Passive Diffusion Samplers: Cost Effective Sampling Techniques for Sampling Groundwater

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ABSTRACT

For several years now Passive Diffusion Sampler (PDS) technology has been applied to many sites to improve the information gained during monitoring and to reduce the cost of sampling. Wide acceptance of these samplers has been gained for hydrophobic Volatile Organic Compounds (VOCs) using the polyethylene bag technique with hundreds of studies demonstrating their effectiveness since 1998. While this material is extremely useful for these specific target analytes, there is a need to identify additional materials that would enable similar performance for hydrophilic organics, semivolatile organics and inorganic target analytes as well. Additional studies using new materials have been underway and progress can be reported on two additional options.

These include:
Nylon-Screen Diffusion Sampler (NSDS)
Rigid Porous Polyethylene Samplers (RPPS)

Along with USGS, efforts to develop passive diffusion samplers for common long term monitoring inorganic and organic parameters include both laboratory and field demonstration studies. Recent data will be presented to demonstrate the performance and feasibility of these materials in prototype sampler designs.

INTRODUCTION

The use of passive diffusion sampler technology for groundwater monitoring projects provides cost-saving alternatives to conventional sampling methodologies, eliminating well purging and decreasing field labor and waste disposal costs. In typical applications, they provide depth-specific, time-weighted samples of dissolved phase analytes of concern. Like all sampling methods, these techniques have their own characteristic strengths and limitations that determine their applicability given the data quality objectives, contaminants of concern, and hydrology of the wells being monitored. The three types of samplers to be discussed are the polyethylene diffusion bag sampler (PDBS), the nylon-screen diffusion sampler (NSPDS) and the rigid porous polyethylene sampler (RPPS)

All three samplers rely on natural advective movement of groundwater across the open interval and, in the absence of vertical flow in the well, reflect dissolved phase concentrations of analytes in the aquifer immediately adjacent to the well screen.

POLYETHYLENE DIFFUSION BAG SAMPLERS (PDBS).

Developed and patented by Don Vroblesky of the USGS and Thomas Hyde of General Electric, PDBS are made of low-density polyethylene, which acts as a semi-permeable membrane. The membrane is fashioned into a long sealed tube, typically 24 inches long and 1 ¼ inches in

diameter, filled with approximately 230 mL of certified, laboratory-grade, deionized water (Fig. 1). Different sizes are available to meet sampling requirements. The PDBS is lowered into a groundwater well and suspended at a specific depth in the saturated portion of the open (screened) interval of the well. Most VOCs, excluding certain ketones, ethers and alcohols, diffuse though the membrane. Diffusion occurs until equilibrium is established between VOC concentrations in the groundwater and those in the PDBS. The PDBS is then raised to the surface and the contents transferred immediately into vials, which are sent to laboratories for analysis. Pictured below is a filled PDBS with an optional mesh protective sleeve, deployment line, attachment clips and weight.

Figure 1: Passive Diffusion Bag Sampler
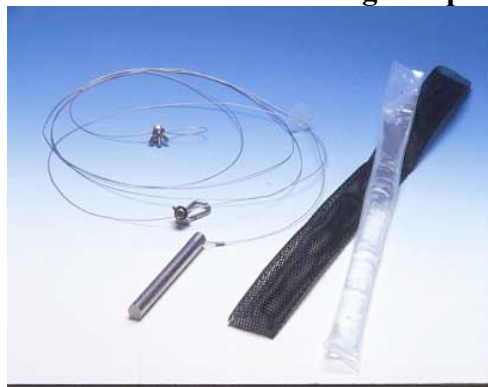
In laboratory studies, the VOCs in Table 1 were shown to exhibit good diffusion and good correlation with samples taken by other methods. Compounds exhibiting poor correlation are also shown.

Table 1[1]

VOAs showing good correlations between samples taken with PDBS and water outside the PDBS

Benzene	Dibromochloromethane	*trans*-Dichloroethene	1,1,2-Trichloroethane
Bromodichloromethane	Dibromomethane	1,2-Dichloropropane	Trichloroethene
Bromoform	1,2-Dichlorobenzene	*cis*-1,2-Dichloropropene	Trichlorofluoromethane
Chlorobenzene	1,3-Dichlorobenzene	1,2-Dibromoethane (EDB)	1,2,3-Trichloropropane
Carbon tetrachloride	1,4-Dichlorobenzene	*trans*-1,3-Dichloropropene	1,1,2,2Tetrachloroethane(PCA)
Chloroethane	Dichlorodifluoromethane	Ethyl benzene	Tetrachloroethene
Chloroform	1,2-Dichloroethane	Naphthalene	Vinyl chloride
Chloromethane	1,1-Dichloroethene (1,1-DCE)	Toluene	Xylenes
2-Chlorovinyl ether	*cis*-1,2-Dichloroethene	1,1,1-Trichloroethane	

Compounds showing poor correlations

Acetone[2]	Methyl-*tert*-butyl ether (MTBE)	Styrene	Methyl-*iso*-butyl ketone[2] (MIBK)

1. Vroblesky, D.A. and T.R. Campbell, (2001), equilibration Times, Stability & Compound Selectivity of Diffusion Samplers for Collection of Groundwater VOC Concentrations, Adv. Env. Res. 5(1); pp 1-12
2. Sivavec, T.M. and S.S. Bagel, 2000. General Electric Company, written communication.

Hydrologic and field data suggest that PDBs be left in place at least two weeks to allow ample time for equilibration of contaminant distribution and restabilization of the well and flow-dynamics to occur after PDB deployment (possibly longer for less permeable formations). In quarterly, semiannual and annual monitoring situations, PDBs are deployed and left in place

until the next sampling round, allowing sample collection and deployment of the next sampling round's PDBS to occur during a single field event.

Ions, large or strongly polar molecules, and hydrophilic compounds do not diffuse well across polyethylene. Therefore, some contaminants of interest, like semivolatile organics, oxygenates, metals and other inorganic parameters are not candidates for sampling by PDB technology. However, the diffusion characteristics of PDBs can solve problems that plague samplers of alkaline or turbid wells. Because sediment, including colloidal clay particles, cannot diffuse into PDBs, turbidity and associated matrix interference will cease to be a problem. Similarly, the foaming and loss of VOCs that can occur when sampling alkaline groundwater into pre-preserved VOA vials is avoided because alkaline constituents diffuse very poorly, if at all, into PDBs.

Disproportionate contribution from individual aquifer zones lying within or adjacent to the zone of interest is avoided through use of PDBs. Pumping, even by low-flow methods, produces a flow-weighted sample biased toward water from any zone of higher hydraulic conductivity. These effects can cause sample dilution or contamination. Dependant only on horizontal flow through the open interval of the well, PDBS sampling avoids aquifer pumping stress and associated sample agitation, so samples taken through the use of PDBS technology are more likely to be representative of aqueous phase VOCs in the aquifer directly adjacent to target interval than samples taken by other methods.

The PDBS' ability to reflect dissolved VOC concentrations in the adjacent aquifer allows determination of stratification and vertical concentration gradients of VOC contaminants. Generally, each two foot-long PDBS represents not more than five feet of the well screen interval. VOC concentrations may be measured at specific well screen depths by hanging PDBS in tandem. In addition to gaining information about the well's hydrogeological attributes, correct positioning of a future single PDBS may be determined.

In a cost evaluation study at McClellan AFB, the costs associated with use of PDBS, passive Diffusion Multi Layer Samplers (DMLS™), low-flow purge (MicroPurge®), and conventional purge sampling methods were compared. The PDBS cost $65 per sample, compared to from $308 to $555 per sample for the other methods (Parsons Engineering, Inc. 1999)

In a subsequent study at McClellan AFB, a cost comparison of PDBS, Micropurge® and conventional purge methods was made (McCellan AFB, 2000). The comparison assumed one VOC sample tested per monitoring well per year (exclusive of quality control samples) for 500 wells, tested at a frequency of 125 wells per quarter and 5% field duplicates. Capital costs were $9,000 for the PDB compared to $11,800 to $12,525 for the other methods. One-time costs were $32,500 for both the PDB and conventional purge, and zero for the MicroPurge. Most notably, however, annual recurring costs were $98,000 for the PDB compared to $412,000 for the MicroPurge and $377,000 for the conventional purge (the latter two costs include disposal of purge water).

Through the Interstate Technology Regulatory Cooperation's (ITRC) Diffusion Sampler Work Group (DSWG), a wealth of data on deployments and side-by-side comparisons of the use of PDBS technology and conventional sampling technologies (purge and bail, moderate- and low-flow- rate pumping, and MicroPurge® technologies) has been gathered. It is available on the

ITRC's website at www.itrcweb.org under the Diffusion Samplers and includes the USGS's User Guide for Deployment of the PDBs (Vroblesky, 2001), and the ITRC DSWG's Recommendations for the Use of PDBS for Long-Term Monitoring of Volatile Organic Compounds in Groundwater (2002). The DSWG consists of representatives from the USAF, US Navy, US EPA, USGS, ACOE, private industry and six different state agencies. It is through this group's unbiased efforts that great strides have been made in the regulatory communities' acceptance of the use of PDBS technology.

NYLON-SCREEN PASSIVE DIFFUSION SAMPLER

Nylon-screen passive diffusion samplers (NSPDS) were developed by Don Vroblesky of the USGS to sample for a broader range of analytes than can be collected by PDBS.

A NSPDS typically consists of a 175 mL polypropylene wide mouth bottle (diameter of 62 mm at top, 58 mm at bottom and a height of 58 mm) filled with analyte-free water, with a 125 micron-mesh nylon screen placed across opening and covered with a cap that has an opening of about 58 mm in diameter (Fig. 2). The resulting bottle volume to diffusion area (V/A—see Webster et al, 1998) is about 60 or about equal to the height of the bottle.

**Figure 2: Nylon-Screen Passive Diffusion Sampler**

Sample volume may be a concern if using these devices to test for a wide range of analytes. They can be stacked in a mesh sleeve if additional volume is needed. The minimum required sample volume to conduct most standard analyses may be much less than the typically requested volume, depending on the choice of analytical methods and desired detections. Prior coordination with the laboratory could eliminate volume limitation as a concern. The ITRC DSWG, in conjunction with three well-respected commercial laboratories, put together a list of minimum volumes needed for the most common groundwater parameter analyses. It may be found on the ITRC's website at www.itrcweb.org.

For deployment in wells, the NSPDS samplers are placed inside a mesh liner, which is attached to the hanging line with zip ties. The nylon-screen is faced downward to minimize mixing of water in the samplers during recovery. The screen retains the water in the bottle by means of a vacuum. Over time, chemicals diffuse across the nylon-screen and equilibrate with the water inside the sampler. Upon retrieval, the contents of the sampler are transferred to laboratory sample containers or blank caps are used to replace the cutout cap holding the screen and the sampler bottles themselves are sent to the laboratory for analysis.

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NSPDS of a smaller volume initially were tested in field studies in 2002 by Vroblesky, Petkewich and Campbell. They looked at an arsenic-contaminated ground-water-discharge zone beneath a stream and collected samples for arsenic, calcium, chloride, iron, manganese, sulfate, and dissolved oxygen. Data indicated that, in general, nylon-screen diffusion samplers are capable of obtaining concentrations of inorganic solutes in groundwater that correspond to concentrations obtained by low-flow sampling and that NSPDS in stream-bed sediment can be used to locate contaminant-discharge zones of ground-water inorganic solutes.

In January 2003 Columbia Analytical Services, in cooperation with criteria developed by Don Vroblesky of the US Geological Survey (USGS), conducted equilibration studies for the larger volume (175 mL) nylon-screen samplers and included VOCs (Benzene, PCE, TCE, and 1,4 dioxane) as well as inorganic constituents, perchlorate, chloride, arsenic, and iron. All contaminants exhibited excellent diffusion from the test jars into the sampler water and equilibration was generally achieved in 24 hours. Further studies were conducted by Columbia Analytical Services in April of 2003 (Vroblesky, Scheible, and Teall, 2003) on a suite of metals, and again, with the exception of silver, the nylon-screen samplers showed good migration from test jars into sampler water (Fig. 3). Subsequent studies by Columbia in August 2003 with samplers more suitable for 2-inch diameter wells (30 and 60 mL bottles with heights of about 60 mm and V/As of up to 175) showed poor comparisons with water in test jars. This would suggest that these samplers are suitable for use in larger diameter wells (4" or larger).

Figure 3: Nylon-Screen 4-day lab test of metals (CAS, April 2003)
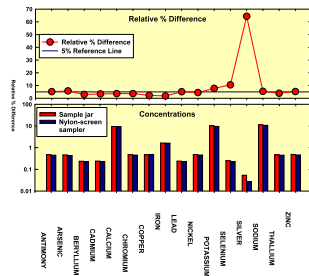
More recent field trials (Environmental Alliance, August 2004, for perchlorates and BBL, October 2004, for 1,4- dioxane) used samplers with bottles of 60 V/A and results were very good for both perchlorate and 1,4 dioxane. Additional field studies are planned in 2005.

Sampling for reduction-oxidation (redox)-sensitive metals, such as lead, iron, and manganese, in an open borehole with NSPDS (or other passive in-well methods) should be approached with caution, specifically if the aquifer at the well screen is anaerobic and the water in the borehole has become aerobic through oxygenation via the air-water interface. To avoid oxidation and

precipitation of redox-sensitive metals, it may be necessary to use anaerobic water as the sampler filling solution. However, when deployed in anaerobic water, the fill solution in the diffusion sampler becomes anaerobic by diffusion. Insufficient work has been done to determine whether prefilling with anaerobic water is necessary.

RIGID POROUS POLYETHYLENE SAMPLERS

Rigid porous polyethylene samplers (RPPS) were also developed by Don Vroblesky of the USGS to sample for a broader range of analytes than can be collected by PDBS.

RPPS consist of a 1.5-inch outside diameter (OD), 6-7-inch-long, rigid polyethylene tube with caps on both ends (Fig. 4). The tube is constructed from thin sheets of foam-like porous polyethylene with pore sizes of 6 to 15 microns. The sampler is filled with water free of the target analytes, capped at both ends, placed inside a mesh liner, which is subsequently attached to a deployment rope using cable-ties and deployed in a well. Over time, chemicals diffuse across the porous polyethylene and equilibrate with the water inside the sampler. Upon retrieval, the contents of the sampler are transferred to laboratory sample containers.

Figure 4 – RPPS with (top) and without (bottom) mesh covering used to secure sampler to deployment rope.

The original RPPS were designed with stop cocks at each end to facilitate transfer of sample to the sample containers. This design did leak from membrane pores. Subsequent designs replaced the stop cock caps with a simple cap at one end and a plug at the other. The RPPS is deployed plug-down in the well. When the RPPS is retrieved it is inverted, the plug is removed, and the contents poured into the sample bottles immediately. Leakage is minimized and sample transfer into the bottles is much quicker.

Tests performed to date indicate that the maximum feasible sampler length is approximately 7.5 inches. Use of a longer sampler results in leakage of sampled water out of the sampler walls due to the higher head pressure present in the sampler (Vroblesky, 2004). For a sampler having a diameter of 1.5 inches OD, the resultant sample volume is about 175 mL. Larger volumes can be obtained by using a larger-diameter sampler, when the well diameter allows, or by using multiple

samplers attached end-to-end or side-by-side. It should be noted that the minimum required sample volume to conduct most standard analyses may be much less than the typically requested volume, depending on the choice of analytical methods and desired detections. Prior coordination with the laboratory could eliminate this minimum volume limitation as a concern. The ITRC DSWG, in conjunction with three well-respected commercial laboratories, put together a list of minimum volumes needed for the most common groundwater parameter analyses. It may be found on the ITRC's website at www.itrcweb.org.

In an early bench-scale test, results indicated that this type of sampler could yield accurate results for some VOCs (including MTBE), chromium, and chloride (Vroblesky, 2004). The equilibration time for VOCs and chloride is 8 days or less. Solutes in the samplers had achieved equilibrium with the solutes in the test solution by the first sampling time, 8 days after deployment. The equilibration time for chromium was less certain because reliable samples for chromium were not collected until the 22nd day, at which time chromium concentrations in the sampler had fully equilibrated with the test water.

RPPS devices were included in a field demonstration of multiple passive groundwater sampling devices at the former McClellan AFB (Sacramento, California) in 2004 (Demonstration of Alternative Groundwater Sampling Technologies at McClellan AFB, Parsons, unpublished, expected publication in 2005). According to the preliminary data, the RPPS performed well for monitoring for anions, metals and hexavalent chromium. While performing similarly to the low-flow purge method, the RPPS did not work as well as the other passive devices in this study for VOCs and 1,4-dioxane.

The RPPS are undergoing laboratory testing and field trials in 2005. The additional laboratory and field tests will further determine the applicability of these devices to the full range of analytes that are of interest in groundwater. In a recent laboratory study, the RPPS worked quite well for anions, most metals, hexavalent chromium and 1,4-dioxane, as seen in Tables 2 through 4 (Columbia Analytical Services, Inc., 2005).

Table 2: Metals

	14-day Deployment			21-day Deployment		
Metals	Jar (mg/L)*	RPPS (mg/L)	% Migration**	Jar (mg/L)*	RPPS (mg/L)	% Migration**
Antimony	0.0878	0.0810	92%	0.0847	0.0799	94%
Arsenic	0.0840	0.0768	91%	0.0853	0.083	97%
Barium	0.0900	0.0845	94%	0.0884	0.084	95%
Beryllium	0.0855	0.0749	88%	0.0867	0.0787	91%
Cadmium	0.0885	0.0782	88%	0.0900	0.0829	92%
Chromium	0.169	0.152	90%	0.177	0.160	90%
Cobalt	0.0892	0.0797	89%	0.0918	0.0851	93%
Copper	0.148	0.0927	63%	0.546	0.276	51%
Nickel	0.871	0.628	72%	0.972	0.819	84%
Selenium	0.0715	0.0687	96%	0.0746	0.0744	100%
Silver	0.0466	0.0141	30%	0.0391	0.0147	38%
Thallium	0.0805	0.0858	107%	0.0890	0.0852	96%
Vanadium	0.0852	0.0762	89%	0.0872	0.0809	93%
Zinc	0.0968	0.104	107%	0.098	0.0972	99%

 * 20 L Glass carboy
** Sampler concentration/Jar concentration X 100

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Table 3: 1,4-Dioxane

	14-day Deployment			28-day Deployment		
	Jar (ug/L)*	RPPS (ug/L)	% Migration**	Jar (ug/L)*	RPPS (ug/L)	% Migration**
1,4-Dioxane	80	74	92.50%	64	67	104.69%

 * 20 L Glass carboy
** Sampler concentration/Jar concentration X 100

Table 4: Wet Chemistry

Wet Chemistry	14-day Deployment		
	Jar Conc. (*u*g/L*)	Sampler Conc (*u*g/L)	% Migration**
Perchlorate	18	18	100%
Chloride	14.7	14.6	99%
Hexavalent Chromium	0.0800	0.0763	95%
Nitrate Nitrogen	6.40	6.36	99%
Sulfate	4.07	4.74	116%

 * 20 L Glass carboy
** Sampler concentration/Jar concentration X 100

In this study the RPPS worked well for volatiles, except for those of low water solubility (see Table 5-6, Columbia Analytical Services, 2005). It is theorized that the less soluble compounds partially sorbed to the polyethylene material.

Table 5: Volatile Organic Compounds

Volatile Organics	Spiked Conc.	Solubility (g/100 mL)	14-day Deployment		
			Jar Conc. (*u*g/L)*	RPPS Conc (*u*g/L)	% Migration**
Acetone	160	very	150	160	107%
Benzene	77	0.18	60	60	100%
Bromodichloromethane	89	0.6735	74	73	99%
Bromoform	91	0.301	55	58	105%
Bromomethane	66	1.522	60	56	93%
2-Butanone (MEK)	110	25.6	105	105	100%
Methyl tert-Butyl Ether (MTBE)	99	5.1	92	95	103%
Carbon Disulfide	72	0.1185	54	50	93%
Carbon Tetrachloride	64	0.08048	21	35	167%
Chlorobenzene	71	0.0497	28	41	146%
Chloroethane	76	0.574	73	65	89%
Chloroform	1500	0.795	1400	1300	93%
Chloromethane	77	0.5325	75	72	96%
Dibromochloromethane	80	0.4	62	62	100%
1,1-Dichloroethane	84	0.506	76	74	97%
1,2-Dichloroethane (EDC)	99	0.8608	86	86	100%
1,1-Dichloroethene	68	0.225	52	49	94%
cis-1,2-Dichloroethene	75	0.08	66	63	95%
trans-1,2-Dichloroethene	68	0.63	56	53	95%
1,2-Dichloropropane	87	0.27	74	76	103%
cis-1,3-Dichloropropene	81	<0.1	57	53	93%
trans-1,3-Dichloropropene	80	<0.1	58	56	97%
Ethylbenzene	60	0.0206	11	31	282%
2-Hexanone	99	1.4	91	92	101%
Methylene Chloride	88	1.32	82	77	94%
4-Methyl-2-pentanone (MIBK)	98	1.9	90	91	101%

Volatile Organics, (continued)	Spiked Conc.	Solubility (g/100 mL)	14-day Deployment Jar Conc. (ug/L)	RPPS Conc (ug/L)	% Migration*
Styrene	68	0.032	17	34	200%
1,1,2,2-Tetrachloroethane	88	0.2962	79	78	99%
Tetrachloroethene (PCE)	57	0.015	5	21	420%
Toluene	68	0.0526	30	40	133%
1,1,1-Trichloroethane (TCA)	58	0.1495	40	45	113%
1,1,2-Trichloroethane	83	0.442	75	74	99%
Trichloroethene (TCE)	62	0.442	33	39	118%
Vinyl Chloride	64	0.11	61	58	95%
o-Xylene	68	0	9	32	356%
m+p-Xylenes	130	0	17	56	329%

 * 20 L Glass carboy
** Sampler concentration/Jar concentration X 100

Table 6: Methane, Ethane, Ethene

Analytes	Spiked Conc.	14-day Deployment Jar Conc. (ug/L)	RPPS Conc (ug/L)	% Migration*
Methane	11	9.1	10	109%
Ethane	22	18	21	116%
Ethene	20	19	20	105%

 * 20 L Glass carboy
** Sampler concentration/Jar concentration X 100

Studies were also performed for semivolatile compounds, this time using 4 L glass carboys. Again sorbing of poorly soluble compounds was evidenced (Table 7, Columbia Analytical Services, Inc., 2005).

Table 7: Semivolatile Organics

Semivolatiles Analytes (Spiked at 264 ug/L)	7-day Deployment Jar Conc	RPPS Sampler Conc.	% Migration*	14-day Deployment Jar Conc	RPPS Conc.	% Migration*	21-day Deployment Jar Conc.	RPPS Conc.	% Migration*
N-Nitrosodimethylamine	190	120	63%	240	250	104%	220	220	100%
Aniline	220	140	64%	63	210	333%	170	170	100%
Bis(2-chloroethyl) Ether	220	190	86%	230	220	96%	210	220	105%
Phenol	220	120	55%	220	210	95%	210	210	100%
2-Chlorophenol	220	190	86%	230	220	96%	210	220	105%
1,3-Dichlorobenzene	48	0	0%	26	15	58%	24	20	83%
1,4-Dichlorobenzene	48	0	0%	28	19	68%	27	23	85%
1,2-Dichlorobenzene	56	0	0%	33	21	64%	32	28	88%
Benzyl alcohol	220	81	37%	210	190	90%	240	220	92%
Bis(2-chloroisopropyl) Ether	190	160	84%	180	170	94%	190	190	100%
2-Methylphenol	220	140	64%	240	220	92%	220	230	105%
Hexachloroethane	44	2	5%	21	3.8	18%	16	4.3	27%
N-Nitrosodi-n-propylamine	220	170	77%	260	250	96%	220	240	109%
4-Methylphenol	220	110	50%	240	220	92%	210	210	100%
Nitrobenzene	190	160	84%	230	220	96%	210	210	100%
Isophorone	240	160	67%	270	250	93%	240	240	100%
2-Nitrophenol	200	190	95%	210	230	110%	210	230	110%
2,4-Dimethylphenol	220	130	59%	240	210	88%	210	200	95%

Semivolatiles (continued)	7-day Deployment			14-day Deployment			21-day Deployment		
Analytes (Spiked at 264 ug/L)	Jar Conc.	RPPS Conc.	% Migration*	Jar Conc	RPPS Conc.	% Migration*	Jar Conc.	RPPS Conc.	% Migration*
Bis(2-chloroethoxy)methane	220	150	68%	230	210	91%	200	210	105%
2,4-Dichlorophenol	210	160	76%	220	210	95%	200	210	105%
Benzoic acid	160	0	0%	220	100	45%	210	110	52%
1,2,4-Trichlorobenzene	42	2.6	6%	14	3.5	25%	12	5.2	43%
Naphthalene	55	13	24%	33	17	52%	28	21	75%
4-Chloroaniline	230	130	57%	140	210	150%	210	200	95%
Hexachlorobutadiene	44	0	0%	13	0	0%	8.9	0	0%
4-Chloro-3-methylphenol	220	88	40%	260	190	73%	230	200	87%
2-Methylnaphthalene	43	1.9	4%	18	4.2	23%	12	4.1	34%
Hexachlorocyclopentadiene	0	0		0	0		0	0	
2,4,6-Trichlorophenol	190	180	95%	190	330	174%	180	330	183%
2,4,5-Trichlorophenol	200	100	50%	210	190	90%	190	200	105%
2-Chloronaphthalene	44	0	0%	16	3.4	21%	11	2.8	25%
2-Nitroaniline	210	73	35%	250	180	72%	240	170	71%
Acenaphthylene	56	0	0%	27	2.6	10%	20	5.3	27%
Dimethyl Phthalate	250	59	24%	270	160	59%	230	150	65%
2,6-Dinitrotoluene	220	86	39%	230	170	74%	230	180	78%
Acenaphthene	48	0	0%	21	0	0%	15	1.3	9%
3-Nitroaniline	250	52	21%	170	130	76%	260	140	54%
2,4-Dinitrophenol	210	31	15%	240	100	42%	260	120	46%
Dibenzofuran	47	0	0%	19	0	0%	13	1.2	9%
4-Nitrophenol	260	48	18%	240	130	54%	260	120	46%
2,4-Dinitrotoluene	240	61	25%	250	140	56%	280	190	68%
Fluorene	53	0	0%	22	0	0%	15	0	0%
4-Chlorophenyl Phenyl Ether	51	0	0%	21	0	0%	16	0	0%
Diethyl Phthalate	260	42	16%	260	120	46%	240	130	54%
4-Nitroaniline	260	0	0%	200	130	65%	260	150	58%
2-Methyl-4,6-dinitrophenol	240	50	21%	250	120	48%	270	150	56%
N-Nitrosodiphenylamine	160	41	26%	120	30	25%	130	47	36%
4-Bromophenyl Phenyl Ether	59	3.4	6%	25	0	0%	19	0	0%
Hexachlorobenzene	72	0	0%	27	0	0%	12	0	0%
Pentachlorophenol	190	0	0%	170	83	49%	190	100	53%
Phenanthrene	63	11	17%	29	0	0%	20	0	0%
Anthracene	120	0	0%	67	0	0%	36	0	0%
Di-n-butyl Phthalate	170	0	0%	110	2	2%	100	0	0%
Fluoranthene	97	0	0%	38	0	0%	25	0	0%
Pyrene	65	0	0%	21	0	0%	12	0	0%
Butyl Benzyl Phthalate	130	0	0%	100	0	0%	87	0	0%
3,3'-Dichlorobenzidine	190	0	0%	62	14	23%	220	13	6%
Benz(a)anthracene	140	0	0%	120	0	0%	69	0	0%
Chrysene	180	0	0%	180	0	0%	100	0	0%
Bis(2-ethylhexyl) Phthalate	92	0	0%	77	0	0%	41	0	0%
Di-n-octyl Phthalate	100	0	0%	97	0	0%	36	0	0%
Benzo(b)fluoranthene	93	0	0%	73	0	0%	31	0	0%
Benzo(k)fluoranthene	150	0	0%	150	0	0%	74	0	0%
Benzo(a)pyrene	110	0	0%	110	0	0%	55	0	0%

Semivolatiles (continued)	7-day Deployment			14-day Deployment			21-day Deployment		
Analytes (Spiked at 264 ug/L)	Jar Conc.	RPPS Conc.	% Migration*	Jar Conc	RPPS Conc.	% Migration*	Jar Conc.	RPPS Conc.	% Migration*
Indeno(1,2,3-cd)pyrene	91	0	0%	62	0	0%	39	0	0%
Dibenz(a,h)anthracene	120	0	0%	110	0	0%	64	0	0%
Benzo(g,h,i)perylene	96	0	0%	62	0	0%	41	0	0%

* Sampler concentration/Jar concentration X 100

The data from these laboratory studies suggests that these devices may be useful for inorganics, water soluble volatile and semivolatile analytes of concern. It may be that equilibrium will be established if these samplers are allowed to remain deployed for longer periods of time. Additional field studies are needed.

These devices are currently deployed at a site in New Jersey for metals (Roux & Associates) and at a site in Florida for 1,4-dioxane (Kubal-Furr Associates).

CONCLUSIONS

The PPBS are suitable for sampling groundwater wells for volatile organics for long-term monitoring projects. Both the NSPDS and the RPPS may be suitable for sampling groundwater wells for anions and other inorganic analytes of interest but, without further field testing, their suitability for the full range of volatile and semivolatile compounds should be limited to those exhibiting good water solubility.

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The PDBs are available commercially through two authorized suppliers: Columbia Analytical Services, Inc. at 800-695-7222 x 11 (www.caslab.com), and Eon Products, Inc. at 800-474-2490 (www.eonpro.com).