Prepared in cooperation with the
U.S. NAVY, SOUTHERN DIVISION,
NAVAL FACILITIES ENGINEERING COMMAND

Field Testing of Passive Diffusion Bag Samplers for Volatile Organic Compound Concentrations in Ground Water, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 and May 2000

Water-Resources Investigations Report 00-4246

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

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By Don A. Vroblesky *and* Matthew D. Petkewich

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Columbia, South Carolina
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CONTENTS

Abstract 1
Introduction 1
Purpose and Scope 2
Acknowledgments 3
Methods 3
Field Test Results and Conclusions 4
Summary 10
References 10

Figures

1. Map showing locations of sampling sites at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 to May 2000. 2
2-3. Graphs showing:
2. Comparison between passive diffusion bag sampling method and conventional purge sampling method, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 6
3. Comparison between passive diffusion bag samples and low-flow samples in resampled wells, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, May 2000 8

Tables

1. Well-construction details and number of passive diffusion bag samplers deployed, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota 3
2. Comparison of total 1,2 dichloroethene and trichloroethene concentrations obtained by purge-and-sample method to concentrations obtained by using passive diffusion bag samplers in wells where a single passive diffusion sampler was deployed at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 4
3. Concentrations of selected volatile organic compounds in water from multiple passive diffusion bag samplers and conventional purge sampling, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 5
4. Concentrations of selected volatile organic compounds in water from diffusion and low-flow sampling, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, May 2000 7

Conversion Factors

Mulitply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter

Degrees Celsius (^{o}C), can be converted to degrees Fahrenheit (^{o}F) by the following equation: $^{o}F = (9/5 \times {}^{o}C) + 32$

Abbreviations and Acronyms

mL	milliliter
µg/L	micrograms per liter
1,1-DCA	1,1-dichloroethane
1,1-DCE	1,1-dichloroethene
1,2-DCE	total 1,2-dichloroethene
1,1,1-TCA	1,1,1-trichloroethane
LDPE	Low-density polyethylene
NIROP	Naval Industrial Reserve Ordnance Plant
PCE	Tetrachloroethene
PDB	Passive diffusion bag
TCE	Trichloroethene
USEPA	U.S. Environmental Protection Agency
VOA	Volatile organic analysis
VOC	Volatile organic compound

Field Testing of Passive Diffusion Bag Samplers for Volatile Organic Compound Concentrations in Ground Water, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999 and May 2000

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ABSTRACT

Volatile organic compound concentrations from passive diffusion bag samplers were compared with concentrations from conventional purge (three or more casing volumes) sampling and low-flow purge sampling in side-by-side tests in 17 wells at the Naval Industrial Reserve Ordnance Plant, in Fridley, Minnesota. An initial comparison of 1,2-dichloroethene and trichloroethene concentrations obtained by using passive diffusion bag samplers and the conventional purge method in wells where one passive diffusion bag sampler was deployed showed good agreement at several wells but poor agreement at others. Collection of data from multiple diffusion samplers during the conventional purge sampling and during the low-flow sampling, however, suggests that the volatile organic compound concentrations from the passive diffusion bag samplers accurately reflect the volatile organic compound distribution in the screened interval, whereas the conventional purge and low-flow purge samples reflect mixing during pumping. The data also show that contaminant stratification was present in some wells. In one well, trichloroethene concentrations ranged from 470 to 1,600 micrograms per liter over a vertical distance of approximately 6 feet.

INTRODUCTION

Low-density polyethylene passive diffusion bag (PDB) samplers, filled with deionized water or air, can be an inexpensive alternative sampling method for volatile organic compounds (VOCs) in contaminated wells (Vroblesky and Hyde, 1997; Gefell and others, 1999). The use of PDB samplers in wells has generated interest because they can be used to sample ground water without the need for prior well purging. Investigations have shown that PDB sampling methods can result in substantial cost savings over traditional sampling methods (Parsons Engineering Science Inc., 1999; McClellan AFB Environmental Directorate, 2000).

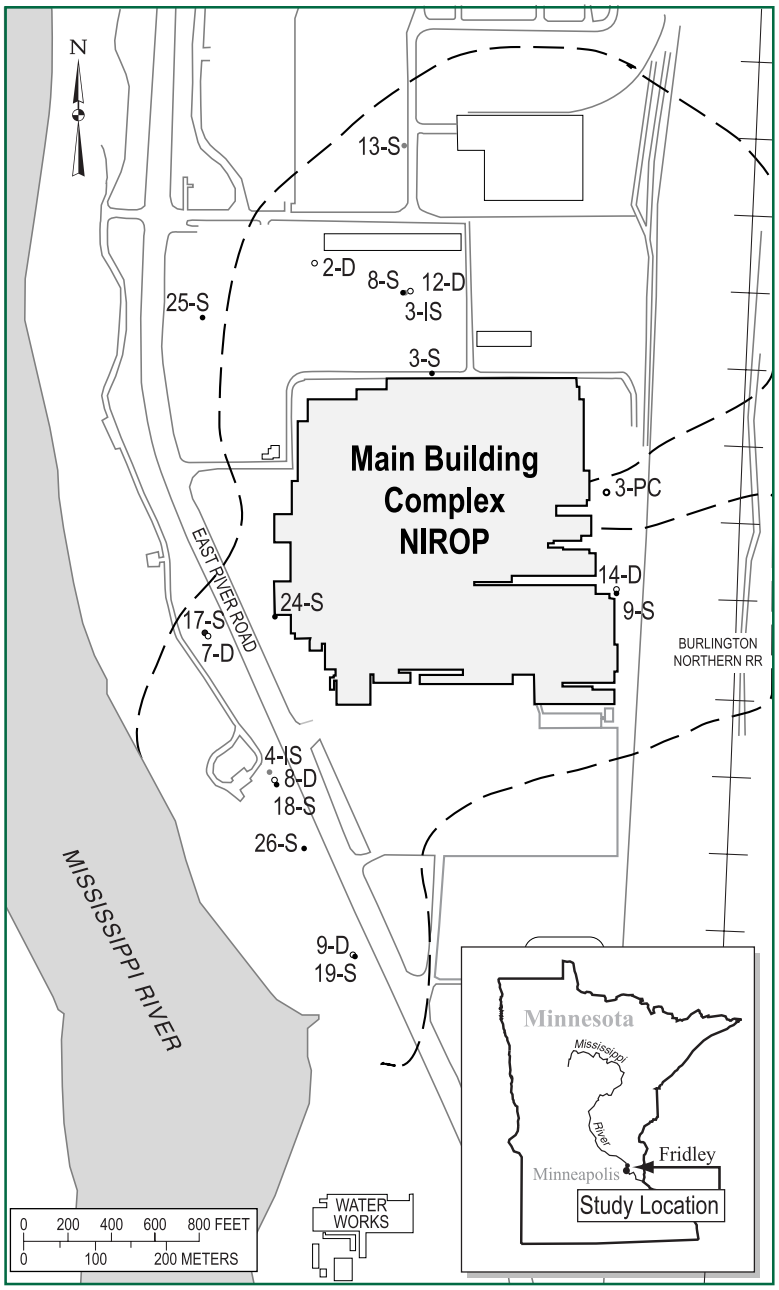
The Naval Industrial Reserve Ordnance Plant (NIROP), in Fridley, Minnesota, has been in operation since 1940. Activities at the plant resulted in ground-water contamination by chlorinated aliphatic hydrocarbons, primarily trichloroethene (TCE). The TCE contamination has migrated from the NIROP property and probably extends to the Mississippi River (fig. 1) (Tetra Tech NUS, Inc., 2000). As part of an effort to reduce long-term monitoring costs associated with well sampling, Southern Division Naval Facilities Engineering Command requested the U.S. Geological Survey to examine the potential for using PDB samplers as a low-cost alternative to the standard sampling approaches used at the site.

The uppermost aquifer system at NIROP consists of heterogeneous interbedded medium- to coarse-grained sands with layers of fine-grained sand

and gravel and low-permeability sediment layers ranging from silt to clay. The uppermost aquifer is referred to as an aquifer system because it can be roughly divided into two water-bearing zones varying substantially in thickness and hydraulic connection across the site. The shallowest zone ranges in thickness from 41 to 93 feet (ft), and the deeper zone ranges in thickness from 19 to 55 ft (Tetra Tech NUS, Inc., 2000). Most of the wells tested during this investigation are screened in this aquifer system. Beneath the uppermost aquifer system, and separated from it by a leaky confining unit, is a bedrock dolomitic limestone that functions as an aquifer; well 3-PC was open to this aquifer (fig. 1).

Purpose and Scope

The purpose of this report is to present the findings of an investigation to determine whether the use of PDB samplers is a viable VOC sampling method for observation wells at the site. The investigation involved comparing VOC concentrations in water obtained by using PDB samplers with VOC concentrations in water obtained by using the conventional purge-and-sample method routinely used at the site. In addition, VOC concentrations in water from PDB samples from selected wells collected with PDB samplers were compared with VOC concentrations in water obtained by low-flow sampling. PDB samplers were placed in 19 observation wells. Multiple PDB samplers were placed in 8 of the wells.



Base Map from Tetra Tech NUS, Inc., 2000

EXPLANATION

— —	APPROXIMATE EXTENT OF TRICHLOROETHENE CONTAMINATION IN SHALLOW GROUND WATER (TETRA TECH NUS, INC., 2000)
17-S	WATER-TABLE WELL IN (SHALLOW) UNCONSOLIDATED SEDIMENTS
9-D	DEEP WELL IN UNCONSOLIDATED SEDIMENTS
1-IS	INTERMEDIATE DEPTH WELL IN UNCONSOLIDATED SEDIMENTS
3-PC	BEDROCK WELL

Figure 1. Locations of sampling sites at the Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota, November 1999 to May 2000.

Acknowledgments

This investigation was funded by the U.S. Navy, Southern Division, Naval Facilities Engineering Command.

METHODS

Each PDB sampler consisted of a 2-inch diameter low-density polyethylene (LDPE) tube containing deionized water and heat-sealed at both ends. On the outside of each sampler, LDPE mesh provided abrasion protection. This sampling method is patented (patent number 5,804,743) and is available for nonexclusive licensing from the U.S. Geological Survey Technology Enterprise Office, MS-211, National Center, 12201 Sunrise Valley Drive, Reston, Virginia (telephone 703-648-4450; fax 703-648-4408).

PDB samplers were attached to weighted lines by plastic cable ties. In most wells, single PDB samplers were deployed at the approximate vertical centers of the saturated screened intervals.

PDB samplers were tested in 19 wells at NIROP (table 1; fig. 1). During the initial test, the samplers were deployed in October 1999, allowed to equilibrate approximately 30 days, and recovered in November 1999. Seventeen of the wells were instrumented with single PDB samplers, and two wells were instrumented with multiple PDB samplers. In a second test, multiple PDB samplers were deployed in seven wells in April 2000, allowed to equilibrate approximately 35 days, and recovered in May 2000.

Recovery of the PDB samplers consisted of removing them from the wells, cutting them open, and decanting the water into 40-milliliter (mL) volatile organic analysis (VOA) vials. The samples were preserved with hydrochloric acid, stored at approximately 4 degrees Celsius (°C), and transferred to a commercial laboratory for analysis using the U.S. Environmental Protection Agency (USEPA) method 8260b (U.S. Environmental Protection Agency, 1999).

During the November 1999 test, the wells were purged and sampled by the site contractor using the method typical for the site. This method consisted of first purging each well by removing at least three casing volumes of water and monitoring until the pH, specific conductance, and temperature stabilized. In well 12-D (fig. 1; table 1), this involved removing 300 gallons of water (four casing volumes). Once the well was purged, water samples for VOC analysis were collected by using the pump and then sent for analysis using USEPA method 8260b (U.S. Environmental Protection Agency, 1999) to the same laboratory that analyzed the PDB samplers.

Table 1. Well-construction details and number of passive diffusion bag samplers deployed, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota

[PDB, passive diffusion bag; DU, deep unconsolidated sediments; MU, middle unconsolidated sediments; DLS; deep limestone; SU, shallow unconsolidated sediments; NA, data not available]

Well number (fig. 1)	Screen length (feet)	Screened depth below top of casing (feet)		Zone	Number of PDB samplers deployed	
		Top	Bottom		Test 1 (1999)	Test 2 (2000)
2-D	10	102.3	112.5	DU	1	0
3-IS	10	67.4	77.4	MU	1	0
3-PC	27	132.9	159.6	DLS	6	6
3-S	15	19.7	34.8	SU	1	9
4-IS	10	66.9	76.9	MU	1	0
7-D	10	108	118	DU	1	0
8-D	10	118	128	DU	1	6
8-S	10	19.8	29.7	SU	1	4
9-D	10	114.3	124.3	DU	1	0
9-S	10	19.3	29.3	SU	1	0
12-D	10	122.9	132.9	DU	1	0
13-S	10	23.9	33.9	SU	1	0
14-D	10	82.6	92.6	DU	1	0
17-S	10	29	39	SU	1	0
18-S	10	30.8	40.8	SU	1	6
19-S	10	35	45	SU	1	5
24-S	15	21.7	36.7	SU	3	0
25-S	10	NA	NA	SU	1	0
26-S	NA	NA	NA	SU	1	5

A second test (April to May 2000) was done to provide further information in wells showing poor agreement. During the second test, VOC concentrations in multiple PDB samplers were compared with VOC concentrations collected by using low-flow methods.

The low-flow sampling approach (Barcelona and others, 1994; Shanklin and others, 1995) was used to reduce mixing due to the removal of large quantities of water during the purging process. Low-flow sampling for the second test consisted of pumping the wells at a rate of approximately 100 to 300 mL per minute until the temperature, pH, and specific conductance stabilized and no additional water-level drawdowns were observed. Typically, this required purging less than a gallon of water over a time period of approximately 15 minutes.

Four to nine PDB samplers were deployed in each of the seven wells during the second test. At all of the tested wells except well 3-S, a submersible positive-displacement pump was deployed at the same time as the PDB samplers. In well 3-S, an obstruction in the well prevented installation of the pump; therefore, a Tygon tube was attached to the PDB-sampler line at the time of sampler deployment. One end of the tube was open at the depth of the PDB sampler, and the other end extended to the surface for attachment to a peristaltic pump.

After field-parameter stabilization, water samples were collected for VOC analysis. The submersible pumps then were removed from the wells with the attached PDB samplers, and the water recovered in the PDB samplers was transferred to VOA vials. Both sets of samples were sent to a commercial laboratory for analysis using USEPA method 8260b (U.S. Environmental Protection Agency, 1999). The same general approach was used to sample well 3-S; however, well 3-S was sampled by low-flow methodology using a peristaltic pump.

FIELD TEST RESULTS AND CONCLUSIONS

A comparison of total 1,2-dichloroethene (1,2-DCE) and TCE concentrations obtained by using PDB samplers to concentrations obtained by using the conventional purge method in wells where one PDB sampler was deployed showed good agreement at several wells and poor agreement in others (table 2). For this investigation, good agreement was considered to be a concentration difference of less than 5 micrograms per liter (µg/L) for 1,2-DCE and to be a concentration difference of either less than 10 µg/L or less than 10 percent for TCE. Of the sites

Table 2. Comparison of total 1,2 dichloroethene and trichloroethene concentrations obtained by purge-and-sample method to concentrations obtained by using passive diffusion bag samplers in wells where a single passive diffusion sampler was deployed at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999

[1,2-DCE, total 1,2-dichloroethene; TCE, trichloroethene; PDB, passive diffusion bag; <, less than; >, greater than. Samples obtained by the purge-and-sample method were collected by a private consultant. Concentrations are in micrograms per liter (µg/L)]

Well number (fig. 1)	Sample date	1,2-DCE concentration		TCE concentration		Well volumes purged	Gallons of water purged
		PDB-sampling method	Purge-and-sample method	PDB-sampling method	Purge-and-sample method		
2.D	11/3/99	2.8	3.1	2.5	4.4	3	54
3-IS	11/3/99	6.4	4.2	69	42#	4	40
3-S	11/3/99	3.7	260#	38	730#	4	6
4-IS	11/4/99	53	57	860	910	3	27
7-D	11/3/99	<1	4.4	2.2	17#	3	180
8-D	11/4/99	52	12#	23	70#	4	260
8-S	11/3/99	440	620#	240	340#	4	8
9-D	11/3/99	10	9.1	68	62	4	240
9-S	11/3/99	22	19	180	160#	5	10
12-D	11/3/99	22	2#	14	24	4	300
13-S	11/2/99	<2	<2	<1	<1	3	9
14-D	11/2/99	<2	<2	<1	<1	3	156
17-S	11/3/99	71	68	40	42	3	9
18-S	11/4/99	130	650#	570	2,300#	4	12
19-S	11/3/99	15	19	410	610#	3	6
25-S	11/2/99	<2	<2	<1	<1	3	9
26-S	11/4/99	52	38#	2,900	3,800#	3	6

#Sites that showed poor comparison between methods (>5 µg/L difference between methods for total 1,2-DCE, >10 µg/L or >10 percent difference between methods for TCE).

that did not meet these criteria, samples from well 3-IS had higher 1,2-DCE and TCE concentrations in water from the PDB sampler than from the pumped sample, implying that higher concentrations were present in the well than were indicated by the pumped sample, and the PDB sampler better represented the higher concentrations. Samples from well 9-S had TCE concentrations that differed by 11 percent, but the concentration was higher in water from the PDB sampler than from the pumped sample, again implying that the PDB sampler better represented the higher concentrations. Samples from well 7-D had higher concentrations of TCE in water from the purged sample than in water from the PDB sample (table 2); however, some differences probably are to be expected after purging 180 gallons of water from the well.

Other wells showed substantially poorer agreement in VOC concentrations between the PDB samples and the conventional purge samples. In particular, wells 3-S, 8-S, 18-S, 19-S, and 26-S showed substantially higher VOC concentrations in water from the conventional purge sampling than in water from the PDB samplers (table 2). Examination of the data from two wells where multiple diffusion samplers were deployed during the first test (table 3) provides some clues as to a possible source of the poor agreement in some of the wells. At well 24-S, the analytical data show no significant concentration difference between sampling methods for 1,1-dichloroethane (1,1-DCA), 1,1-dichloroethene (1,1-DCE), 1,2-DCE, and TCE. Data from the PDB sampler, however, indicates the presence of relatively high 1,2-DCE concentrations and relatively low TCE concentrations near the top of the screen and the opposite near the base of the screen (fig. 2A). This may mean that the dechlorination potential is higher in sediment near the base of the screen than near the top of the screen or it may be the product of differential transport. In any case, it is apparent that the 1,2-DCE and TCE concentrations change over the screened interval. Thus, pumping the well would lead to mixing of these differing concentrations. Although the 1,2-DCE and TCE concentrations obtained by the conventional purging approach differs from the concentrations found in the PDB sampler from the same depth, it appears that the pumped sample represents an approximate average concentration across the screened interval (fig. 2A, table 3). The data suggest that some of the differences in results between the two methods may be from mixing of stratified contaminant concentrations by the purging of three or more casing volumes.

At well 3-PC, no contaminant stratification was apparent from the PDB-sampler data (fig. 2B); however, the tetrachloroethene (PCE) concentrations from the PDB sampler were approximately 15 µg/L lower than in water from the pumped sample. After purging 285 gallons of water, the contributing areas and sources of water sampled are probably much different between the conventional purged sample and waters in contact with the PDB sampler, thus leading to differences in concentrations of PCE. TCE and 1,2-DCE were not significant components in the contamination at well 3-PC.

Table 3. Concentrations of selected volatile organic compounds in water from multiple passive diffusion bag samplers and conventional purge sampling, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999

[1,1-DCA, 1,1-dichloroethane; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; PCE, tetrachloroethene; TCE, trichloroethene; PDB, passive diffusion bag sampler; P&S, conventional purge-and-sample method (samples were collected by private consultant); <, less than. Concentrations are in micrograms per liter]

Well number (fig. 1)	Sampling method	Depth below top of casing (feet)	1,1-DCA	1,1-DCE	1,2-DCE	PCE	TCE
3-PC	PDB	134.8	<1	<1	<2	22	1.7
3-PC	PDB	138.8	<1	<1	<2	23	1.7
3-PC	PDB	142.8	<1	<1	<2	25	1.7
3-PC	PDB	146.8	<1	<1	<2	24	1.7
3-PC	PDB	150.8	<1	<1	<2	24	1.6
3-PC	PDB	154.8	<1	<1	<2	25	1
3-PC	P&S	144.7	<1	<1	<2	40	2.7
24-S	PDB	24.3	3.5	1.9	780	<1	200
24-S	PDB	28.3	3.6	2.1	600	<1	350
24-S	PDB	32.3	2.4	1.4	380	<1	500
24-S	P&S	28.3	3.4	1.6	520	<1	330

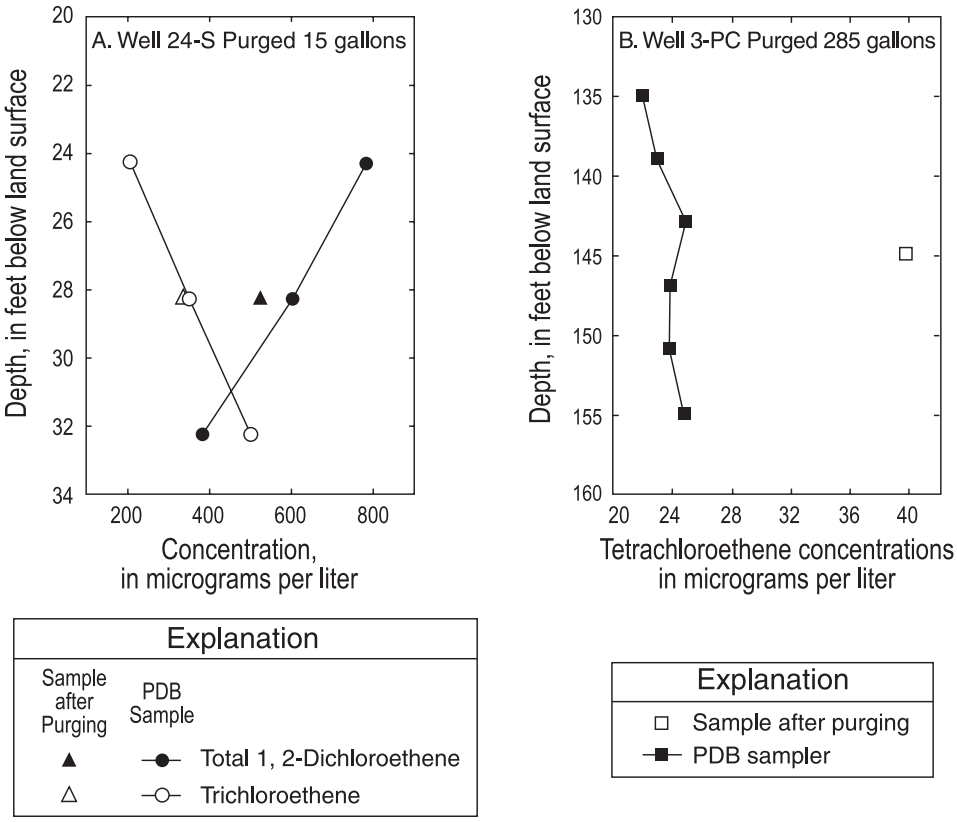


Figure 2. Comparison between passive diffusion bag (PDB) sampling method and conventional purge sampling method, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, November 1999.

To determine whether the differences between the methods could be attributed to mixing as a result of the conventional purging approach, seven of the wells where poor agreement was observed were resampled by using a combination of multiple PDB samplers and a low-flow purging method (table 4). At well 3-PC, where PCE concentrations differed by 15 µg/L between the conventional purge and the PDB samplers, resampling showed that the PCE concentrations in water from the PDB samplers and the low-flow sampling differed by only about 2 µg/L. These data suggest that purging 285 gallons during the first sampling adversely affected the results.

Well 18-S showed substantial differences in concentration between methods during the first sampling (table 2). Concentrations of 1,2-DCE and TCE were 650 and 2,300 µg/L, respectively, in water from the conventional purge method but only 130 and 570 µg/L, respectively, in water from the PDB sampler (table 2). During the second sampling, the PDB samplers showed that substantial stratification of VOCs is present over a vertical interval of approximately 6 ft (fig. 3A). TCE concentrations ranged from 470 µg/L at a depth of 31.48 ft to 1,600 µg/L at a depth of 37.61 ft (table 4). The 1,2-DCE concentration changed from 240 to 480 µg/L over the same interval. Although the TCE concentration from the low-flow sampling (1,000 µg/L) differs from the closest PDB samplers (1,300 and 1,600 µg/L), the low-flow-sampling concentrations are consistent with what would be expected from mixing the concentrations over the screened interval during pumping (fig. 3A). During the first round of sampling, the PDB sampler was positioned in the center of the well screen in an area where concentrations were substantially lower than near the base of the screened interval. Therefore, mixing of water across the screened interval during pumping could produce pumped concentrations exceeding those in the single PDB sampler, as shown in table 2. The data suggest that the VOC concentrations from the PDB samplers accurately reflect the VOC distribution in the screened interval. The data also suggest that the discrepancy between PDB, conventional

Table 4. Concentrations of selected volatile organic compounds in water from diffusion and low-flow sampling, Naval Industrial Ordnance Reserve Plant, Fridley, Minnesota, May 2000

[1,1,1-TCA, 1,1,1-trichloroethane; 1,1-DCA, 1,1-dichloroethane; 1,2-DCE, 1,2-total dichloroethene; PCE, tetrachloroethene; TCE, trichloroethene; PDB, passive diffusion bag; LF, low-flow; <, less than. Concentrations are in micrograms per liter]

Well	Sampling method	Depth below top of casing (feet)	1,1,1-TCA	1,1-DCA	1,2-DCE	Benzene	PCE	TCE
3-PC	PDB	135.6	<1.0	<1.0	<2.0	<1.0	8.3	1.6
3-PC	PDB	140.2	<1.0	<1.0	<2.0	<1.0	8.5	1.5
3-PC	PDB	145.3	<1.0	<1.0	<2.0	<1.0	8.8	1.7
3-PC	PDB	150.2	<1.0	<1.0	<2.0	<1.0	8.9	1.6
3-PC	PDB	157.1	<1.0	<1.0	<2.0	<1.0	9.5	1.7
3-PC	LF[+]	157.6	<1.0	<1.0	<2.0	<1.0	11	1.3
3-S	PDB	24.11	22	4.2	87	<2.0	<2.0	360
3-S	PDB	25.36	21	4.5	85	<2.0	<2.0	360
3-S	PDB	26.51	21	4.6	90	<2.0	<2.0	360
3-S	PDB	28.01	17	5	84	<2.0	<2.0	330
3-S	PDB	29.41	5.3	10	120	<2.0	<2.0	220
3-S	PDB	30.26	<2.0	16	160	<2.0	<2.0	280
3-S	PDB	31.41	<2.0	15	190	<2.0	2.5	390
3-S[R]	PDB	31.41	<2.0	15	190	<2.0	2.8	410
3-S	PDB	32.61	<5.0	<5.0	180	<5.0	<5.0	380
3-S	LF[#]	30.11	15	8.3	130	<2.0	<2.0	360
8-D	PDB	119.1	<1.0	1	40	5	<1.0	16
8-D	PDB	121.2	<1.0	1.1	41	5	<1.0	17
8-D	PDB	122.9	<1.0	1	40	4.8	<1.0	17
8-D	PDB	124.9	<1.0	1	40	4.9	<1.0	17
8-D	PDB	126.5	<1.0	1.1	41	4.8	<1.0	17
8-D	LF[+]	124.9	<1.0	1.1	38	3.1	1.1	26
8-S	PDB	22.45	<2.0	<2.0	110	<2.0	3.5	230
8-S	PDB	25.2	<2.0	<2.0	110	<2.0	3.9	260
8-S	PDB	30.1	<5.0	<5.0	640	<5.0	<5.0	170
8-S	LF[+]	29.45	<10	<10	740	<10	<10	230
18-S	PDB	31.48	<5.0	<5.0	240	<5.0	<5.0	470
18-S	PDB	32.66	<5.0	<5.0	260	<5.0	<5.0	500
18-S	PDB	33.71	<10	<10	220	<10	<10	940
18-S	PDB	35.71	<10	<10	450	<10	<10	1,300
18-S	PDB	37.61	<10	<10	480	<10	<10	1,600
18-S	LF[+]	36.86	<10	<10	380	<10	<10	1,000
19-S	PDB	35.86	<1.0	3.1	8.5	<1.0	3.1	130
19-S	PDB	38.11	<2.0	3.4	15	<2.0	<2.0	310
19-S	PDB	39.86	<1.0	2.9	8.7	<1.0	2.8	140
19-S	PDB	43.06	<1.0	3.5	9.1	<1.0	3.1	120
19-S	LF[+]	42.26	<1.0	2.6	11	<1.0	2.4	160
26-S	PDB	32.76	<20	<20	86	<20	<20	2,700
26-S	PDB	34.71	<20	<20	53	<20	<20	3,400
26-S	PDB	39.91	<20	<20	56	<20	<20	2,900
26-S	LF[+]	39.16	<20	<20	<40	<20	<20	2,000
26-S[R]	LF[+]	39.16	<1.0	<1.0	37	<1.0	<1.0	2,000

[R]Replicate sample.
[+]Sample collected using submersible positive-displacement pump.
[#]Sample collected using peristaltic pump.

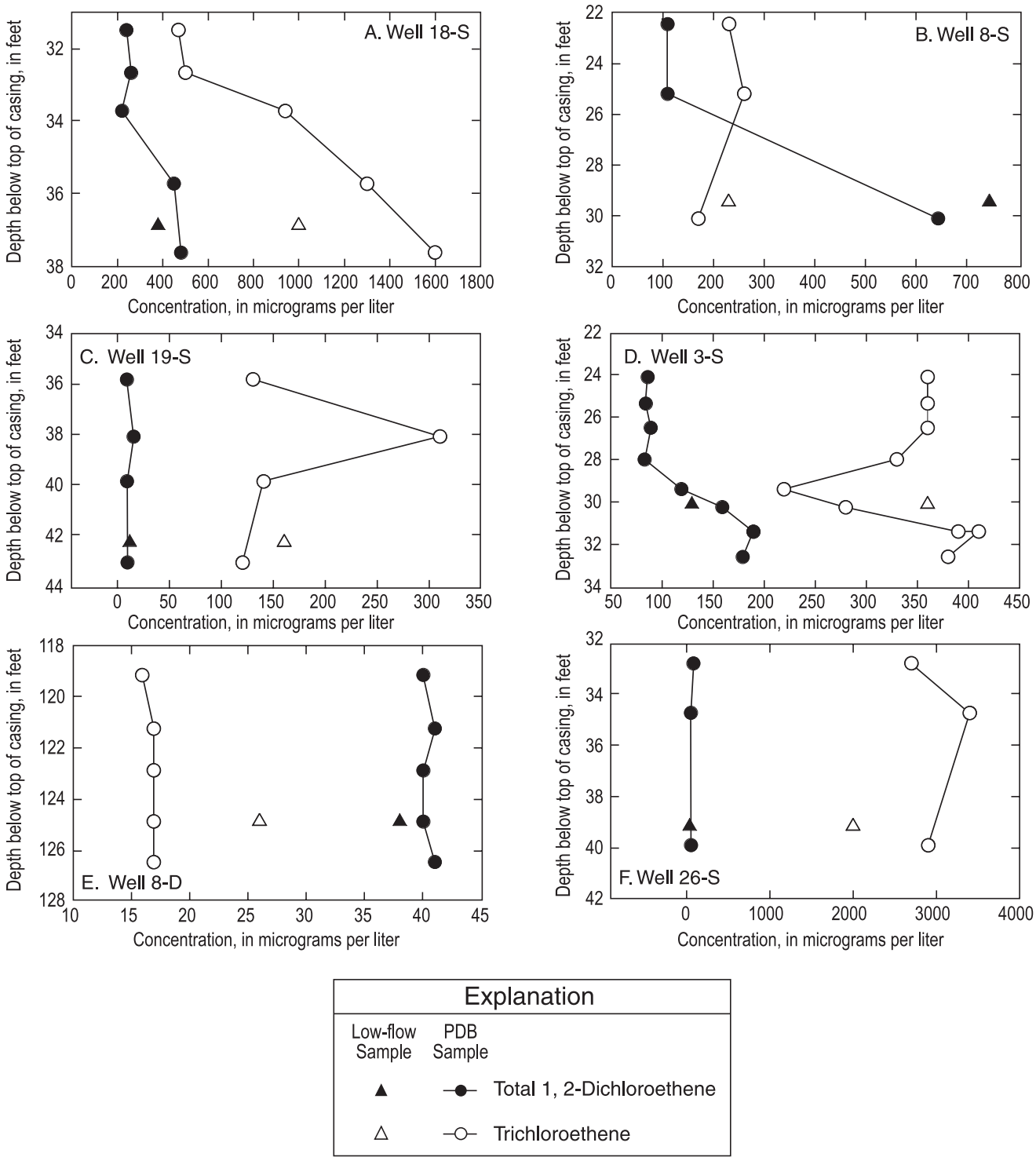


Figure 3. Comparison between passive diffusion bag (PDB) samples and low-flow samples in resampled wells, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, May 2000.

purge, and low-flow purge sample concentrations is caused by mixing of the stratified contamination or of areally heterogeneous concentrations during pumping.

A similar argument can be postulated to explain the substantial differences in concentration between the two methods at well 8-S during the first round of sampling (table 2). The resampling with multiple PDB samplers shows that concentrations shallower than 26 ft deep differ from those at 30 ft deep (fig. 3B). The TCE concentration in the low-flow sample is an approximate average of the concentrations measured across the length of the well screen with the PDB samplers. The 1,2-DCE concentration is higher in water from the low-flow sample than from the PDB sampler; however, this may be expected in an area where the 1,2-DCE concentration increased with depth from 110 to 640 µg/L over an interval of 5 ft (fig. 3B). Because the low-flow sample was collected from the base of the interval, it is not unreasonable to suppose that concentrations continued to increase with depth below the sampled interval, and that the low-flow sample represents an integration of water that included higher concentrations than were evident from the PDB samplers. Thus, the data are again consistent with the hypothesis that the PDB samplers accurately reflected the ambient VOC concentrations.

Well 19-S is another well where discrepancies were noted between TCE concentrations from the conventional-purge samples and the PDB samples (table 2). Resampling the well by using multiple PDB samplers and low-flow sampling again showed substantial discrepancies in the TCE concentrations; however, examination of the vertical TCE-concentration distribution strongly suggests that the low-flow sample represents a mixing of stratified TCE layers in the screened interval (fig. 3C). The data again suggest that the PDB samplers provided an accurate representation of ambient concentrations. The difference in TCE concentrations measured between the two sampling events (410 to 610 µg/L in November 1999 and 130 to 310 µg/L in May 2000) is consistent with observation that TCE concentrations have shown substantial temporal variability in previous years (Keith Henn, Tetra Tech NUS, written commun., 2000).

Substantial discrepancies in the 1,2-DCE and TCE concentrations between the PDB sampling and the conventional sampling also were observed in water from well 3-S during the first test (table 2). A possible explanation for the poor agreement is that the diffusion sampler was not properly positioned. When the sampler was recovered, at least 5 ft of line that was intended to be below the water table was dry, implying that the diffusion sampler was inadvertently placed too shallow and possibly even partially above the water table. Thus, a comparison of the two approaches during the first test may be inappropriate. During the second test at the well, however, data from the PDB samplers showed that concentrations of 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethane (1,1-DCA), 1,2-DCE, and TCE were stratified along the length of the well screen (fig. 3D, table 4). The data suggest that the low-flow sampling represents an averaging of concentrations, whereas the PDB sampler represents concentrations at points (fig. 3D).

In wells 8-D and 26-S, no substantial vertical concentration stratification was observed (figs. 3E, 3F), despite the substantial difference in concentrations obtained by the PDB samplers and the conventional purge sampling (table 2). When well 8-D was sampled by using low-flow purging, the concentrations from the pumped sample were similar to those in the PDB samplers (0.1-µg/L difference for 1,1-DCA, 3-µg/L difference for 1,2-DCE, 1.8-µg/L difference for benzene, and 9-µg/L difference for TCE) (table 4). The concentration discrepancy obtained while using the conventional purge approach probably was a reflection of pumping 260 gallons of water and may represent lateral mixing of chemically heterogeneous water. At well 26-S, TCE concentrations obtained by using the conventional purge approach were substantially higher than in water from the PDB sampler (table 2), and concentrations obtained by using low-flow sampling were substantially lower than those in water from the PDB sampler (fig. 3F). These data and the previous discussion suggest that the pumped sample integrated water with different concentrations than those that were present in the screened interval of the well.

SUMMARY

VOC concentrations from PDB samplers were compared to VOC concentrations from conventional purge sampling and low-flow purge sampling in side-by-side tests at NIROP, in Fridley, Minnesota. PDB samplers were tested in 19 wells at NIROP. The samplers were deployed in October 1999, allowed to equilibrate approximately 30 days, and recovered in November 1999. In a second test, PDB samplers were deployed in 7 wells in April 2000, allowed to equilibrate approximately 35 days, and recovered in May 2000.

A comparison of 1,2-DCE and TCE concentrations obtained by using PDB samplers and the conventional purge method in wells where one PDB sampler was deployed showed good agreement at several wells but poor agreement in others. For this investigation, good agreement was considered to be less than 5 µg/L difference for 1,2-DCE and less than 10 µg/L or less than 10 percent difference for TCE. Of the sites that did not meet these criteria, some sites (wells 3-IS and 9-S) had higher concentrations in water from the PDB sampler than in water from the conventional purge sample, implying that the PDB sampler more accurately reflected the local concentrations.

Concentration data from multiple diffusion samplers during the conventional-purge sampling and during the low-flow sampling indicates that the VOC concentrations in many of the wells are stratified within the screened interval. At well 18-S, TCE concentrations ranged from 470 to 1,600 µg/L over a vertical distance of approximately 6 ft. In this and other wells where stratification was observed, the concentration in the pumped sample appears to represent a mixing of waters having differing concentrations, whereas the PDB samplers represent localized concentrations. Other discrepancies between VOC concentrations from the conventional purge method and the PDB samplers appear to be related to the removal of multiple casing volumes of water (in some cases more than 100 gallons) prior to sampling. The data suggest that the VOC concentrations from the PDB samplers accurately reflect the VOC distribution in the screened interval of the tested wells. The data further suggest that PDB samplers are a viable method for sampling ground-water VOCs at NIROP. Multiple diffusion samplers may be required at some sites where contaminant stratification is present in the screened or open interval.

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