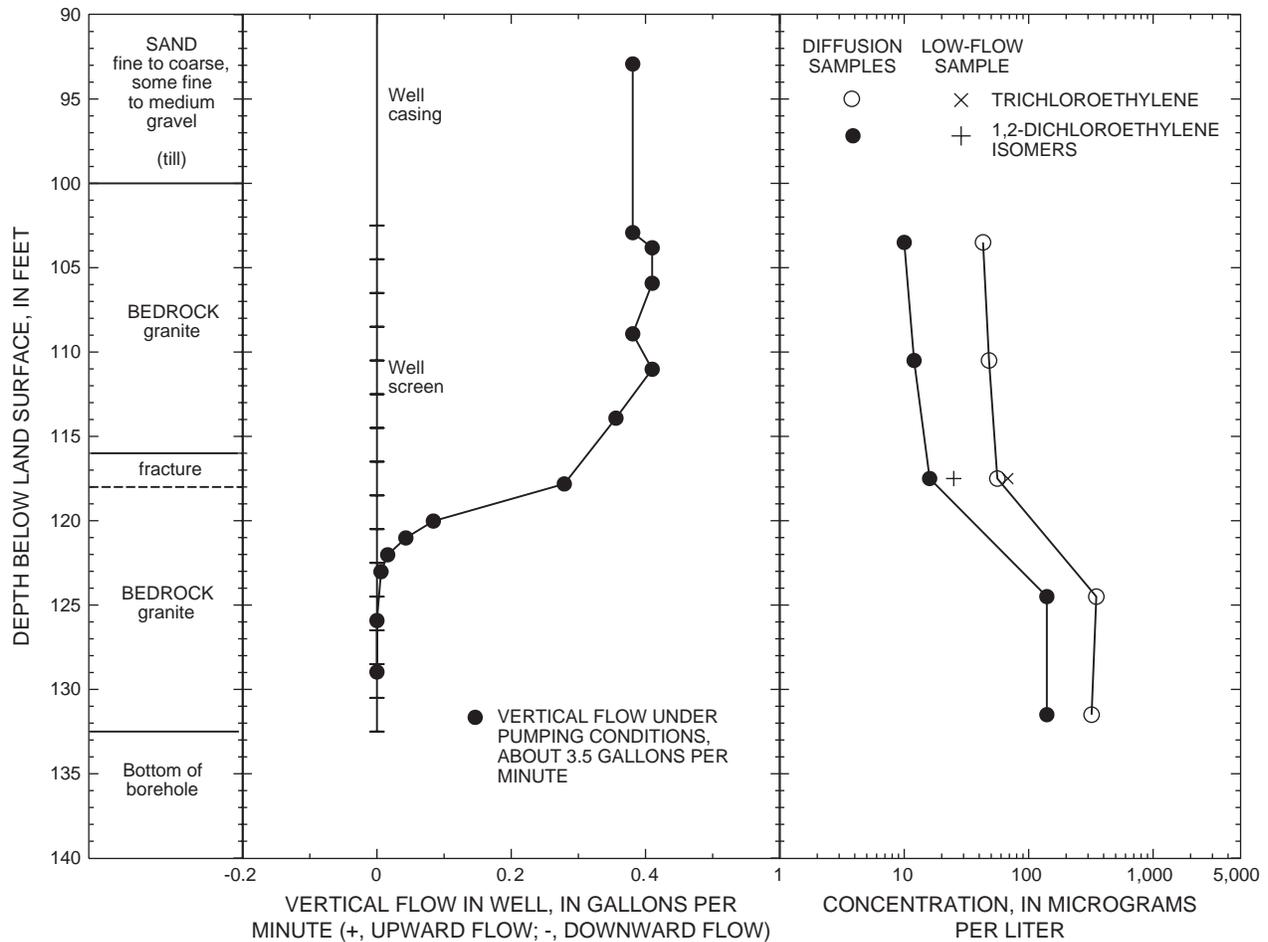


Figure 8. Lithology, well casing and screen, borehole-flowmeter data, and concentrations of 1,2-dichloroethylene isomers and trichloroethylene in multiple diffusion samples and in the low-flow sample at well PO2-2R in the bedrock aquifer at Hanscom Air Force Base, Bedford, Massachusetts.

no flow was measured in the upper 10 ft of the well screen. Therefore, this fracture, or fracture zone, may extend 5 or 6 ft below its reported upper level and account for the differences in concentrations above and below this zone. Although concentrations differ, nearly uniform distributions of 1,2-DCE and TCE concentrations are present above and below the fracture zone. This distribution of concentrations could reflect concentrations in the formation, however, other explanations are possible. Water in the zone below the fracture appears to be stagnant because no water was contributed to the flow while the well was pumped. Therefore, the lower concentrations above the fracture could represent temporal concentration changes that were not propagated into the zone below the fracture. The nearly uniform distribution of contaminants in the well screen

above the fracture could result from downward flow of contaminants from above into the fracture or upward flow from the fracture.

The relative difference between 1,2-DCE concentrations from the midpoint diffusion sample and the low-flow sample at well PO2-2R is 44 percent and for TCE concentrations is 19 percent. These differences in concentrations between methods, however, are much smaller than the differences in diffusion sample concentrations above and below the fracture. The relative difference of 1,2-DCE concentrations from above and below the fracture is about 170 percent and for TCE concentrations is about 150 percent. Similar to the other wells examined, the entry point(s), or zone(s), of these waters into the well screen is uncertain, however, both the diffusion and low-flow method appear to be sampling water from the same source.

SUMMARY AND CONCLUSIONS

This study has compared a diffusion sampling method to a low-flow sampling method for monitoring VOCs in ground water at the Hanscom Air Force Base, Bedford, Mass. In addition, the possible effects of vertical variations of VOCs and borehole flow in long-screen wells on sampling with diffusion and low-flow methods were examined.

Diffusion samplers have been shown to be a viable alternative to the low-flow sampling method currently being used at Hanscom AFB for monitoring VOCs in ground water. Concentrations of 1,2-DCE and TCE in samples collected at the midpoint of well screens with the diffusion sampling method were compared with concentrations of 1,2-DCE and TCE in samples collected at the same depths in wells with the low-flow sampling method. Concentrations of 1,2-DCE range from 8.2 to 2,500 µg/L in diffusion samples and 5.9 to 2,600 µg/L in low-flow samples. Concentrations of TCE range from 12 to 4,900 µg/L in diffusion samples and 11 to 4,900 µg/L in low-flow samples. A Sign test, applicable to these highly skewed concentrations, indicates that with a probability of 95 percent, it is equally likely to have diffusion sample concentrations of 1,2-DCE and TCE greater than low-flow sample concentrations as it is to have diffusion sample concentrations of 1,2-DCE and TCE less than low-flow sample concentrations.

Analysis of the distribution of 1,2-DCE and TCE concentrations in long-screen wells (screen length 10 ft or greater) in a till aquifer composed of a wide range of particle sizes from silt to boulders and in a bedrock aquifer with multiple diffusion samplers demonstrated that variations in concentrations within well screens differ significantly from well to well at the base. The vertical distribution of these concentrations in the long-screen wells may reflect the distribution of concentrations in the aquifer adjacent to the well screens. Borehole flowmeter data, however, indicate that the distribution of concentrations in samples from wells with long screens may be substantially affected by ambient vertical borehole flow.

In cases where there is either downward or upward borehole flow throughout most of the well screen, the concentrations of VOCs in the water that enter the screen are likely to predominate throughout the screen length as water(s) of different concentrations from other depths may be prevented from entering the screen. Analytical results from a single low-flow

sample should be similar to the analytical results from a single diffusion sample obtained from almost anywhere in the screen. Concentrations of VOCs in the well may be adequately characterized with both methods, however, the results may not be representative of the VOCs in the aquifer adjacent to the screen. Where vertical borehole flow is not present, VOCs in the well and aquifer adjacent to the screen may be adequately characterized with both methods at any specific depth. Delineation of the vertical distribution of VOCs with multiple diffusion samples may be needed, however, to determine an optimal depth for sampling with the low-flow method. If concentrations vary substantially with depth, however, an optimal depth may not exist and a single low-flow sample from any depth within the screen may not adequately characterize the VOCs in the well or the VOCs in the aquifer adjacent to the well. In a situation where borehole flow varies along the length of the screen, multiple diffusion samples may be able to characterize the vertical variations of VOCs in the well, but this depth profile may not represent the distribution of VOCs in the aquifer.

These observations reinforce results from previous studies that have demonstrated the difficulty of collecting representative ground-water samples in wells completed with long screens (Reilly and others, 1989; Church and Granato, 1996; Reilly and LeBlanc, 1998). A single sample collected with any method may not be representative of the formation water. Use of multiple diffusion samplers in conjunction with borehole flowmeter logs in long-screen wells may be useful in defining the vertical distribution of VOCs in the screened interval of an aquifer and evaluating if meaningful water-quality data can be obtained.

Other advantages of the diffusion sampling method over low-flow sampling methods include less overall time for collection of samples, no need for monitoring stabilization parameters to signal when sampling may begin, and minimal waste water. In addition, diffusion samplers have a distinct advantage over low-flow methods in evaluating the distribution of VOCs in wells because multiple samples can be obtained with minimal additional time over the time needed for collection of one sample. Multiple diffusion sampling in a well also can be effective even if diffusion samples are used only to select a location along the well screen where a sample should be taken with another method.

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