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Evaluation of Pore-Water Samplers at a Drainage Ditch, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06

Scientific Investigations Report 2007–5154

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

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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2007

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Suggested citation:
Vroblesky, D.A., and Casey, C.C., 2007, Evaluation of pore-water samplers at a drainage ditch, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06: U.S. Geological Survey Scientific Investigations Report 2007–5154, 9 p.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)

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

$$°F=(1.8\times°C)+32$$

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Evaluation of Pore-Water Samplers at a Drainage Ditch, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06

By Don A. Vroblesky and Clifton C. Casey

Abstract

The U.S. Geological Survey, in cooperation with the Naval Facilities Engineering Command Southeast, used innovative sampling methods to investigate ground-water contamination by chlorobenzenes beneath a drainage ditch on the southwestern side of Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, during 2005–06. The drainage ditch, which is a potential receptor for ground-water contaminants from Installation Restoration Site 4, intermittently discharges water to Corpus Christi Bay. This report evaluates a new type of pore-water sampler developed for this investigation to examine the subsurface contamination beneath the drainage ditch. The new type of pore-water sampler appears to be an effective approach for long-term monitoring of ground water in the sand and organic-rich mud beneath the drainage ditch.

Introduction

Ground-water contamination by volatile organic compounds (VOCs) is present at Installation Restoration (IR) Site 4, Naval Air Station (NAS) Corpus Christi, on the Gulf of Mexico near the city of Corpus Christi, Texas (figs. 1 and 2) (Terraine, Inc., 2006). A drainage ditch on the southwestern side of the site is a potential receptor for the ground-water contamination. Existing methods for examining pore-water concentrations beneath the ditch, however, have shortcomings for long-term monitoring. A study was conducted by the U.S. Geological Survey (USGS), in cooperation with the Naval Facilities Engineering Command Southeast, to evaluate a new type of pore-water sampler capable of obtaining repeated water samples from the sand and organic-rich mud beneath the drainage ditch on multiple sampling events.

Existing technology for sampling contaminants in pore water beneath surface water includes using diffusion samplers, pumping samples from wells, and sediment-core squeezing. Diffusion samplers have been widely used in wells and other environments to passively collect samples for VOC analysis (Karp, 1993; Vroblesky and Hyde, 1997; Imbrigiotta and others, 2002). Examples of passive diffusion samplers include passive diffusion bag (PDB) samplers and passive vapor diffusion samplers (Vroblesky, 2001a, 2001b, 2002a, 2002b; Church and others, 2002). A variety of diffusion samplers have been used to collect water for analysis of inorganic constituents, including peepers and nylon-screen samplers (Hesslein, 1976; Paludan and Morris, 1999; Vroblesky and others, 2002a, 2002b). A broad variety of other diffusion-type samplers are available and are reviewed in a recent journal article (Namieśnik and others, 2005).

Figure 1. Location of Naval Air Station Corpus Christi, Corpus Christi, Texas.

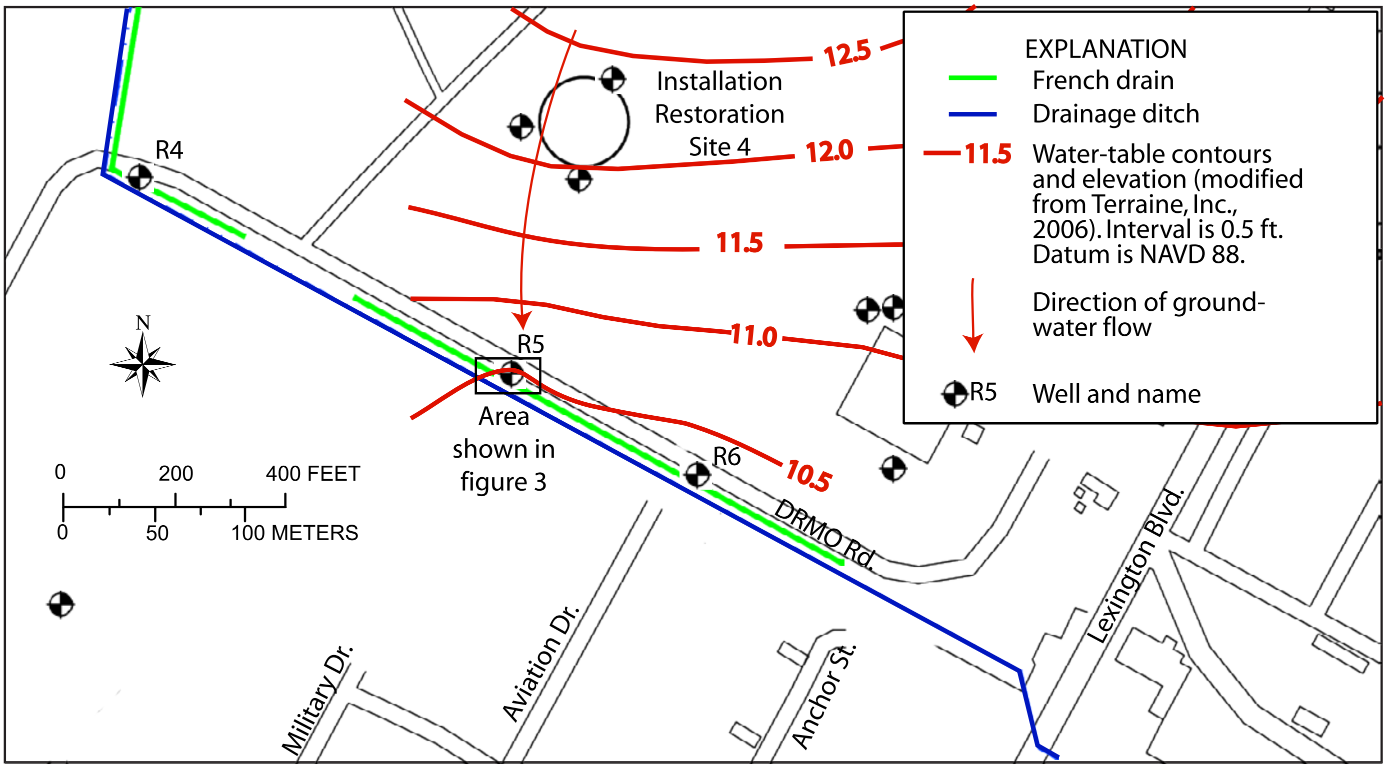

Figure 2. Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas.

Purpose and Scope

The purpose of this report is to describe the development and evaluation of an innovative sampling device (pore-water sampler) as a long-term sampling tool for use in sand and organic-rich sediments. Two variations of six newly developed pore-water samplers were deployed along with three standard PDB samplers. Ground-water samples were collected from a nearby well. A total of 17 water samples were collected and analyzed for VOCs during 2005–2006. The concentrations of VOCs and other constituents in those samples are included.

Site Description

NAS Corpus Christi, Texas, is surrounded on three sides by water: Cayo Del Oso (west), Corpus Christi Bay (north), and Laguna Madre (east) (fig. 1). IR Site 4 is underlain by an unconfined aquifer composed of fine-grained sand to silty or clayey sand. Contour maps of the water table indicate that ground-water flow at IR Site 4 is toward a gaining reach of a drainage ditch, on the southwestern side of the site (EnSafe Inc., 2002; Terraine, Inc., 2006) (fig. 2). Bottom sediment in the drainage ditch consists of organic-rich detritus and mud.

The depth to ground water at IR Site 4 is less than 10 feet (ft). A French-drain structure approximately 20 to 30 ft northeast of the ditch intercepts ground water discharging to the ditch from the contaminated aquifer (fig. 2). When the French drain is in operation, a pump collects ground water in the drain and transfers it to a granular activated carbon tank. The water is then discharged to the sanitary sewer. The French drain was not in operation, however, during this investigation. The drainage ditch is intermittently flooded and is heavily vegetated with cattails.

Methodology

For this investigation, two different variations of six newly developed pore-water samplers (as well as three standard water-filled PDB samplers) were installed at a drainage ditch on the southwest side of IR Site 4 (table 1). The samplers were installed at five sites within approximately 20 ft of each other near well R5 (fig. 3).

Pore-Water Samplers

A new type of pore-water sampler was developed to allow repeated sample collection in and beneath the organic-rich bottom sediment in the drainage ditch. One variation of the new pore-water sampler consists of an inner perforated polyethylene pipe, approximately 1.4 inches in diameter, enclosed in a larger perforated pipe, approximately 2.5 inches in diameter and about 0.7 ft long (figs. 4 and 5). The annular space between the two pipes is filled with granular sand as

Table 1. Descriptions of sampling points in the drainage ditch, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06.

Site shown in figure 3	Sampler identifier	Sampler type	Sampler depth, in feet below drainage-ditch bed
1	WDS1	1.4-inch-diameter pore-water sampler	1.5
1	PDBWD1	Polyethylene diffusion bag sampler	.25
1	SW1	1.4-inch-diameter pore-water sampler	.2
1	SW4	1.4-inch-diameter pore-water sampler	In surface water above ditch bed
2	WDS2	2.5-inch-diameter pore-water sampler	1.25
3	WDS3	2.5-inch-diameter pore-water sampler	1.6
3	PDBWD3	Polyethylene diffusion bag sampler	.25
4	WDS4	1.4-inch-diameter pore-water sampler	1.4
5	PDBWD4	Polyethylene diffusion bag sampler	.25

a filter pack (fig. 6), and the sand is prevented from moving through the perforated pipe by two sheets of polyethylene mesh. One sheet is wrapped tightly around the outer face of the inner pipe, and the other is held against the inner face of the outer pipe (fig. 5). The raised, beveled perforations on the outer pipe allow water to move into the sampler and prevent the sampler from becoming clogged by organic detritus, such as leaf matter. The sand pack between the inner and outer pipes provides further filtration. The tubing connected to the inner pipe provides a means of recovering water from the sampler by use of a peristaltic pump. A second variation is similar to the one just described except that the dimensions of the outer pipe are smaller (about 1.4 inches in diameter), and the inner pipe consists of a perforated section of 3/16-inch-diameter nylon tubing (fig. 7).

Four of the new samplers (two of each diameter variation) were installed by burying them approximately 1.5 ft below the bottom of the ditch bed (table 1) by means of a hand auger and temporary casing that was advanced with the auger hole to prevent hole collapse. Upon removal of the temporary casing, the hole was backfilled with native sediment. Tubing (1/4-inch outer-diameter nylon) attached to the inner pipe of the pore-water sampler extended up to the ditch-bed surface, then horizontally along the ditch-bed surface to a protective valve box on the shore. The tubing provided a means of collecting the pore-water samples by using a peristaltic pump.

In addition, four samplers were buried less than a foot deep beneath the ditch bed. These included one new sampler (1.4-inch diameter) and three standard PDB samplers (table 1). The PDB samplers in this investigation were polyethylene bags filled with deionized water (Vroblesky, 2001a, 2001b).

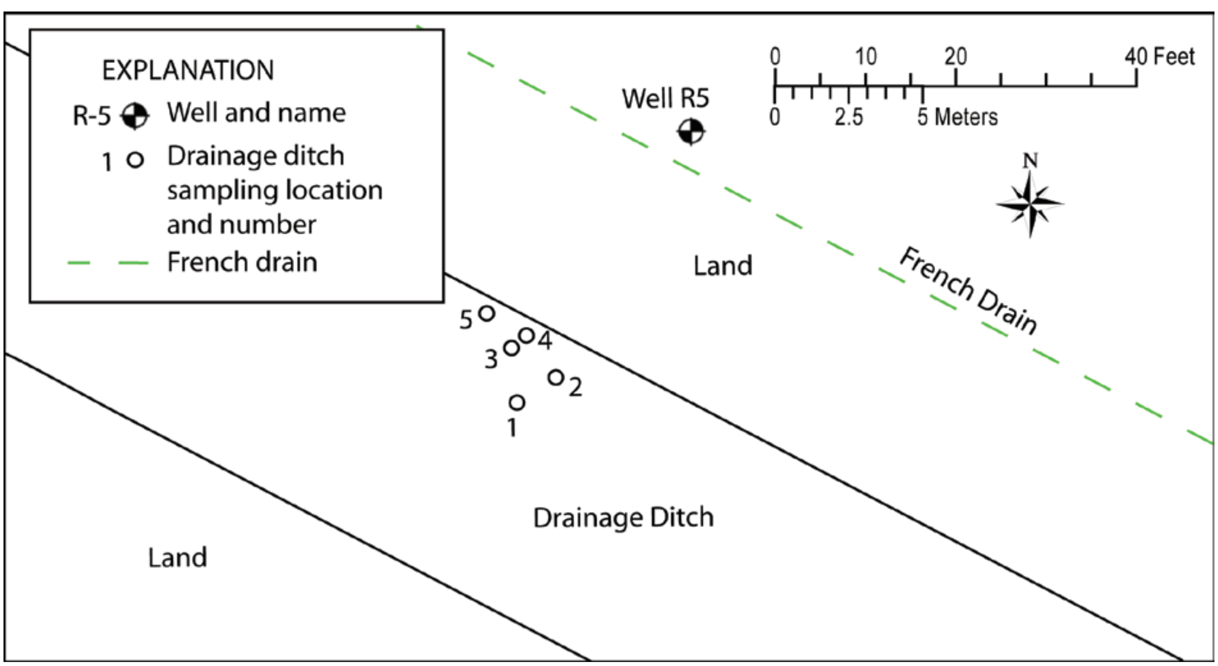

Figure 3. Sampling locations in and adjacent to the drainage ditch, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas. (Site location shown in figure 2.)

Figure 4. A 2.5-inch-diameter pore-water sampler with scale.

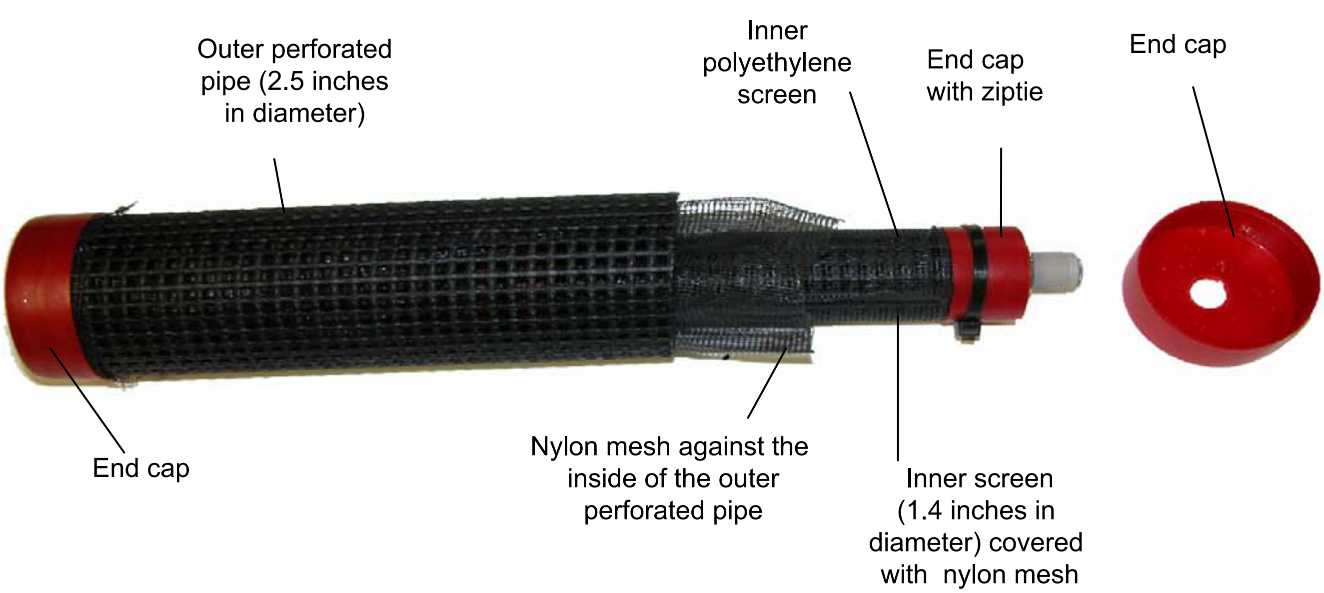

Figure 5. Lengthwise exploded view of a 2.5-inch-diameter pore-water sampler.

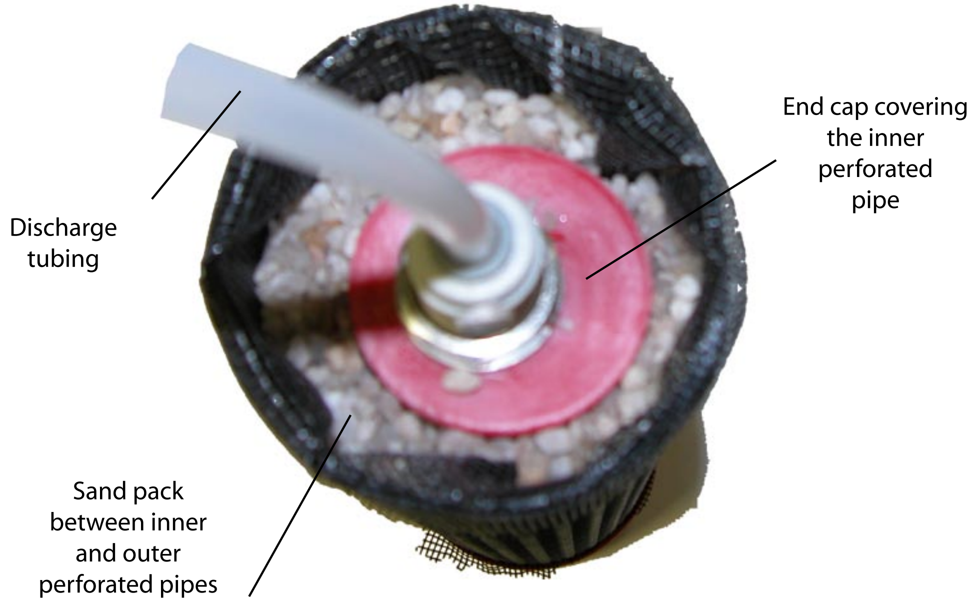

Figure 6. End view of a 2.5-inch-diameter pore-water sampler with the end cap removed to show the sand pack.

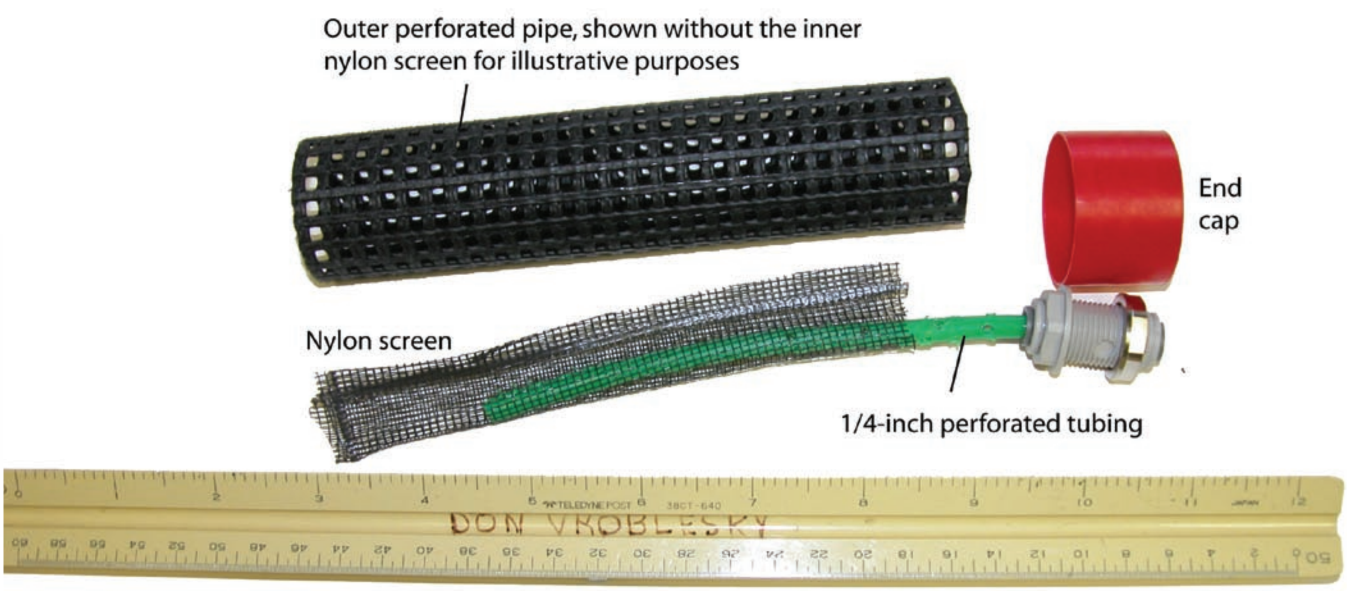

Figure 7. Disassembled 1.4-inch-diameter pore-water sampler.

The PDB samplers were installed to collect water samples for chlorobenzene analysis from directly beneath the sediment/surface-water interface in the drainage ditch. One new sampler (1.4-inch diameter) was installed in surface water at the ditch (table 1).

The samplers remained in place approximately 5 months prior to the collection of water samples. The water samples were collected by connecting a peristaltic pump to the nylon tubing attached to the inner pipe of the sampler. Approximately three sampler volumes of water were pumped to purge the sampler prior to sample collection. In the case of the larger diameter samplers (2.5 in.), approximately 1 liter of water was purged prior to sample collection. In the case of the smaller diameter samplers (1.4 in.), approximately 300 milliliters of water was purged prior to sample collection. Samples were then sent to a laboratory for VOC analysis (table 2). Selected samples were analyzed for turbidity, pH, specific conductance, sulfide, carbon dioxide, alkalinity, and dissolved iron (Fe^{2+}) (table 3).

Low-Flow Sampling

Low-flow sampling methodology (Barcelona and others, 1994; Shanklin and others, 1995; Sevee and others, 2000) was used to collect ground-water samples from well R5. During low-flow sampling, the well was purged using a peristaltic pump at a rate of approximately 250 milliliters per minute until the temperature, pH, dissolved oxygen, and specific conductance stabilized and no additional water-level drawdowns were observed. Stabilization of water properties was monitored using a flow-through cell containing temperature, pH, dissolved oxygen, and specific conductance sensors. The water properties were considered to be stabilized when the observed changes over three 3-minute intervals were within ±3 percent for temperature and specific conductance, within ±0.1 units for pH, and within ±10 percent for dissolved oxygen.

Table 2. Concentrations of selected volatile organic compounds in water samples, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06.

[CB, chlorobenzene; 1,2-DCB, 1,2-dichlorobenzene; 1,4-DCB, 1,4-dichlorobenzene; <, less than; J, estimated value; —, no sample; all concentrations are in micrograms per liter; suffix R represents a duplicate sample]

Location	Sampler number	Date	CB	1,2-DCB	1,4-DCB	Ethane	Methane
R5	R5	9/19/2005	57	<1.4	6.5	—	—
R5	R5	8/15/2006	72	1.45	7.18	<2	2,670
1	WDS1	9/19/2005	160	<5.6	16J	11	4,300
1	WDS1	8/15/2006	50.3	1.67	11.8	<2	1,730
1	PDBWD1	9/19/2005	74	<2.2	7.1J	—	—
1	SW1	9/19/2005	36	<5.6	<6.7	.66J	1,500
1	SW1	8/15/2006	3.05	.281	4.08	—	—
1	SW4	9/19/2005	2.3J	<1.4	<1.7	—	—
1	SW4	8/15/2006	15.6	<.25	1.08	—	—
2	WDS2	9/19/2005	85	<2.2	3.1J	—	—
2	WDS2R	9/19/2005	110	<3.5	5.1J	—	—
2	WDS2	8/15/2006	54.5	.452	2.86	—	—
3	WDS3	9/19/2005	140	<3.5	8.9J	—	—
3	PDBWD3	9/19/2005	76	<.56	5.8	—	—
4	WDS4	9/19/2005	68	1.8	7.5	—	—
4	WDS4	8/15/2006	79.4	1.58	8.67	<2	2,850
5	PDBWD4	9/19/2005	16	.64J	2.8	—	—

Evaluation of Pore-Water Samplers

All of the newly developed pore-water samplers were capable of collecting water from the sand and organic-rich mud beneath the ditch and in surface water in September 2005. In addition, chlorobenzene was detected in water collected from all of the pore-water samplers (table 2).

During August 2006, four of the six samplers remained operational. Sampler WDS3 did not obtain water, however, and the inner screen failed in sampler WDS4, allowing the sampler to pump highly turbid water (571 Nephelometric turbidity units [NTUs]) mixed with sand from the internal sand pack. A likely explanation for the failure of WDS3 is that the tubing extending to the shoreline was inadvertently crushed underfoot while related activities were conducted in the drainage ditch in 2006 or following sampling in 2005. This possible source of error probably could be resolved in future designs by running the tubing that extends from the sampler to the shoreline through a narrow piece of polyvinyl chloride pipe to prevent damage to the tubing. The failure of sampler WDS4 is likely related to the fragile nature of the nylon screen used in the device. This issue probably could be resolved with the use of a more robust polyethylene screen.

Water collected from the pumped pore-water samplers had a higher turbidity (11.2 to 66 NTUs) than water pumped from well R5 (3.7 NTUs) (table 3). The higher turbidity was likely the result of using very coarse-grained sand (1,410 to 2,000 microns) in the samplers during this study. Sample-water turbidity probably could be reduced by using finer-grained sand as the sampler filter pack.

The constituent concentration data collected during this study show that the samplers can function as adequate long-term sampling devices for monitoring ground-water contaminant concentrations beneath drainage ditches. Improvements that would make the samplers more reliable include the use of a sand pack that closely approximates the grain size in the target horizon, the use of polyethylene screen material, and protection for the tubing in places where it may be crushed by surface activity.

Advantages and Disadvantages of the Tested Pore-Water Samplers

Existing technology for sampling contaminants in pore water beneath surface water includes using diffusion samplers, pumping samples from wells, and sediment-core squeezing. The pore-water samplers tested during this investigation overcame deficiencies in the existing sampling technologies used to collect pore water beneath streams.

The pore-water samplers used with pumps in this investigation have advantages over existing diffusion sampler technologies because of the ability to provide repeated samples and ease of use. Most existing diffusion samplers are not rechargeable. Therefore, diffusion samplers generally are one-time use instruments, and the exact sampling location cannot be resampled for confirmation of analytical results. In the case of the rechargeable diffusion sampler (Jacobs, 2002), the sampler must be refilled with deionized, deoxygenated water,

Table 3. Concentrations of inorganic constituents in water samples, Installation Restoration Site 4, Naval Air Station Corpus Christi, Corpus Christi, Texas, 2005–06.

[mg/L, milligrams per liter; S.U., standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, Nephelometric turbidity units; —, data not collected; <, less than; >, greater than]

Location	Sampler number	Date	Dissolved oxygen (mg/L)	Temperature (Celsius)	Turbidity (NTU)	pH (S.U.)	Specific conductance (µS/cm)	Sulfide (mg/L)	Carbon dioxide (mg/L)	Alkalinity (mg/L)	Iron(II) (mg/L)
R5	R5	9/19/2005	<0.05	—	—	—	—	<0.1	—	—	—
R5	R5	8/15/2006	.1	30.42	3.7	6.46	898	<.1	70	325	16
1	WDS1	9/19/2005	.05	—	—	—	—	—	—	—	—
1	WDS1	8/15/2006	.1	28.13	15.5	6.6	1,873	<.1	100	375	>10
1	SW1	8/15/2006	<.05	29.04	11.2	6.77	3,394	—	—	—	—
1	SW4	8/15/2006	.1	28.48	66	6.94	895	—	—	—	—
2	WDS2	8/15/2006	.2	28.13	33.7	6.58	—	—	—	—	—
4	WDS4	9/19/2005	.15	—	—	—	—	—	—	—	—
4	WDS4	8/15/2006	.3	30.65	571	6.45	537	<.1	100	350	>10

but creating deoxygenated water can be time consuming and troublesome. The pore-water samplers used with pumps during this investigation allow samples to be collected from the same location indefinitely, as long as sufficient time elapses between sampling events for the ambient water to return to prepumping conditions. Another advantage of the pumped pore-water sampler used in this investigation is that the sampler is self-filling with ambient formation water and does not need to be recharged manually.

Use of the pore-water samplers also has advantages over the use of wells to obtain samples beneath streams. Wells installed in surface-water bodies to monitor constituent concentrations in pore water are limited in their application. For example, wells require a surface expression, such as a standpipe, that may be subject to disturbance by floating objects or currents in surface-water bodies. Moreover, bottom sediments in quiescent surface-water bodies are often fine-grained, necessitating the use of a sand pack or other sediment-filtering material to surround the well screen. The samplers used in this investigation do not require a stand pipe that extends to the surface of the water body. Instead, water is extracted from the samplers through a small-diameter tube that runs from the sampler to the shoreline, where samples can be collected by means of a peristaltic pump. Thus, no boat is needed to collect the samples.

Obtaining a sample with a pore-water sampler has an advantage over sediment analysis or sediment squeezing as a means of obtaining a sample. Because of the need to conduct repeated sampling at the same location and the uncertainties this introduces, sediment analysis and sediment squeezing are impractical for repeated, long-term monitoring at one location.

Pore-water samples also can be obtained from seepage meters consisting of an open-ended 55-gallon steel drum that is pushed into the bottom sediment of a surface-water body (Lee, 1977) and a collapsed bag that is attached to the outlet of the drum above the sediment. After a period of time, the bag is removed, and the volume of collected water is measured and used to calculate the ground-water seepage rate into surface water. The collected water also can be analyzed for aqueous chemistry. The disadvantage of using seepage meters for monitoring VOCs in the pore water, however, is the potential for volatilization loss of VOCs by diffusion through the bag membrane of the seepage meter.

A potential disadvantage of the pore-water samplers tested here is that the turbidity associated with the water may result in whole-water analyses that overestimate the dissolved concentrations of some contaminants if those contaminants are sorbed to the suspended sediment and included in the analyses. It is likely, however, that the use of a fine-grained sand for the filter material, rather than the very coarse-grained sand used here, would substantially reduce the turbidity of the samples in future versions of the sampler.

Summary

The USGS, in cooperation with the Naval Facilities Engineering Command Southeast, evaluated a new type of pore-water sampler, developed to obtain water samples from the sand and organic-rich mud beneath a drainage ditch on the southwestern side of IR Site 4 at NAS Corpus Christi, Texas, during 2005–06. For this investigation, two different variations of a new type of pore-water sampler were installed in the drainage ditch on the south side of IR Site 4. The newly developed sampler consists of a sand-packed screen enclosed in a perforated pipe. These samplers were installed beneath the sediment of the drainage ditch and connected to shore by tubing, where the tubing was used to pump a sample from the pore-water sampler screens. Samples were obtained from the new samplers in 2005 and 2006. PDB samplers also were installed and sampled in the drainage-ditch sediment in 2005.

All of the newly developed pore-water samplers were capable of obtaining water from the sand and organic-rich mud beneath the ditch in 2005, and four of the six samplers were capable of obtaining a water sample from the same locations in 2006. The two ineffective samplers in 2006 likely failed because of factors that can be easily corrected by changes in the sampler design. The concentration data indicate that the samplers were capable of providing samples for chlorobenzene analysis at this site and probably would provide adequate long-term monitoring for contaminant concentrations in pore water beneath ditches. The study results also indicate that the samplers overcame deficiencies in technologies previously used to collect pore-water samples beneath streams.

References Cited

Barcelona, M., Wehrmann, H.A., and Varljen, M.D., 1994, Reproducible well-purging procedures and VOC stabilization criteria for ground-water sampling: Ground Water, v. 32, p. 12–22.

Church, P.E., Vroblesky, D.A., Lyford, F.P., and Willey, R.E., 2002, Guidance on the use of passive-vapor-diffusion samplers to detect volatile organic compounds in ground-water-discharge areas, and example applications in New England: U.S. Geological Survey Water-Resources Investigations Report 02-4186, 79 p.

Ensafe Inc., 2002, Response action plan, Installation Restoration, Sites 1, 2, and 3, NAS Corpus Christi, Texas: Consultant's report prepared for Naval Facilities Engineering Command, North Charleston, South Carolina, September 2002, 13 p.

Hesslein, R.H., 1976, An in situ sampler for close interval pore water studies: Limnology and Oceanography, v. 21, p. 912–914.

Imbrigiotta, T.E., Ehlke, T.A., and Lacombe, P.J., 2002, Comparison of dialysis membrane diffusion samplers and two purging methods in bedrock wells, *in* Gavaskar, A.R., and Chen, A.S.C., eds., Remediation of chlorinated and recalcitrant compounds—2002: Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, Calif., May 2002, Columbus, Ohio, Battelle Press, Paper 1D-02.

Jacobs, P.H., 2002, A new rechargeable dialysis pore water sampler for monitoring sub-aqueous in-situ sediment caps: Water Research, v. 36, p. 3121–3129.

Karp, K.E., 1993, A diffusive sampler for passive monitoring of underground storage tanks: Ground Water Monitoring & Remediation, v. 13, no. 1, p. 101–106.

Lee, D.R., 1977, A device for measuring seepage flux in lakes and estuaries: Limnology and Oceanography, v. 22, no. 1, p. 140–147.

Namieśnik, Jacek, Zabiegala, Bożena, Kot-Wasik, Agata, Partyka, Monika, and Wasik, Andrzej, 2005, Passive sampling and/or extraction techniques in environmental analysis—a review: Analytical and Bioanalytical Chemistry, v. 381, p. 279–301.

Paludan, C., and Morris, J.T., 1999, Distribution and speciation of phosphorus along the salinity gradient in intertidal marsh sediment: Biogeochemistry, v. 45, p. 197–221.

Sevee, J.E., White, C.A., and Maher, D.J., 2000, An analysis of low-flow ground water sampling methodology: Ground Water Monitoring and Remediation, Spring 2000, v. 20, no. 2, p. 87–93.

Shanklin, D.E., Sidle, W.C., and Ferguson, M.E., 1995, Micropurge low-flow sampling of uranium-contaminated ground water at the Fernald Environmental Management Project: Ground Water Monitoring and Remediation, v. 15, no. 3, p. 168–176.

Terraine, Inc., 2006, 2006 Annual groundwater sampling report, Installation restoration sites 1, 3, 4, and Building 8, Corpus Christi Army Depot, NAS Corpus Christi, Corpus Christi, Texas: North Charleston, South Carolina, Consultant's report to Naval Facilities Engineering Command, October 2006, 14 p.

Vroblesky, D.A., 2001a, User's guide for polyethylene-based passive diffusion bag samplers to obtain volatile organic compound concentrations in wells, Part 1—Assembly and quality control and assurance: U.S. Geological Survey Water-Resources Investigations Report 01-4060, 18 p.

Vroblesky, D.A., 2001b, User's guide for polyethylene-based passive diffusion bag samplers to obtain volatile organic compound concentrations in wells, Part 2—Field tests: U.S. Geological Survey Water-Resources Investigations Report 01-4061, 102 p.

Vroblesky, D.A., 2002a, Part 1. Guidance on the use of passive-vapor-diffusion samplers, *in* Church, P.E., Vroblesky, D.A., Lyford, F.P., and Willey, R.E., Guidance on the use of passive-vapor-diffusion samplers to detect volatile organic compounds in ground-water-discharge areas, and example applications in New England: U.S. Geological Survey Water-Resources Investigations Report 02-4186, 79 p.

Vroblesky, D.A., 2002b, Laboratory and field testing of passive vapor-diffusion sampler equilibration times, temperature effects, and sample stability, *in* Church, P.E., Vroblesky, D.A., Lyford, F.P., and Willey, R.E., Guidance on the use of passive-vapor-diffusion samplers to detect volatile organic compounds in ground-water-discharge areas, and example applications in New England: U.S. Geological Survey Water-Resources Investigations Report 02-4186, 79 p.

Vroblesky, D.A., and Hyde, W.T., 1997, Diffusion samplers as an inexpensive approach to monitoring VOCs in ground water: Ground Water Monitoring and Remediation, v. 17, no. 3, p. 177–184.

Vroblesky, D.A., Petkewich, M.D., and Campbell, T.R., 2002a, Field tests of diffusion samplers for inorganic constituents in wells and at a ground-water-discharge zone: U.S. Geological Survey Water-Resources Investigations Report 02-4031, 24 p.

Vroblesky, D.A., Petkewich, M.D., and Campbell, T.R., 2002b, Considerations for sampling inorganic constituents in ground water using diffusion samplers, *in* Gavaskar, A.R., and Chen, A.S.C., eds., Remediation of chlorinated and recalcitrant compounds—2002: Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, Calif., May 2002, Columbus, Ohio, Battelle Press, Paper 1F-05.

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Vroblesky and Casey—**Evaluation of Pore-Water Samplers at a Drainage Ditch, Naval Air Station Corpus Christi**—Scientific Investigations Report 2007–5154