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Evaluation of the Snap Sampler for Sampling Ground Water Monitoring Wells for VOCs and Explosives

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Abstract: A series of laboratory and field studies were conducted to determine the ability of the Snap Sampler to recover representative concentrations of VOC and explosives in ground water. For the laboratory studies, statistical analyses of the data (for each analyte) were conducted to determine if the concentrations of analytes in samples taken with the Snap Sampler were significantly different from known concentrations of the analytes in samples collected from a standpipe (i.e., control samples). For the field studies, concentrations of analytes in samples taken with the Snap Sampler were compared with concentrations of the analytes in samples taken using the EPA's low-flow purging and sampling protocol. Again, statistical analyses were used to determine if there were statistically significant differences between the individual analyte concentrations in these samples. Two field trials were conducted for VOCs and one field trial was conducted for explosives. In the laboratory studies, the Snap Sampler recovered concentrations of VOCs that were comparable to those in the control samples after equilibrating the Snap Sampler for 3 days. Comparable concentrations of explosives were recovered after equilibrating the Snap Sampler for 24 hours. In the field studies, concentrations of VOCs and explosives were comparable to concentrations of these analytes in samples that were collected using low-flow purging and sampling.

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Preface

This report was prepared by Louise Parker and Nathan Mulherin, both of the Environmental Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, NH.

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The report was prepared under the general supervision of Dr. Terrence Sobecki, Chief, Environmental Sciences Branch; Dr. Lance Hansen, Deputy Director; and Dr. Robert E. Davis, Director, CRREL.

The Commander and Executive Director of ERDC is COL Richard B. Jenkins. The Director is Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters

1 Introduction

It is generally accepted within the scientific community that low-flow purging and sampling methods (e.g., Puls and Barcelona 1996, U.S. EPA Region 1 1996, Nielsen and Nielsen 2002) are an improvement over older sampling methods, such as volume-based purging and sampling and sampling with a bailer. One of the major improvements associated with these sampling methods is that turbulence during sampling is reduced, resulting in lower turbidity samples. Because metals and more hydrophobic contaminants (e.g., PCBs and PAHs) can be associated with colloids and other particulate matter that cause turbidity, low-flow sampling can reduce falsely elevated concentrations for these constituents. Thus, the samples collected by low-flow sampling primarily contain dissolved constituents or colloids that are mobile in the formation or filter pack.

However, because low-flow sampling relies on pumping, it pulls water from the most permeable zone(s) in the formation, and this may or may not be the zone of interest. Pumping can also cause extensive mixing within the well, which eliminates in-well stratification that sometimes is present and can be of interest in some cases. Low-flow sampling can also be more expensive than passive sampling because 1) it is time consuming, 2) dedicated sampling equipment is expensive and the use of non-dedicated pumps requires extensive and costly decontamination between sampling events, and 3) it generates purge water that may require costly disposal. Given these issues, finding a sampling method that is less labor-intensive and costly but able to yield quality data is clearly desirable.

Recently, passive sampling techniques, such as the use of the Polyethylene Passive-Diffusion Bag (PDB) sampler (Vroblesky 2001), have gained acceptance in the regulatory community (e.g., Interstate Technology and Regulatory Council [ITRC] 2004, 2006, 2007, NJ Department of Environmental Protection 2004). Passive sampling techniques rely on continuous natural flow through the well screen (Robin and Gillham 1987, Powell and Puls 1993). Most research to date indicates that water in the screened portion of the well is representative of the formation if the well has been designed and developed properly (Michalski 1989, Gillham et al 1985, Robin and Gillham 1987, Powell and Puls 1993). Therefore, where the use

of passive sampling is appropriate, cost reductions can include better delineation of contamination with depth within the screened zone (in stratified wells), reduced volumes of purge water waste, reduced labor during sampling, and reduced equipment costs. Also, data quality improvements can result in wells with vertical stratification when passive sampling methods are used to delineate contaminant stratification (Vroblesky and Peters 2000, Vroblesky and Petkewich 2000, Vroblesky et al. 2003). Based upon a field study conducted at 14 Department of Defense (DOD) sites, Parsons Inc. (2003) estimated that the potential cost savings of using passive techniques for long-term monitoring at DoD facilities could be on the order of 70% compared with low-flow sampling.

Although passive samplers are easier and less expensive to use than methods that involve purging and sampling with a pump, most passive diffusion samplers have limitations. For example, the PDB sampler can only be used for VOCs, and the dialysis (regenerated cellulose) membrane undergoes biodegradation after several weeks (typically 4–6 weeks but the actual time depends on conditions in the well). Also, diffusion samplers yield a sample with a time-weighted average concentration rather than a sample that reflects the concentration in the well at the time of sampling. This is because the time it takes for the sampler to reflect a change in the concentration of an analyte in the well depends on the rate of diffusion of each analyte through the membrane. This depends on the rate of exchange of water within the well, the water temperature, the type of membrane, and the chemical and physical properties of the specific analyte.

In comparison, passive samplers such as the Snap Sampler and the HydraSleeve Sampler can be used to collect samples in real time. Typically, these samplers collect whole water samples and are not limited with respect to analyte type. These samplers can also be classified as equilibrated grab samplers (ITRC 2006, 2007). Equilibrated grab samplers are typically deployed prior to sampling and are left in the well for an equilibration period. This equilibration period allows time for the well to recover from any disturbance caused by placing the device in the well, for the natural flow pattern in the well to be reestablished, and for the materials in the sampler to equilibrate with the analytes in the well water. Because the well has time to recover before the sample is collected, the well is less agitated during the sampling event and particles that are not normally mobile in the formation are less likely to be entrained in the



Figure 1. Snap Sampler.

sample when it is collected. Numerous studies have shown that Teflon (used to coat the spring and in the caps) is sorptive of some organic analytes, especially VOCs (Curran and Tomson 1983, Barcelona et al. 1985, Reynolds and Gillham 1985, Parker et al. 1990, Gillham and O'Hannesin 1990, Parker and Ranney 1994, 1997, 2000). Allowing the materials in the sampler to equilibrate with the analytes in the well water should prevent losses due to sorption. The time needed for equilibration will depend on the sampling device (and the materials in the sampler), the physical and chemical properties of the analyte(s), the ambient flushing rate of the well, and temperature.

Description and Unique Features of the Snap Sampler

The Snap Sampler consists of four components: a specially designed bottle that has openings on two ends and contains spring-loaded end caps, a sampler body that holds the bottle and contains the trigger mechanism that closes the bottles, a trigger line, and a docking station (Fig. 1). The bottles contain a perfluoroalkoxy (PFA) Teflon-coated spring mechanism that is connected to PFA Teflon end caps at both ends of the bottles. Currently, 40-mL glass VOA vials and 125-mL polypropylene bottles can be obtained from the developer/manufacturer (ProHydro, Inc.; <http://www.snapsampler.com/>). The Snap Sampler body holds the bottles in the open position with a release pin system. Currently stainless steel or acetal (Delrin) plastic Snap Sampler bodies can be purchased from the manufacturer. The trigger line connects to the release pin and consists of a movable internal FEP-coated (fluorinated ethylene polypropylene) Teflon

stainless steel cable surrounded by plastic tubing. Three types of plastic tubing are available, depending on the user's data quality needs; these include high-density polypropylene (HDPE) tubing and two fluoropolymer tubing materials: polyvinylidene fluoride (PVDF) Kynar tubing or PFA Teflon tubing.

These samplers are deployed in the well with the end caps of the bottle(s) in an open position. After the equilibration period, the trigger line is pulled, closing the sample bottle(s). Once retrieved, the sample can remain in the sampler bottle, eliminating transfer of the sample at the well head. For VOCs, the VOA vials can be used in common autosamplers (e.g., Tekmar and Archon), eliminating transfer in the laboratory as well. These samplers fit in 2-in.-diameter and larger wells. To obtain a larger sample volume or more than one sample at a time, two to four samplers can be deployed in series on the same trigger line or on separate trigger lines (Fig. 2). (More information on how to deploy a Snap Sampler and prepare the sampler bottles is given in Appendix C.)



Figure 2. Assembled string of three Snap Samplers with a trigger line.

One of the advantages associated with using the Snap Sampler is that the sample bottles are sealed under in-situ conditions. Thus, there is no chance for interaction of the sample with other zones in the water column

(above the sampling zone), including the stagnant casing water, as the device is brought to the surface. Because the VOA vials can be used, samples collected for VOCs can remain in the Snap Sampler bottle, eliminating a transfer at the pump head and exposure to airborne contaminants at the site. For samples that are left in the original Snap Sampler bottle (or vial), there should not be any changes in dissolved gases in the samples, and losses of volatiles should be reduced. (Increases in the dissolved oxygen level can affect concentrations of metals subject to oxidation/precipitation reactions.)

Because this device is not triggered until after the well has recovered from any disturbance associated with placing the sampler in the well, presumably samples should not have artificially elevated turbidity but would contain any naturally mobile colloid-borne contaminants that flow through the well. In contrast, even low-flow sampling has been shown to artificially elevate particle levels in some wells and hydrologic settings (Bailey et al. 2005), and some passive diffusion samplers should not be used for sampling colloid-borne contaminants. As an example, Puls and Paul (1997) found that chromium concentrations were concentrated in the Diffusion Multilevel Sampler (DMLS) (developed by Ronen et al. 1987) and attributed this to the accumulation of entrained colloidal particles in the sampler cells with time. Apparently the particles entered through the porous membrane and settled out before they could exit the sampler (thereby accumulating in the sampler).

Other Studies Conducted with this Sampler

Although this sampler was in its early prototype stages when we first began to test it nearly three years ago, it has undergone several field tests. One field study was conducted with the University of Waterloo in Southern Ontario (by Britt, Parker, and Cherry) is in review and thus was not available at the time this document was written. The other was conducted at the former McClellan Air Force Base (Parsons 2005). This field test was conducted for the Omaha District of the Army Corps of Engineers, Air Force Center for Environmental Excellence, and Air Force Real Property Agency. This work has not been published in a peer-reviewed journal but the final report is available on line.

In the Parsons (2005) study, six different passive samplers were compared with a low-flow purging and sampling method and a well-volume purging

and sampling method (i.e., the well was purged of 3–5 well volumes and then a sample was collected using a bailer). The six passive samplers included several diffusion samplers (including the PDB sampler) and two equilibrated grab devices including the Snap Sampler. Analytes that were compared included several VOCs (including 1,4-dioxane), anions, and metals (including hexavalent Cr). However, for the Snap Sampler, comparisons were only made with the VOCs and anions. (Metals were not sampled with this sampler because the sampler used in this study was constructed with stainless steel, which could affect metal concentrations.)

Unfortunately, interpreting the results from this study is difficult. This is due in part to the differences in the methods used in sampling and sample handling, the numerous methods that were used to analyze the data, and issues with some of statistical analyses (where the data was pooled for the various analytes prior to conducting the statistical analyses). However, regression plots of the (pooled) VOC data were informative. These plots showed that the Snap Sampler VOC concentrations correlated relatively well with those taken using low-flow purging and sampling ($r^2 = 0.995$), although the Snap Sampler concentrations were substantially higher (the slope was 1.77). In contrast, a similar comparison of the Snap Sampler and three-well volume samples indicated that the concentrations of VOCs agreed well ($r^2 = 0.90$ with a slope of 1.04). The findings were similar for the anions. That is, concentrations of the anions were higher in the Snap Sampler samples than they were in the low-flow samples but were similar in magnitude in the Snap Sampler and the three-well volume purged samples. Parsons concluded that the VOC concentrations in the Snap Sampler samples may actually be more representative of the concentrations in the well than the low-flow samples. They also concluded that the concentrations of volatiles were higher in the Snap Sampler samples because there was less transfer and loss associated with these samples (than, for example, samples taken with the PDB sampler). However, they had no explanation as to why the anion concentrations would also be higher with this sampler. Given that the findings were similar for the anions, this suggests to us that these differences were because the water sampled was not the same, i.e., the water quality of the low-flow purging and sampling samples was different from that in the Snap Sampler samples. In contrast, the purged-volume sampling method collected water that was similar in character to that sampled with the Snap Sampler. This may be an important distinction that merits further study.

Using this Sampler to Profile Contamination with Depth

One potential use of passive samplers is to profile contamination in the well with depth. This capability is based on the observation that stratification is sometimes observed in well screens, although the relationship between in-screen stratification and aquifer stratification cannot always be determined. In other wells, stratification is eliminated by diffusive mixing or hydraulically driven mixing due to vertical flow in the well. Vertical flow results when the well screen intersects zones that vary in hydraulic head, a problem that is particularly found in wells with longer screens (20 ft and longer) (Elci et al. 2001). Convective circulation within wells also results when there is a density gradient in the well water. A density gradient can result from differences in the concentrations of constituents in the water or from differences in the temperature of the water within the well (Diment 1967, Gretner 1967, Samuel 1968, Britt 2005, Vroblesky et al. 2006). In instances where there is convective flow, oxygen can be transported from shallower parts of the well to deeper parts of the well, including the screened portion of the well (Vroblesky et al. 2006). This has been shown to impact not only the ability of a passive sampler to recover representative samples but also the ability of low-flow purging and sampling to recover representative samples. However, Vroblesky et al. (2006) demonstrated that either an in-well inflatable packer or a (polyethylene disk) baffle could be used to prevent temperature-induced convective flow in wells when placed at the top of the well screen. This approach worked equally well for both passive and low-flow sampling methods.

Baffles have been used in other studies to inhibit in-well mixing. As an example, Britt (2006) used baffles and Snap Samplers to profile phenol contamination in a well. He found a difference in concentration of five orders of magnitude along the 10-ft-long screen. In contrast, previous samples taken using low-flow sampling and the Snap Sampler without any baffles indicated that there was no difference in the contaminant concentrations with depth.

While using mixing inhibitors in wells substantially reduces mixing in the well, it is not known how much impact these baffles have on any mixing that occurs in the well bore. However, this does appear to be a promising approach for better delineating stratification in a formation using existing monitoring wells.

2 Purpose

The purpose of these studies was to determine the ability of the Snap Sampler to recover representative concentrations of two classes of contaminants of concern to the U.S. Army and the Department of Defense (DOD): explosives and VOCs. Both laboratory and field studies were used to test this sampler.

3 Materials and Methods

The first phase of this study consisted of laboratory studies where the ability of the Snap Sampler to recover comparable concentrations of VOCs and explosives was determined by comparing analyte concentrations in samples collected from a standpipe using Snap Samplers with control samples taken from the spigot on the same standpipe. Statistical analyses of the data (for each analyte) were used to determine if the concentrations of analytes in samples taken with the Snap Sampler were significantly different from the control samples.

In the second phase of this work, field studies were conducted to compare concentrations of VOCs and explosives in samples collected with Snap Samplers with concentrations of these analytes in samples collected from the same well and sampling depth using low-flow purging and sampling. Three sites were selected for these studies: CRREL (Hanover, NH), the former Louisiana Army Ammunition Plant (LAAP) (Minden, LA), and the Silresim Sanitary Landfill (Lowell, MA). The CRREL and Silresim sites had VOC contaminants, and LAAP had explosives contamination. Again, statistical analyses were used to determine if there was a statistically significant difference between the individual analyte concentrations in the Snap Sampler samples vs. those in the low-flow samples (for each analyte).

Standpipe Studies

All the studies using a standpipe were conducted at room temperature (~20–22°C). Two standpipes were used: one that contained a test solution of dissolved VOCs and a second that contained explosives-contaminated well water. Each standpipe was constructed of 20-cm- (8-in.-) diameter, schedule-40 PVC pipe with a PVC end cap on the bottom and stood approximately 244 cm (8 ft) high. The standpipes were filled with the test solution to within ~10–13 cm (4–5 in.) of the top. This allowed enough room to place the samplers in the standpipe without having the test solution overflow the standpipe. The top of the standpipe was covered with a thin plastic disc that was then covered tightly with aluminum foil to reduce losses from volatilization.

The VOC test solution was made by first adding the neat chemicals directly to deionized water in two 20-L (5-gal.) glass carboys. The carboys were filled so there was minimal headspace and then covered with two layers of tightly fitting aluminum foil. To dissolve the analytes, the solutions were stirred for 13 days using a magnetic stirrer (with a Teflon-coated stir bar). The spiked test solution was then poured into the standpipe and diluted by adding an additional 60 L of deionized water. The diluted test solution was then circulated for 15 minutes to mix it. This was accomplished by placing a hose in the bottom of the standpipe and pumping the test solution to the top of the standpipe using a peristaltic pump. For the first study, the initial target concentrations for the analytes were 1 mg/L (for each analyte).

For the subsequent VOC studies, it was necessary to replenish the analytes in the test solution because of losses due to volatilization. This was done by filling two glass 20-L (5-gal.) glass carboys with the test solution from the standpipe. The carboys were then spiked as described previously and stirred for at least six days. The spiked solutions were then pumped back into the standpipe and mixed by circulating the test solution as described previously.

The explosives test solution was contaminated ground water obtained from the former Louisiana Army Ammunition Plant in Minden, Louisiana.

In all these studies, the samplers were deployed at the same depth as the sampling port (spigot) on the standpipe (80 cm from the bottom of the standpipe). Typically, paired samples were obtained by either collecting a sample with the Snap Sampler and then drawing a control sample from the spigot on the standpipe, or vice versa. The order in which the controls and samples were obtained was alternated until all the sample-control pairs were collected, so that any bias due to sampling order was eliminated.

Laboratory Studies with VOCs

First VOC Standpipe Study

In this study, two trigger lines with a single Snap Sampler per line were deployed in the standpipe that contained a test solution of low ppm-levels (~1 mg/L) of seven VOCs. The VOCs included *trans*-1,2-dichloroethylene (tDCE), benzene, toluene, trichloroethylene (TCE), *o*-dichlorobenzene

(oDCB), *m*-xylene (mXYL), and tetrachloroethylene (PCE). Each sampler was deployed on a separate trigger line with a single 40-mL Snap Sampler VOA vial. The samplers were left for 24 hours to equilibrate. The control samples were collected in glass, 40-mL VOA vials, which were filled so there was no headspace and sealed with outer screw caps. As soon as the sampling was completed, the samples were taken up two flights of stairs to the laboratory where they were stored in a refrigerator (at 4°C) until they were analyzed either later that day or the next morning.

This protocol was repeated twice (giving three rounds of sampling). During the first and third rounds of sampling, the Snap Samplers were triggered prior to collecting the corresponding control samples. During the second round of sampling, the order the samples were collected was reversed (i.e., the control sample was collected before the Snap Sampler sample was collected). To minimize mixing of the solution in the standpipe, the Snap Samplers were not removed from the standpipe until after the last control sample was drawn.

At the time of analyses, aliquots of each sample were transferred to glass, 1.8-mL autosampler vials using a glass Pasteur pipet. The autosampler vials were also filled so that there was no headspace in the vials. Primary standards and mixed primary standards were prepared in methanol and stored as described by Parker and Ranney (2000). On analysis days, working standards were made by dilution of the mixed primary standard into deionized water.

Analytical determinations were made using reversed-phase HPLC (RP-HPLC) as described by Parker and Ranney (1998). The UV detector was set at 215 nm, and separations were obtained on a 25- × 0.46-cm (5-μm) LC-18 column (Supelco) and eluted with 1.5 mL/min. of 65/35 (V/V) methanol/water. The detector response was obtained from the digital integrator operating in the peak height mode. To eliminate any bias associated with the order of analyses, each pair of samples was analyzed twice: once with the control sample first and the Snap Sample second, and once using the opposite order.

First Holding-Time Study for VOCs

The purpose of this study was to determine whether analyte concentrations of samples stored in the Snap Sampler vials were affected by sample

holding time. Specifically, we wanted to determine whether representative concentrations of the VOCs could be recovered after storing the samples for the maximum holding times for VOCs for both preserved (14 days) and unpreserved (7 days) samples. Separate studies were run for the unpreserved and preserved samples. For both studies, five trigger lines were deployed in the standpipe, each with a single sampler vial per trigger line, and left in the standpipe for 24 hours to equilibrate. The Snap Sampler samples and the control samples were collected in pairs, alternating the sampling order. For the first study the samples were not preserved, and all the samples were stored in a refrigerator at 4°C for 7 days. The study was then repeated except that the samples were preserved and then held for 14 days in the refrigerator.

To preserve the control samples, 0.5 mL of a 50% hydrochloric acid (HCl) solution was added to the VOA vial. The Snap Sampler samples were acidified using the method given by the manufacturer: 0.125 mL of the acid was added to the well in the cap, the septum was then punctured, and then the remaining 0.125 mL of acid was added to the well in the cap.

Analyses were as described previously.

Second Holding-Time Study for VOCs

The procedure for this study was the same as for the previous holding-time study except that the Snap Samplers were equilibrated in the standpipe for 72 hours rather than for 24 hours. In both of these studies, five Snap Samplers were deployed.

Studies with Explosives

The analytes contained in this test solution included hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitrobenzene (TNB), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), 1,3-dinitrobenzene (DNB), and 2,4-dinitrotoluene (DNT). Concentrations of TNB, RDX, and TNT were all in the low mg/L levels (~1–5 mg/L). Concentrations of HMX were in the high 100 µg/L range (~700 µg/L), and concentrations of DNB and DNT were in the low 100 µg/L range (~100–200 µg/L).

First Standpipe Study with Explosives Test Solution

For this study, five trigger lines, each with a single Snap Sampler containing a 125-mL glass bottle, were deployed in the standpipe and left to equilibrate for 24 hours. Control samples were collected in 40-mL glass VOA vials with Teflon-lined screw caps. The samples were stored in a refrigerator overnight. The next day, an aliquot was transferred to a glass, 1.8-mL autosampler vial using a glass Pasteur pipet, and the samples were analyzed.

The combined explosives standard in acetonitrile (U.S. EPA Method 8330 Calibration Mix #1) was diluted in (HPLC-grade) acetonitrile and stored in the dark in the freezer. Working standards were made each sampling day by adding the diluted standard to deionized water as described by Parker and Clark (2002).

Analytical determinations were performed using RP-HPLC on a modular system as described by Parker and Ranney (1997). Separations were obtained on a 150- × 3.9-mm (4- μ m) LC-8 column (Waters) and eluted at 1.4 mL/min with 85/15 (V/V) water/isopropanol (Walsh and Ranney 1999, Jenkins et al. 2001). The UV detector was set at 254 nm, with the digital integrator operating in the peak height mode.

Holding-Time Study for Explosives

The experimental procedure for this study was similar to the previous experiment except that the samples were kept in the refrigerator (at 4 °C) for the maximum holding time (i.e., 7 days with no preservation) prior to analysis.

To prepare the standards, the U.S. EPA's method 8330 explosives (mix #1) primary standard was first diluted to 10 mg/L in ACN. Standards were then prepared in a 1.8-mL autosampler vials by adding 900 μ L of deionized (DI) water, 270 μ L of acetonitrile, and 30 μ L of the diluted 8330 standard to each vial. For the test samples, 900 μ L of each sample was pipetted into an autosampler vial using a glass Pasteur pipet, and 300 μ L of acetonitrile was added (to match the composition of the analytical standards). Blanks were made by adding 900 μ L of DI water and 300 μ L of acetonitrile to each autosampler vial.

Analytical determinations were made on a modular HPLC system from Thermo Electron Corporation composed of the following Finnigan SpectraSYSTEM components: a model P4000 pump, a UV2000 dual-wavelength UV/VS absorbance detector set at 210 and 254 nm (cell path 1 cm), and a AS300 autosampler. Samples were introduced with a 100- μ L sample loop. Separations were achieved on a 150- $\times$ 3.9-mm (4- μ m) NovaPak LC-8 column (Waters Chromatography Division, Milford, Massachusetts) at 28°C and eluted at 1.4 mL/min with 85:15 water/isopropanol (V/V).

Field Studies

For the field studies, a 3/4-inch-diameter bladder pump (the Mini Bladder Pump by Durham Geo Slope Indicator of Stone Mountain, GA) and a Snap Sampler trigger line, with one to three Snap Samplers, were placed in each well. (A small-diameter pump was used in these studies so that all the equipment could be placed in the well at the same depth at the same time.) The pump was placed in the well at approximately the midpoint of the well's screened interval. The Snap Samplers, stacked one above the other on a single trigger line, were placed in the well so that they straddled the entry port of the bladder pump. After placing the pump and the Snap Samplers in the well, the equipment was left in the well for two to four days. This allowed time for the well to recover from the disturbance caused by placing the equipment in the well and gave the materials in the sampler and pump time to equilibrate with the analytes in the well water.

After the equilibration period, the samplers were triggered and then samples were collected using a low-flow purging and sampling protocol (Puls and Barcelona 1996, U.S. EPA Region 1 1996). Purge parameters that were monitored included turbidity, dissolved oxygen (DO), specific conductance, salinity, and temperature. Turbidity was monitored using a portable field turbidity meter (LaMotte model 2020). In most cases, samples were not collected until a turbidity reading of 10 NTU or less was obtained. Dissolved oxygen, specific conductance, salinity, and temperature were monitored using an oxygen/conductivity/salinity/temperature meter (Model 85 - YSI Environmental, Yellow Springs, OH). These parameters were monitored until three successive readings varied by no more than $\pm 10\%$. Depending upon the site, it typically took 1 to 2 hours for the purge parameters to stabilize.

Once the low-flow samples were labeled and placed on ice, the Snap Samplers were removed from the well and disassembled, and the samples were placed on ice. The sample collection process was then repeated for the next well.

CRREL Field Study

The first field trials with the Snap Sampler were conducted in one of CRREL's ground water monitoring wells that is contaminated with TCE. (A more thorough site description can be found in Appendix A.) The 10-cm- (4-in.-) diameter PVC monitoring well used in this study was screened from 35.7 to 38.7 m (117 to 127 ft) below ground surface (bgs), with a static water level at 33.8 m (111 ft) bgs. The concentration of TCE in this well was ~70 µg/L.

For this study, a trigger line containing one Snap Sampler with a Snap Sampler VOA vial was deployed in the well at the same depth as the inlet for the 3/4-inch bladder pump. The sampling equipment was then left for 24 hours to equilibrate. On the following day, the Snap Sampler was triggered and then a sample was collected using low-flow purging and sampling. A flow rate of ~30 mL/min was used, and the low-flow sample was collected in 40-mL VOA vials. No drawdown of the water level has been observed in this well at this rate of pumping.

Once the samples were collected, a new Snap Sampler vial was placed in the Snap Sampler, the sampler was connected to the trigger line, the trigger line with the sampler was redeployed in the well, and the process was repeated the next day. This process was repeated until five separate tests had been completed. As soon as the samples were collected, they were taken to the laboratory where they were either refrigerated and then analyzed the next morning or analyzed immediately.

Analyses were similar to those described previously for the first VOC standpipe study. The primary standard was made by adding a known amount of neat TCE to methanol in a 50-mL glass volumetric flask and then weighing the flask. This standard was kept in the freezer. On analysis days, working standards were made by dilution of the primary standard into deionized water.

Field Study at the Former Louisiana Army Ammunition Plant

Five 10-cm- (4-inch-) diameter PVC wells at the former Louisiana Army Ammunition Plant (LAAP) were selected for this study. (This property is now owned by the Louisiana National Guard and known as Camp Minden.) The criteria used to select these wells included well diameter, screen length, sampling depth, concentrations of explosives, and ease of access to the well site. The wells varied in depth from 7.6 to 26.2 m (25 to 86 ft) bgs, and screen lengths varied from 1.5 to 3 m (5 to 10 ft). Recent data indicated that concentrations of RDX ranged from 30 to 17,000 µg/L, and concentrations of TNT ranged from 400 to 8,000 µg/L. (More information on this site and the wells used in this study can be found in Appendix A.)

One trigger line with three Snap Samplers in tandem was deployed in each of the wells. Each Snap Sampler held a 125-mL glass bottle. The Snap Samplers were deployed so that the middle sampler was at the same depth as the inlet of the 3/4-inch-diameter bladder pump. Samplers and pumps were deployed in all five wells on the same day and were left to equilibrate for two or three days. Two wells (108 and 110) were sampled after a 48-hr equilibration period and the other three wells were sampled after a 72-hr equilibration period.

On the sampling day, the Snap Samplers in each well were triggered first and then the low-flow samples were collected using a sampling rate of ~80–100 mL/min. Once the low-flow samples were collected, the Snap Samplers were removed from the well, the bottles were removed from the samplers, and the septum caps were screwed onto the ends of the bottles. (Although the manufacturer states that the springs can be removed from the bottles at this point when sampling for non-volatiles, the springs were not removed from these bottles.) The bottles were placed on ice and shipped by overnight delivery to the laboratory for analysis. Upon their arrival at CRREL, the samples were refrigerated at 4°C and analyzed the next day.

Samples, blanks, and standards were prepared as described previously for the holding time study (for explosives). Two of the three Snap Sampler samples and two of the three control samples collected were analyzed. Analyses were conducted in the same fashion as described for the holding time study.

Field Study at the Silresim Superfund Site

Four wells at the Silresim Superfund Site in Lowell, MA, were selected for the final field study. Three of the wells were constructed with 5-cm- (2-in.-) diameter schedule 40 PVC casing; the fourth was constructed with 15-cm (6-in.) diameter steel casing. The depth of these wells was between 7 and 18 m (22 and 59 ft) bgs, and the screened sections of these wells were all fully submerged. The three PVC wells had been sampled by the site manager on a semi-annual schedule since (at least) November 1995. The steel-cased well had not been sampled since November 2000. Contaminants in these wells included the BTEX¹ compounds and several chlorinated VOCs. (Additional information on this site and these wells can be found in Appendix A.)

In each well, one trigger line, with two Snap Samplers in tandem, was deployed. Each Snap Sampler contained a 40-mL Snap Sampler VOA vial. The Snap Samplers were installed so that they straddled the desired sampling depth; the 3/4-inch bladder pump was installed so that it was ~0.7 ft above the middle of the Snap Samplers. The pumps and samplers were then left to equilibrate for either three or four days.

On the sampling day, the Snap Samplers were triggered and then the pump and samplers were lowered 21 cm (0.7 ft) so the inlet of the bladder pump was at the same depth as the midpoint of the two Snap Samplers when those samples were collected. The low-flow samples were collected in 40-mL VOA vials that already contained 0.5 mL of 50% HCl preservative. The Snap Sampler vials were preserved as was described previously for the holding time studies (for VOCs). The samples were then labeled and were packed in ice until they could be refrigerated.

Once the field work was complete, the samples were again packed in ice and shipped via courier transport to a commercial, EPA-approved laboratory. Analyses were conducted using gas chromatography/mass spectrometry according to EPA's SW 846 Method 8260B (U.S. EPA 1996).

¹ BTEX compounds are typical components of petroleum byproducts such as gasoline. BTEX stands for Benzene, Toluene, Ethylbenzene, and Xylenes.

Statistical Analyses

For all data sets where the data were normally distributed, paired *t*-tests (at 95% confidence level, $\alpha = 0.05$) were performed on the data to determine if there was a statistically significant difference between the values for the Snap Sampler and those for the control samples (for the standpipe studies) or the low-flow samples (for the field studies). In instances where the data were not found to be normally distributed (using a P value of 0.050), the data were first log-transformed and then tested for a normal distribution. In those instances where a normal distribution was found, a paired *t*-test was then performed on the log-transformed data. In instances where neither the raw data nor the log-transformed data were normally distributed, a Wilcoxon signed rank test was used to determine if there was a significant difference between the treatments (i.e., the Snap Sampler vs. the low-flow samples).

4 Results and Discussion

Standpipe Studies

Studies with VOCs

First Study

The results from the first standpipe study for the seven VOCs tested in this study are summarized in Table 1. (The data for all the samples are given in Appendix Table B1.) For all the analytes, the percent difference between the mean values (in the Snap Sampler vs. the control samples) was less than 2%. Statistical analyses of the data revealed that there was no significant difference between the VOC concentrations with either sampling method for any of the seven analytes.

Table 1. Summary of the findings from the first standpipe study with VOCs.

	Mean concentration (mg/L)		
Analyte	Control	Snap Sampler	Percent difference
tDCE	0.940	0.930	-1.1
Benzene	0.994	0.989	-0.5
TCE	0.970	0.965	-0.5
Toluene	0.970	0.962	-0.9
oDCB	1.02	1.01	-1.5
mXYL	0.958	0.947	-1.2
PCE	0.906	0.895	-1.2

First Holding-Time Study

In the first study, the samples were analyzed almost immediately after sampling. However, in most circumstances the samples are shipped to a laboratory and the samples are not analyzed until several days later, and in some cases, the samples are held for the maximum holding time prior to being analyzed. Since the Snap Samplers contain materials that would be sorptive of some VOCs (i.e., Teflon-coated springs and Teflon caps)

(Parker and Ranney 1997, 1998), this study was conducted to determine if samples held for the maximum holding time would still yield samples that were equivalent to the control samples. In this study, the samples were held 7 days with no preservative and 14 days with preservative.

The results from this study are summarized in Table 2. While there were no statistically significant differences between the concentrations in the control samples and those in the Snap Sampler vials in the previous study (when the samples were analyzed almost immediately), there were statistically significant differences for most of the analytes in this study.

For the samples that were held for seven days without any preservative, there were statistically significant differences for five of the seven analytes. Mean concentrations in the Snap Samplers were as much as 61% lower (i.e., for toluene) (Table 2). (Appendix Table B2 gives the results for all the samples.)

For the samples that were held for 14 days with preservative, there were statistically significant differences for six of the seven analytes. Concentrations in the Snap Samplers were as much as 36% lower (for mXYL) (Table 2). (Appendix Table B3 gives the results for all the samples.)

These results, especially the losses seen in the preserved samples (where biodegradation of the analytes could not be a factor causing loss of analytes), suggested to us that perhaps the equilibration period (one day) had not been long enough to prevent sorptive losses of some analytes. Therefore, we decided to repeat this experiment using a longer equilibration time.

With respect to the mechanical performance of the Snap Sampler, we did have one problem. One of the vials broke when we tried to remove it from the holder. This may have been because the vial did not seat properly in the holder.

Second Holding-Time Study

The protocol for this study was the same as the previous study except that the samplers were equilibrated for three days rather than the 24 hours used in the previous study. The results from this study are also summarized in Table 2. Generally, there were statistically significant differences

Table 2. Summary of the findings from the holding-time studies for VOCs.

Holding time (days)	Equilibration time (days)	Preserved?	Mean concentrations (mg/L)													
			tDCE		Benzene		TCE		Toluene		oDCB		mXYL		PCE	
			Control	SS	Control	SS	Control	SS	Control	SS	Control	SS	Control	SS	Control	SS
7	1	No	0.235	0.242*	0.155	0.097*	0.235	0.231	0.131	0.05*	0.278	0.267*	< DL	< DL	0.177	0.166*
Percent difference				3		-38		-2		-61		-3.9				-6.1
7	3	No	0.417	0.435*	0.27	0.254	0.378	0.388*	0.191	0.172	0.328	0.328	0.111	0.008*	0.274	0.273
Percent difference				4.1		-0.7		2.8		-9.7		0		-93		-0.3
14	1	Yes	0.245	0.233*	0.206	0.205	0.245	0.230*	0.195	0.184*	0.298	0.271*	0.05	0.032*	0.192	0.162*
Percent difference				-4.6		-0.5		-5.9		-5.9		-8.9		-36		-16
14	3	Yes	0.591	0.599*	0.418	0.430*	0.536	0.539	0.309	0.298*	0.493	0.483*	0.243	0.187*	0.403	0.387*
Percent difference				1.5		2.9		0.5		-3.5		-2		-23		-3.8

*Values with a statistically significant difference from control samples.

for most of the analytes in this study but the differences were less than those seen in the previous (24-hour) holding time study.

For the samples that were held for seven days without any preservative, there were statistically significant differences for only three of the seven analytes. However, these losses (with the exception of mXYL) were substantially less than those seen in the samples that had been equilibrated for only one day (Table 2). (Appendix Table B4 gives the results for each sampler.)

For the samples that were held for 14 days with preservative, there were statistically significant differences for six of the seven analytes (Table 2). However, there was no longer a consistent negative bias associated with the Snap Sampler samples (i.e., for half of the analytes, concentrations were slightly higher in the Snap Sampler). Again, the losses were substantially less with the longer equilibration time for all the analytes. (Appendix Table B5 gives the results for each sampler.)

Given that differences in the VOC concentrations between the Snap Sampler and control samples were generally less than 5% after equilibrating for three days, we believe that three days should be an adequate equilibration time for the VOCs, with the possible exception of mXYL. We are not certain why this analyte appears to require a longer equilibration time.

Standpipe Studies with Explosives

First Explosives Study

In this study, the Snap Samplers were equilibrated for 24 hours and then the samples were analyzed the next day. For all six explosives compounds, mean concentrations in the Snap Sampler were within ~3% of the mean concentrations for the control samples (Table 3). (The results for all the samples can be found in Appendix Table B6.) Statistical analyses revealed that none of these differences were statistically significant. These results agree well with previous findings by our laboratory (Parker and Ranney 1994, 1997, Parker et al. 1990) that have shown that, unlike VOCs, sorption of explosives by polymers is minimal.

Table 3. Results from the first standpipe study with explosives (following a 24-hour equilibration period).

	HMX		TNB		RDX		1,3-DNB		TNT		2,4-DNT	
	Control	Snap S.	Control	Snap S.	Control	Snap S.	Control	Snap S.	Control	Snap S.	Control	Snap S.
Mean Conc. (mg/L)	0.682	0.704	1.94	1.94	5.93	5.92	0.133	0.132	1.40	1.39	0.104	0.104
Significant difference?	No		No		No		No		No		No	
Percent difference	3.2		0		-0.2		-0.8		-0.7		0	

Holding-Time Study

This study was conducted to determine if holding samples for the maximum holding time (with no preservative) affected the recovery of the Snap Sampler samples. In this study, the Snap Samplers were equilibrated for 24 hours and then all the samples were held for the maximum holding time (seven days) prior to analysis. Although there were statistically significant differences between the concentrations in the Snap Sampler and the control samples for three of the seven analytes, in all cases the differences in the mean concentrations were less than 1% (Table 4). (The results for all the samples can be found in Appendix Table B7.) Clearly, a 24-hour equilibration time is adequate for wells contaminated with explosive compounds and their degradation products.

With respect to the mechanical performance of the Snap Samplers, we did have an issue with one of the five samplers we deployed. Apparently, the (125-mL glass) bottle leaked because the o-ring didn't seal properly.

Table 4. Results from the holding-time study with explosives (with 7-day holding time).

	Mean Conc. (mg/L)		Significant Difference?	Percent Difference
	Control	Snap		
Analyte	0.650	0.649	No*	
TNB	2.71	2.69	No [†]	
RDX	4.75	4.72	Yes*	0.63
1,3-DNB	0.212	0.215	No*	
TNT	0.976	0.970	Yes*	0.70
NB	0.116	0.115	Yes*	0.86
2,4-DNT	0.074	0.074	No*	

*Paired t-test

[†]Wilcoxon signed rank test

Field Studies

CRREL Site (TCE)

In this study, concentrations of TCE in samples collected with a Snap Sampler were compared with concentrations of TCE in samples collected using low-flow sampling (Table 5). (Sampling occurred in the same well on five different days.) Although concentrations of TCE were slightly higher

in the samples collected with the Snap Sampler on most days, there was no significant difference between the two sampling methods.

Table 5. Findings from the field study at the CRREL test site.

	TCE Mean Concentration* (mg/L)	
Date	Low-flow Sample	Snap Sample
10-May	0.070	0.070
11-May	0.064	0.067
12-May	0.066	0.067
13-May	0.062	0.063
17-May	0.061	0.063
Mean	0.065	0.066

*Concentrations are the mean of two analyses.

Former Louisiana Army Ammunition Plant (Explosives)

In this study, samples of explosives-contaminated ground water were collected from five monitoring wells using a string of three Snap Samplers (with the 125-mL glass bottles) and low-flow purging and sampling. The well water contained seven explosives: HMX, 1,3,5-TNB, RDX, 1,3-DNB, 2,4,6-TNT, tetryl, and 2,4-DNT.

In this study, we attempted to collect more samples by deploying three (125-mL glass) bottles on a single trigger line. (In the previous studies we had deployed only one Snap Sampler per trigger line.) However, because of the larger number of samplers on the trigger lines, we had numerous mechanical problems with the samplers in this study. In most cases the samplers didn't trigger the first time we activated them, and we had to redeploy them. Also, we could not hear the samplers snap shut when they were triggered (we had been able to hear the VOA vial snap shut in the CRREL well), and in most cases we only recovered two of the three sample bottles that were deployed. The problems we encountered most frequently were that the connector cable became disconnected and/or the end caps did not seat correctly. Also, in an effort to get the sampler to trigger, in one instance we pulled on the trigger line so hard that we broke the cable and in another we had to fix the socket on the sampler end of the trigger line. We found that when we deployed only two samplers on a trigger line (vs. three), we were able to collect both samples successfully.

With respect to how well the data for the two sampling methods agreed, the mean concentration for each sampling method and well is given in Table 6. (The results for all the samples can be found in Appendix Table B8.) Statistical analyses of the data for each analyte revealed that there was no statistically significant difference between the concentrations of any of the seven explosives in the samples collected with either sampling method.

Silresim Site Field Study

At the Silresim site, two Snap Samplers (with two VOA vials) were deployed on a single trigger line in four ground water monitoring wells. Mechanically, the samplers worked well at this site.

The well water at this site contained 13 different VOCs, including several chlorinated compounds (1,1,1-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethylene; 1,2-dichloroethane; cis-1,2-dichloroethylene; chlorobenzene; methylene chloride; PCE; and TCE) and all the BTEX compounds. The findings from this study are given in Table 7. Statistical analyses of these data revealed that there was no significant difference between the concentrations of the VOCs in the samples collected with the Snap Sampler vs. those collected using low-flow purging and sampling for any of the 13 analytes.

Although all the Snap Samplers had triggered on demand, we did notice that the Snap Sampler VOA vials appeared to take on air after standing for a day. When the Snap Sampler vials were first recovered from the well (and capped with the outer caps), there were not any air bubbles in the samples. However, when they were checked the next day, many of these same vials did have small air bubbles in them. It is not clear to us whether the appearance of an air bubble in these samplers resulted from leakage, degassing, or effervescence.

Table 6. Summary of the findings from the field study at the former Louisiana Army Ammunition Plant.

Well number	Mean* Concentration (mg/L)													
	HMX		TNB		RDX		1, 3-DNB		TNT		Tetryl		2,4-DNT	
	Low-flow	Snap	Low-flow	Snap	Low-flow	Snap	Low-flow	Snap	Low-flow	Snap	Low-flow	Snap	Low-flow	Snap
104	2.39	2.18	9.44	8.70	16.7	16.9	0.452	0.465	7.50	7.56	0.185	0.168	0.338	0.326
105	0.448	0.424	2.08	2.11	4.30	4.28	0.156	0.156	0.736	0.676	0.030	0.029	0.070	0.076
108	0.025	0.031	0.94	1.01	0.330	0.407	0.015	0.013	0.896	0.771	nd	nd	0.048	0.027
110	0.526	0.497	0.356	0.327	5.43	5.37	0.046	0.047	0.749	0.604	nd	nd	0.052	0.048
140	0.087	0.079	0.004	0.004	1.36	1.26	0.030	0.026	0.345	0.312	nd	nd	0.018	0.016
Mean	0.696	0.642	2.56	2.43	5.62	5.64	0.140	0.142	2.05	1.98	0.108	0.099	0.105	0.099
% Difference		7.8		5.1		-0.4		-1.3		3		8.2		6.1
Significant difference?		No ^{††}		No ^{**}		No [†]		No ^{**}		No [†]		Not tested		No [†]

*Mean of 2 or 3 samples; each sample analyzed twice

[†]Paired t-test^{**}Paired t-test on log data^{††}Wilcoxon signed rank test

Table 7. Findings from the Silresim Field Study.

Analyte	Well #	Mean Conc. (µg/L)		Significant difference?	Type of test
		Snap	Low-flow		
1,1,1-trichloroethane	EW-10	3,100	3,300	No	Paired-t
	MW-701B	3,800	3,600		
	MW-702B	35,000	34,000		
1,1-dichloroethane	EW-10	75	80	No	Paired-t
	MW-702B	9,500	11,500		
	MW703A	53.5	58		
1,1-dichloroethene	EW-10	75	70	No	Wilcoxon signed rank
	MW-701B	495	445		
	MW-702B	9,500	11,500		
	MW703A	2	2		
1,2-dichloroethane	EW-10	410	460	No	Paired-t
	MW-702B	22,500	33,000		
	MW703A	6	3		
Benzene	MW-701B	80	80	No	Paired-t
	MW-702B	2,500	3,000		
	MW703A	150	170		
Chlorobenzene	EW-10	2,200	2,250	No	Wilcoxon signed rank
	MW-701B	120	120		
	MW-702B	5,000	6,500		
	MW703A	10	10.5		
cis-1,2-dichloroethene	EW-10	460	485	No	Wilcoxon signed rank
	MW-701B	1,500	1,600		
	MW-702B	185,000	270,000		
	MW703A	60	64.5		
Ethylbenzene	EW-10	1,600	1,650	No	Wilcoxon signed rank
	MW-701B	220	210		
	MW-702B	5,500	6,500		
	MW703A	3.5	5		
Methylene chloride	EW-10	350	400	No	Paired-t
	MW-702B	180,000	285,000		
	MW703A	7.5	3.8		
m,p-xylene	EW-10	2,150	2,200	No	Paired-t
	MW-701B	775	710		
	MW-702B	2,500	3,000		
Tetrachloroethene	EW-10	11,500	12,000	No	Paired-t
	MW-701B	485	450		
	MW-702B	14,000	16,000		
Toluene	EW-10	5,250	5,450	No	Wilcoxon signed rank
	MW-701B	1,400	1,350		
	MW-702B	6,500	8,500		
	MW703A	4	4.5		
Trichloroethene	EW-10	7,400	7,900	No	Paired-t
	MW-701B	1,100	790		
	MW-702B	140,000	110,000		

5 Conclusions

Laboratory studies conducted with known concentrations of analytes demonstrated that the Snap Sampler can recover comparable concentrations of VOCs and explosives following an equilibration period. For VOCs, a three-day equilibration period should be adequate for the analytes in the well water to reach equilibrium with the materials in the sampler. For explosives, 24 hours should be sufficient for equilibration to occur between the sampler materials and these analytes. However, a longer equilibration time may be prudent so that ground water flow can be reestablished within the well. Two weeks is recommended by the ITRC Passive Sampling Team for most passive samplers (ITRC 2006, 2007).

For the VOCs, concentrations were compared between the Snap Sampler and low-flow purging and sampling at two sites (CRREL and Silresim) for a suite of volatiles. There was no significant difference between the VOC concentrations in the samples taken with the Snap Samplers vs. those in the samples taken using low-flow purging and sampling. A similar comparison test conducted at the former LAAP also indicated that the Snap Sampler recovered comparable concentrations of explosives.

While the Snap Sampler triggered on demand when deployed with only one or two VOA vials per trigger line, this was not the case when three 125-mL glass bottles were deployed on a single trigger line. Since this study was completed, the developer has made a number of design improvements in this sampler technology, including replacing the 125-mL glass bottles with 125-mL plastic bottles with a stronger spring mechanism. We have tried the newer plastic bottles in the same CRREL well used previously. We were able to trigger and recover three bottles in tandem on a single line successfully but had to repeat this a second time when there were four samplers on a single line (the maximum number of samplers recommended per a trigger line by the manufacturer). (The sampler triggered correctly after we made certain there was no tension on the connector cables to each of the bottles.) However, even if only two or three samplers could be deployed on a single trigger line, this would not negate the use of more samplers in a well but would require using an additional trigger line.

All in all, we feel this sampler is a promising cost-effective technology for sampling ground water monitoring wells under in-situ conditions.

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Appendix A. Brief Histories and Descriptions of Field Sites

The CRREL Site – Hanover, New Hampshire

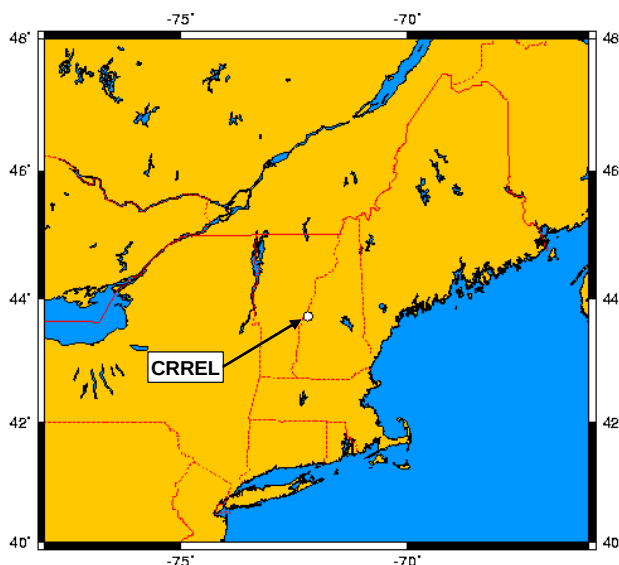


Figure A1. Location of CRREL.

The Cold Regions Research and Engineering Laboratory (CRREL), established in February 1961 and located in Hanover, NH (Fig. A1), is a U.S. Army Corps of Engineers laboratory.

The following information about this site was derived from Shoop and Gatto (1992) and Arthur D. Little (1994).

Site History

CRREL's mission was and still is primarily to provide engineering and research of technologies to assist the Army in developing equipment, procedures, and engineering solutions for maintaining effectiveness in cold climates. Much of CRREL's research was conducted in on-site, refrigerated facilities that were cooled using trichloroethylene (TCE) as its refrigerant. In 1987, the cooling plant was converted to a Freon-based system. However, by then, episodic TCE spills, leaks, and accidents had occurred. Ground water contamination was first detected in three on-site

production wells in November 1990. These wells were used to provide water for a cooling system. Further testing revealed that there was water and soil contamination at other locations on the CRREL compound and in two domestic water supply wells in Vermont. In 1994, a permanent ground water treatment plant was constructed that utilized air-stripping towers to capture the TCE on granular activated carbon. Concentrations of the treated cooling water that is discharged into the Connecticut River are less than five parts per billion. Also, contaminated soil has been treated by injecting potassium permanganate solution. (This compound speeds the neutralization of TCE through oxidation.) TCE levels in on-site production and monitoring wells and discharge waters are regularly monitored and reported to the New Hampshire's Department of Environmental Services. In 2005, TCE levels in the monitoring wells ranged from less than detection to 35 ppm.

Site Hydrogeology

The CRREL compound currently occupies 30 acres of land approximately 1.5 mi north of the town center of Hanover, between NH Highway Route 10 on the east and the Connecticut River to the west. The site is approximately rectangular, measuring 1,360 ft east to west and 970 ft north to south. The compound holds seven major buildings and several other support structures (Fig. A2).

The compound is situated on unconsolidated glacial deposits, which form three main terraces that range from 460 to 520 ft above mean sea level (amsl). The western-most and lowest-elevation terrace drops steeply to the river and has a surface elevation of approximately 380 ft amsl. The monitoring well that was sampled for this study is located on the middle terrace as indicated Figure A2. It has a depth to water bgs of approximately 111–115 ft and a ground elevation of 493 ft.

Drainage of surface water is generally east to west toward the river through an underground storm water system, assisted by culverts and diversion swales. The storm water system also handles spent cooling and refrigeration water from the various office and laboratory buildings, most of which originates from five production wells located on the lower terrace. All other waters are discharged to the municipal sewage system. Most of the storm water is discharged to the river through a single outfall. The yearly average cooling water discharge through the outfall is estimated to

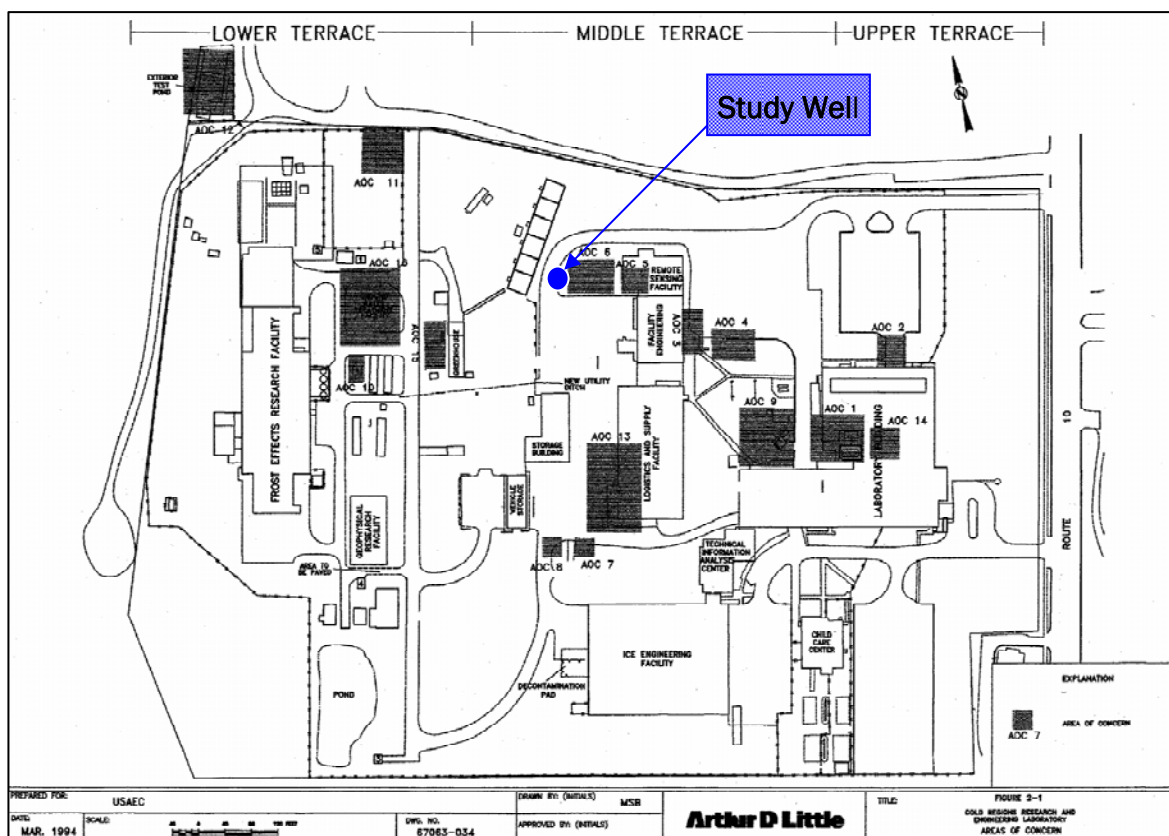


Figure A2. CRREL site map. The Connecticut River (not shown) is approximately 90 m (300 ft) to the left of CRREL's western fence line. The darkened locations represent sixteen known or potential areas of concern. Many of these areas are associated with underground storage tanks.

be 365 million gallons, augmented by an additional 23 million gallons of storm water.

The Connecticut River forms a narrow (~ 500 ft wide near CRREL), 30-mile-long reservoir that is formed behind a hydroelectric-generating facility located 4.5 miles downriver from CRREL. The average daily flow at a location about 0.5 miles upstream of CRREL has been estimated at 4,900 cubic feet per second (cfs). The time required for water to pass through the entire reservoir varies from two to five days, depending on the dam's discharge rate, which is regulated for peak power production.

The underlying geology at CRREL is an overburden of glaciofluvial and glaciolacustrine sediments atop poly-deformed, metasedimentary bedrock. Glaciofluvial, or subglacial stream, deposits were associated with intermittent glacial advance and retreat occurring during the Wisconsin period approximately 20,000 years ago. Glaciolacustrine, or lake-associated,

sedimentation resulted from the glacier's retreat some 13,000–11,000 years ago. These fluvial events carried away the finer materials and left behind fairly coarse-grained and more-widely diverse streambed mineralogy. Sharp geologic boundaries are typically present between the ancient streambeds and the deposits formed otherwise. A major, 87-km-long esker runs beneath the western portion of CRREL. Visual topographic evidence and actual borings support the theory that the esker is approximately 400 ft wide in the vicinity of CRREL. It consists of densely packed, fine to coarse sand having the Unified Soil Classification System (USCS) classifications of SP (poorly graded sands) and SW (well graded sands). Where present, it is believed to be approximately 60 ft thick, lying directly atop bedrock.

Glaciolacustrine deposits in this area resulted after the formation of Lake Hitchcock, which formed through glacial melting and retreat. This large prehistoric lake, which appears to have been a much-swollen representation of the present Connecticut River, extended northward from a moraine at today's Rocky Hill, CT, nearly to St. Johnsbury, VT. With subsequent geologic rebound and episodic drainage, the Connecticut River valley took shape over the past 9000 years by a meandering stream course and an ever-deeper, river-cutting process that left behind a series of steep walls abbreviated by terraces and broad floodplains. Glaciolacustrine sediments underlie all of CRREL and overlie the esker that coincides with much of CRREL's lower terrace. They are composed of three main units: a fine, silty sand (SM), a silt (ML), and a silty clay (CL). The SM layer has compositional ranges of 66–87% sand, 13–29% silt and clay fines, and 0–5% gravel. This unit forms the basal overburden for the eastern two-thirds of the site, and the entire site is overtopped by an ML layer. Soil borings indicate the SM layer ranging in thickness between 20 and 160 ft. The ML layer, between 20 and 110 ft thick, has compositional ranges of 0–79% sand, 21–100% fines, and 0–3% gravel. This layer directly overtops the esker and extends to the surface over the western one-third of CRREL. Only borings on the lower terrace show evidence of layers (up to 75 ft thick) of CL interspersed in the ML layer.

CRREL is situated atop a single unconfined water table aquifer that occurs in both the bedrock and the overburden. Under most of the site it courses through the lacustrine overburden. However, bedrock penetrates up through the water table near the western edge of the property. Ground

water flow in the overburden is generally westward across the site. Hydraulic conductivities in the overburden portion of the aquifer are from 10^{-4} to 10^{-7} ft/s and 10^{-6} to 10^{-8} ft/s in the bedrock. The horizontal ground water velocity is estimated to range between 10^{-1} and 10^{-3} ft/day, with the highest velocities occurring near the center of the property and the slowest in the northwest part of the site.

The Former Louisiana Army Ammunition Plant (LAAP) Site– Minden, Louisiana

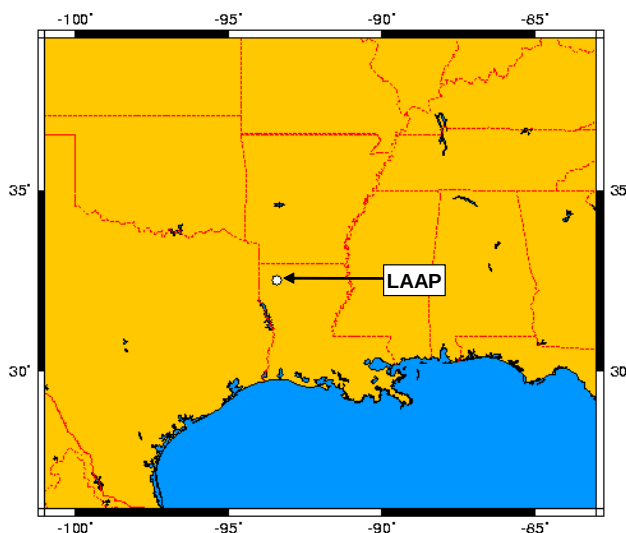


Figure A3. Location of LAAP.

The former LAAP is a U.S. Government-owned, contractor-operated facility occupying approximately 60.6 million m² (14,500 acres) within Louisiana's Bossier and Webster parishes and located approximately 35 km (22 miles) east of Shreveport, LA (Fig. A3). The LAAP is bounded to the north by Interstate 20 and U.S. Highway 80 and to the south by State Route 164. It is bounded to the east and west by Dorcheat Bayou and Clarke Bayou, respectively, with two streams (Boone Creek and Caney Creek) that flow north to south through the site. The facility is approximately 80% wooded, with the remaining 20% occupied by former production lines and mission support facilities.

The following information about this site was derived from Pennington et al. (1999).

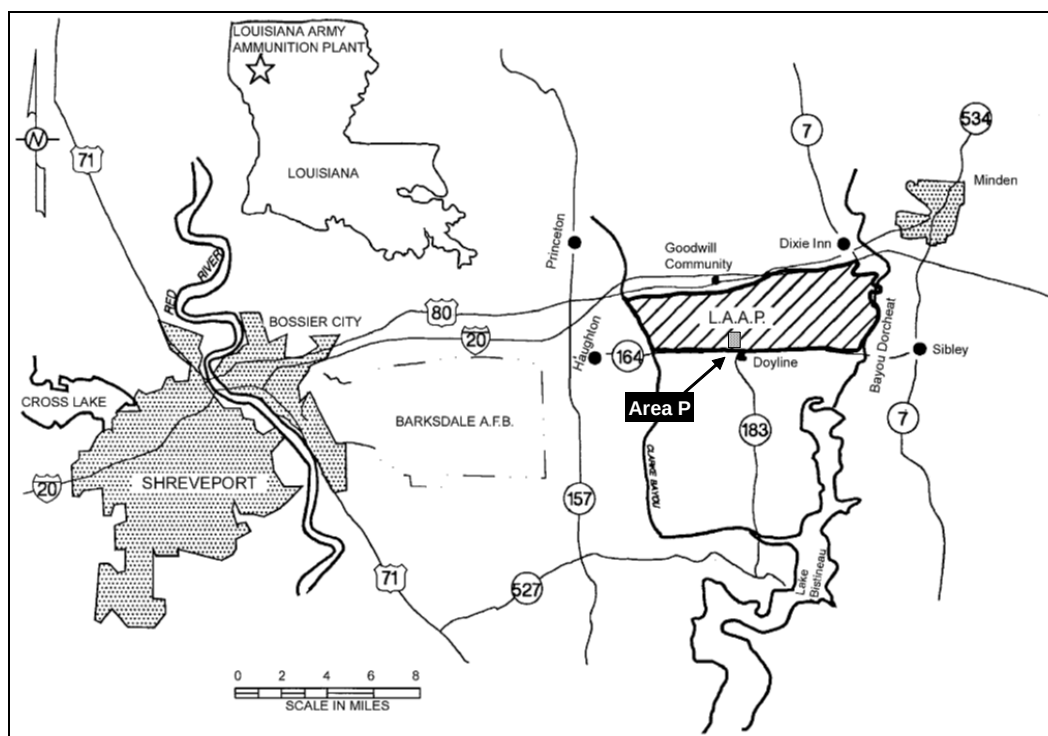


Figure A4. Map of the former LAAP.

Site History

The former LAAP property (Fig. A4) was first acquired by the Federal government in 1941 for the construction of an ordnance manufacturing facility in support of the war effort. In May 1942, construction was completed on eight ordnance loading lines to manufacture ammunition metal parts, load explosives into shell casings, assemble and package for shipping, and provide associated support functions for ammunition production. Production was suspended in August 1945 but resumed in February 1951 with the outbreak of the Korean Conflict. Production continued until October 1957 and was again suspended until September 1961. From that time until October 1994, munitions production occurred on a full- or part-time basis in support of the Vietnam and Persian Gulf Wars. Ordnance operations at the LAAP ceased in the summer of 1996, and the plant remains officially in standby status. The facility operated a total of ten munitions-loading lines and three test areas.

The LAAP was placed on the National Priorities List in March 1989 because of ground water contamination that resulted from past disposal of explosives-laden wastewater in 16 unlined surface impoundment lagoons

in a 25-acre location known as Area P (Fig. A4). Remedial action was begun in 1988 after a site investigation indicated that the holding ponds were leaching explosives into the ground water. Remediation, completed in 1990, included draining the ponds, treating the 2.03×10^8 L (53.6 million gal) of the accumulated rain and wastewater, and incinerating 9.2×10^7 kg (101,900 tons) of the most heavily impacted soils. The area was backfilled with the incinerated soil, capped and compacted with a minimum 0.61-m- (2-ft-) thick layer of uncontaminated clay soil, covered with 10 cm (4 in.) of topsoil, and vegetated.

Site Hydrogeology

Regionally, LAAP lies atop a subsurface structural feature known as the North Louisiana Syncline. This syncline is at the eastern limb of the much larger Sabine Uplift that was formed by deformation of sediments during tectonic activity that began during the Paleozoic Era approximately 225 million years ago. The North Louisiana Syncline and the LAAP are bounded to the south and east by the Monroe Uplift and to the west and north by the Sabine Uplift. Smaller local uplifts exist in the area, which significantly modify the local structural geology and ground water flow regimes. Two major landforms known as dissected uplands and rolling prairie are found within the facility. Minor landforms include abandoned channels, typically filled with clay that was deposited by ancient courses of the ancestral Red River. Local relief is moderate, with elevations varying from about 40 m (130 ft) above mean sea level (msl) near Dorcheat Bayou to 24 m (80 ft) above msl at Clarke Bayou.

Area P consists of Pleistocene-Age terrace deposits that overly the Eocene-Age Cane River Formation. Collectively, the Pleistocene-Age units are a fining upwards sequence deposited in a fluvial environment. The terrace deposits of Area P can be subdivided into the Lower Terrace, consisting of fine sands and a trace of gravel, and the Upper Terrace, consisting of very fine silt, clays, and silty clays. An intermediate clay unit is present at some locations and serves as a limited aquitard. The Eocene-Age Cane River Formation directly underlies all terrace deposits and consists of clay or clay sufficiently indurated to be classified as claystone. The Cane River is not an aquifer beneath Area P and is considered the confining layer for modeling the site.

Ground water at the site exists in two distinct aquifical layers. An Upper Terrace aquifer generally exists under unconfined conditions at depths varying from approximately 1.5 to 7.6 m (5 to 25 ft) below ground level (BGL). The Lower Terrace aquifer (while not present in all areas) typically occurs from 7.6 m (25 ft) BGL to about 15.2 m (50 ft) BGL and overlies the Cane River Formation. The Lower Terrace aquifer tends to produce more water than that of the Upper Terrace. Ground water models of Area P indicate that migration of explosives contaminants in the Upper Terrace is mostly downwards with little horizontal spreading. However, models and water-level measurements indicate that the regional horizontal ground water flow in the Upper Terrace aquifer was in the southwestern direction.

Historical Contaminants Data

The predominant contaminants at the LAAP are TNT and RDX. Information on its general ground water hydrology and site geology, as well as characterization of the contamination plume, is extensive and readily available. Ground water monitoring is conducted on a regular schedule and these data were available. The most recent data can be found in Shaw Environmental Inc. (2006).

The conclusion of the most recent five-year review that evaluated the effectiveness of the remedial action at Area P indicated that while the overall quality of water in the Upper Terrace aquifer was improving, concentrations in the Lower Terrace were increasing (Shaw Environmental Inc. 2006).

Monitoring Wells Used in this Study

The five monitoring wells selected for use in this study were 104, 105, 108, 110, and 140. Wells were selected based on their well diameter, screen length, concentrations of contaminants of interest, and accessibility. Figure A5 shows the locations of these wells; more information on them is given in Table A1. Figure A6 is a recent photograph of Area P.

Our ground water test site is the indicated area at the southern boundary of the LAAP and to the northwest of Doyline, LA.

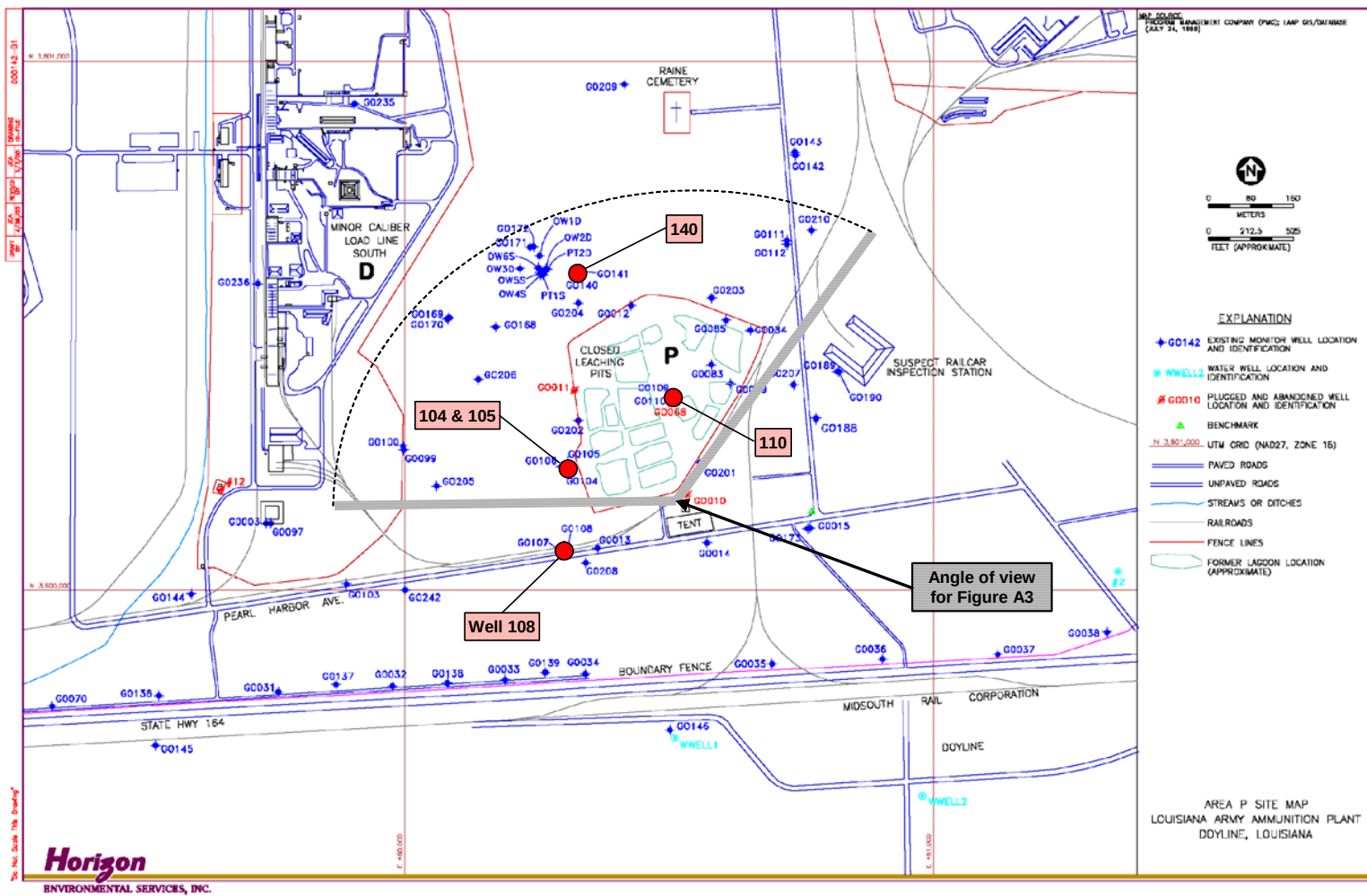


Figure A5. Plan view of Area P at LAAP showing test well locations.



Figure A6. Recent photograph of Area P. The grassed area behind the railroad track and fence line is approximately that area shown enclosed by the red-marked fence line in Figure A5. Well 110, barely visible to right of center, is located in the field behind the fence line. Wells 104, 105, and 140 are all located in the forested area beyond the edge of the field.

Table A1. Description of the test wells at the former Louisiana Army Ammunition Plant.

Well number	Diameter (in.)	Total depth (ft bgs)	Screen interval (ft bgs)	Screen length (ft)	Conc. RDX* (µg/L)	Conc. TNT* (µg/L)	Accessibility
104	4	35	23–33	10	17,000	8,000	Fair
105	4	56	50–55	5	1,500	400	Fair
108	4	80	72–80	8	30	600	Excellent
110	4	86	75–85	10	3,500	650	Good
140	4	25	15–25	10	2,000	1,000	Fair

Silresim Superfund Site – Lowell, Massachusetts

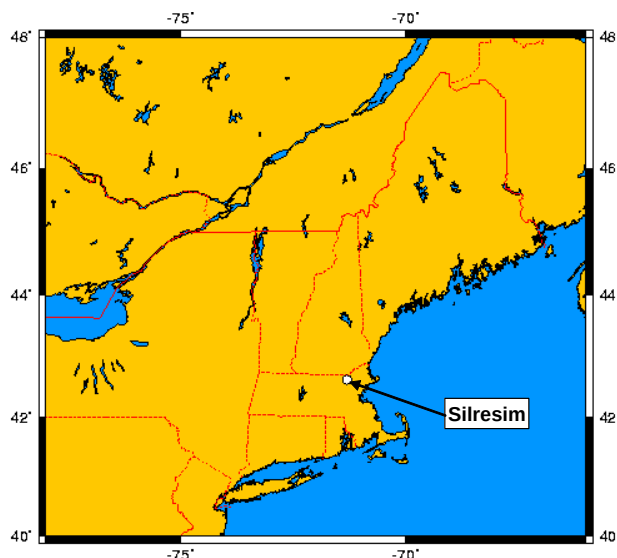


Figure A7. Location of Silresim Superfund Site.

The Silresim Chemical Corporation Site covers 5 acres in an industrial area 1 mile south of the central business district of Lowell, Massachusetts (Fig. A7). It is bordered on the north by Lowell Iron and Steel Company, on the north and northeast by B&M Railroad tracks and rail yard, and on the west by Tanner St. Several residential areas are located to the south, east, and northeast, some as close as 300–500 ft. River Meadow Brook runs parallel to the property and 400 ft beyond Tanner Street. A small wetland area, known locally as East Pond, lies several hundred feet southeast of the property.

The following information was derived from on-line draft reports by Tetra Tech (2004) and GeoTrans (2001).

Site History

The Silresim site and its immediate surrounding areas have been used for industrial activities since the early 1900s. From 1916 to 1971, several petroleum companies used the site for oil and fuel storage. Adjacent properties have housed oil storage terminals, a foundry, a steel-fabricating plant, a vehicle salvage yard for used auto parts, coal storage facilities, and railroad operations. From 1971 through 1977, Silresim Chemical operated a chemical waste reclamation facility on the site. Silresim Chemical's primary

operations involved recycling and reclamation of waste chemicals and their consolidation for off-site disposal. Wastes were accepted at the site in drums, tank trucks, railroad tanker cars, and smaller containers. The waste stream included halogenated solvents, oily wastes, alcohols, plating and metal sludges, and pesticides. Current land-use on nearby properties continues to be commercial, industrial, and residential in nature.

Silresim Chemical declared bankruptcy in 1977 and abandoned the site the following year, leaving behind 30,000 decaying drums and several large storage tanks (Fig. A8). Site investigation revealed that there was clear evidence of numerous spills, leakage of containers, discharge to the city sewer system, and contaminated surface runoff onto adjacent properties. The soil and ground water was polluted with volatile organic compounds (VOCs), semi-volatile organic compounds, pesticides, PCBs, heavy metals, and low levels of dioxin. A noticeable odor is present and is aggravated by hot or humid weather.



Figure A8. Aerial photograph of the Silresim Chemical Corporation when it was an active waste recycling facility (early 1980s). The hundreds of small circular objects covering the site are barrels of chemical waste. (Photo from GeoTrans 2001.)

When the owner abandoned the site in 1978, the state undertook a \$2.2 million cleanup. From 1978 to 1982, immediate threat to public safety was minimized by construction of perimeter fencing, diversion berms, and absorbent-filled trenches, emplacement of 24-hr security, and removal of drums and tanks from the premises. The site was placed on the Environmental Protection Agency's (EPA) National Priorities List in 1982. From 1983 to 1984, the cleanup included the removal of all remaining buildings and structures and the placement of a clay cap over most of the remaining portion the property, with crushed-rock-lined diversion swales leading to underground storm drainage. The Record of Decision (ROD) issued by the EPA in 1991 estimated that the Silresim Chemical Corporation handled approximately three million gallons of waste per year during its eight years of operation. An active ground water treatment plant was built in 1994 and began operating in 1995. The capped property and treatment facility are completely enclosed by a 6-foot chain link fence with locked-gate access. Periods of active soil vapor extraction (SVE) for source removal took place in 1995-96 and 1998-99.

Site Hydrogeology

The underlying geology in the vicinity of Silresim is glacial outwash deposition, 20–100 ft thick over bedrock. The deposits, averaging 80 ft thick, are silty sands and silts of lacustrine origin. The overburden stratigraphy and thicknesses are described from surface to bedrock approximately as follows:

- Unconsolidated overburden layer (unconfined aquifer) 8–12 ft
- Upper varved clayey silt aquitard 15–20 ft
- Semi-confined silty sand aquifer 25 ft
- Lower-varved clayey silt aquitard 30 ft
- Till/weathered bedrock aquifer 15 ft

Surface water drains from the site onto two or possibly three adjacent properties. Ground water beneath the Silresim site is not currently used for drinking water. The Massachusetts Department of Environmental Protection recently reclassified the aquifer in the site area as being of “Limited Use and Value.” The ground water, which ranges from approximately 6 to 10 ft below ground surface in the shallow unconfined aquifer, flows generally to the north and northwest toward River Meadow

Brook, which drains into the Concord River and further into the Merrimack River. The Merrimack River is the source of municipal water for the city of Lawrence. An earlier engineering study estimated that the shallow ground water flow velocity is approximately 30 ft/yr. Another component of ground water flow is through the semi-confined aquifer toward East Pond at an estimated velocity of 10 ft/yr.

Monitoring Wells Used in this Study

The four monitoring wells selected for use in this study were EW-10, MW-701B, MW-702B, and MW-703A. Wells were selected based on their well diameter, screen length, concentrations of contaminants of interest, and accessibility. Figure A9 shows the locations of these wells; more information on them is given in Table A2. Figure A10 is a photographic panoramic view of the site taken in 2006.

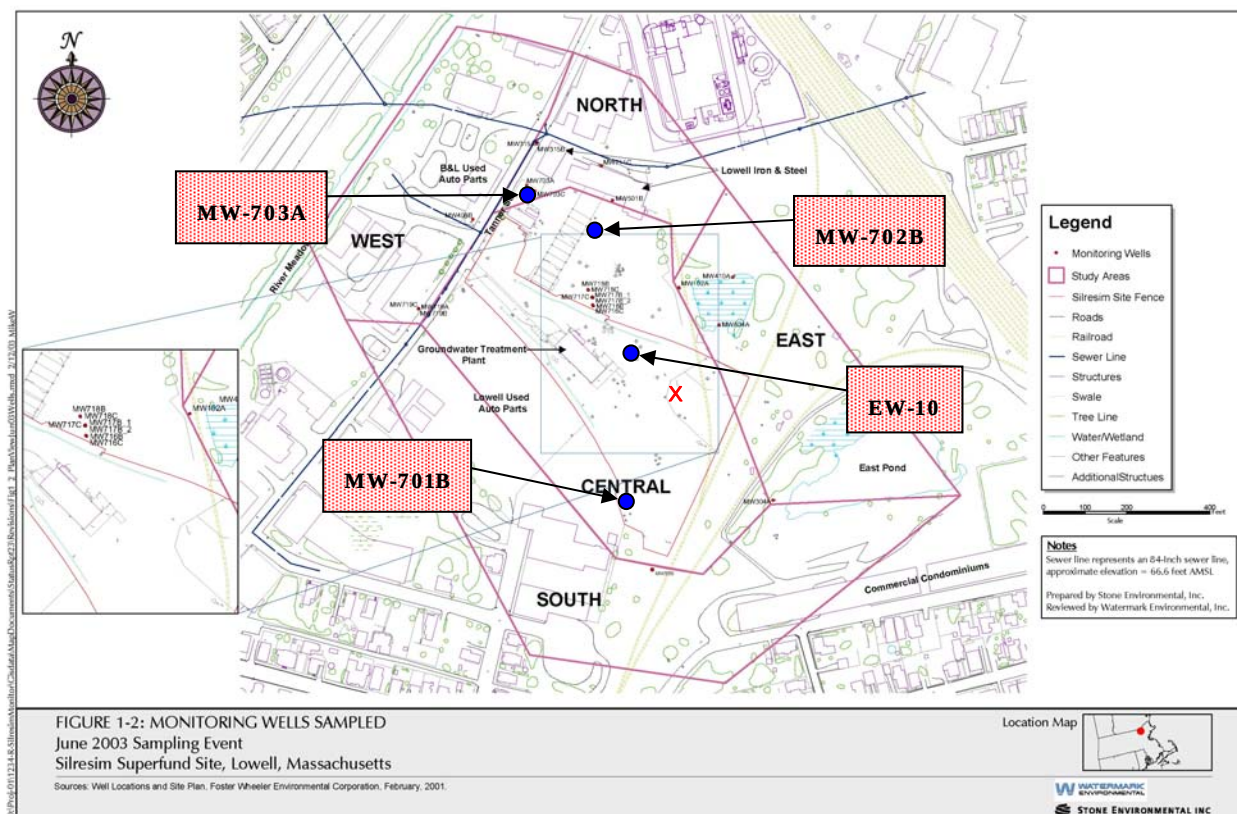


Figure A9. Silresim site map with study wells shown. The red "X" marks the position from which the photo shown in Figure A10 was taken. (Adapted from drawing supplied by J. Parisi.)



Figure A10. Photographic panorama of the Silresim Superfund Site taken in August 2006, looking northwest from the red "X" shown in Figure A9.

Table A2. Description of the tests wells at the Silresim site.

Well ID	Accessibility	Well diameter (in.)	Well casing type	Total depth (ft bgs)	Static water level (ft bgs)	Screen interval (ft bgs)	Sampling depth (ft bgs)
MW701B	good	2	schd-40 pvc	44	12.2	34–44	40.0
MW702B	good	2	schd-40 pvc	44	9.5	34–44	36.2
MW703A	excellent	2	schd-40 pvc	59	9.6*	49–59	52.3
EW-10	good	6	schd-40 steel	22	10.8	7–22	21.6

*Estimated static water level from extrapolation of site manager's December 2006 sampling data.

Appendix B. Data Tables

Table B1. Findings from first standpipe study for VOCs.

	Mean* Concentration (mg/L)													
	tDCE		Benzene		TCE		Toluene		oDCB		mXYL		PCE	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
	1.03	0.95	1.1	1.023	1.07	0.99	1.07	0.99	1.11	1.04	1.06	0.98	0.998	0.91
	1.03	1.00	1.087	1.068	1.06	1.04	1.06	1.03	1.1	1.08	1.05	1.03	0.984	0.956
	0.980	0.940	1.01	1.004	1.01	0.99	0.99	0.98	1.04	1.03	0.99	0.98	0.942	0.931
	0.990	1.000	1.049	1.049	1.02	1.03	1.02	1.02	1.06	1.06	1.01	1.01	0.963	0.97
	0.790	0.850	0.847	0.907	0.81	0.88	0.83	0.89	0.9	0.94	0.81	0.86	0.756	0.825
	0.820	0.840	0.871	0.883	0.85	0.86	0.85	0.86	0.92	0.89	0.83	0.82	0.792	0.779
Mean	0.940	0.930	0.994	0.989	0.97	0.965	0.970	0.962	1.02	1.01	0.958	0.947	0.906	0.895
Percent difference		1.1		0.5		0.5		0.9		1.5		1.2		1.2

*Concentrations are the mean of two analyses

Table B2. Results from the first holding time study for VOCs for the unpreserved samples (with a 7-day holding time).

Samples	Mean* Concentration (mg/L)													
	tDCE		BNZ		TCE		TOL		oDCB		mXYL		PCE	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.233	0.241	0.154	0.128	0.23	0.23	0.127	0.085	0.276	0.264	0.001	0.001	0.173	0.163
B	0.235	0.248	0.156	0.097	0.237	0.239	0.131	0.049	0.278	0.28	0.001	0.001	0.177	0.174
C	0.235	0.241	0.156	0.083	0.234	0.228	0.132	0.028	0.279	0.26	0.001	0.002	0.177	0.162
D	0.234	0.24	0.155	0.052	0.238	0.225	0.131	0.014	0.279	0.268	0.001	0	0.177	0.164
E	0.238	0.241	0.153	0.123	0.238	0.232	0.132	0.075	0.279	0.264	0.001	0.001	0.179	0.167
Mean	0.235	0.242	0.155	0.097	0.235	0.231	0.131	0.05	0.278	0.267	0.001	0.001	0.177	0.166
Significant difference? [†]		Yes		Yes		No		Yes		Yes		No		Yes
Percent difference		3		-38		-2		-61		-3.9		1.4		-6.1

*Mean of two replicate analyses

[†]Statistical analyses were conducted using a paired t-test

Table B3. Results from the first holding time study for VOCs for the preserved samples (with a 14-day holding time).

Samples	Mean* Concentration (mg/L)													
	tDCE		BNZ		TCE		TOL		oDCB		mXYL		PCE	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.244	0.227	0.204	0.201	0.243	0.225	0.193	0.18	0.292	0.263	0.048	0.033	0.19	0.159
B	0.247	0.236	0.205	0.209	0.246	0.231	0.197	0.184	0.301	0.269	0.05	0.027	0.196	0.161
C	0.242	0.234	0.205	0.203	0.246	0.231	0.196	0.186	0.299	0.276	0.05	0.041	0.191	0.16
D	0.244	0.236	0.208	0.206	0.245	0.234	0.196	0.185	0.299	0.279	0.051	0.026	0.19	0.166
Mean	0.245	0.233	0.206	0.205	0.245	0.23	0.195	0.184	0.298	0.271	0.05	0.032	0.192	0.162
Significant difference?		Yes [†]		No ^{**}		Yes [†]		Yes [†]		Yes [†]		Yes [†]		Yes [†]
Percent difference		-4.6		-0.5		-5.9		-5.9		-8.9		-36		-16

*Mean of two replicate analyses

[†]Paired t-test^{**}Wilcoxon test

Table B4. Results from second holding time study for VOCs for unpreserved samples with 3-day equilibration time (7-day holding time).

Samples	Mean* Concentration (mg/L)													
	tDCE		BNZ		TCE		TOL		oDCB		mXYL		PCE	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.42	0.433	0.273	0.199	0.382	0.387	0.192		0.329	0.328	0.113	0.004	0.277	0.271
B	0.42	0.435	0.275	0.26	0.379	0.384	0.191	0.146	0.33	0.328	0.113	0.001	0.278	0.272
C	0.42	0.435	0.269	0.275	0.375	0.393	0.191	0.186	0.329	0.331	0.112	0.018	0.275	0.28
D	0.411	0.438	0.268	0.275	0.373	0.39	0.188	0.184	0.325	0.328	0.108	0.014	0.268	0.273
E	0.414	0.432	0.268	0.264	0.379	0.387	0.192	0.172	0.328	0.328	0.111	0.003	0.272	0.27
Mean	0.417	0.435	0.271	0.254	0.378	0.388	0.191	0.172	0.328	0.328	0.111	0.008	0.274	0.273
Significant difference? [†]		Yes		No		Yes		No		No		Yes		No
Percent difference		4.1		-5.9		2.8		-9.7		0		-93		-0.3

*Mean of two replicate analyses

[†]Statistical analyses were conducted using paired t-tests

Table B5. Results from second holding time study for VOCs for preserved samples with 3-day equilibration time (14-day holding time).

Samples	Mean* Concentration (mg/L)													
	tDCE		BNZ		TCE		TOL		oDCB		mXYL		PCE	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.596	0.599	0.42	0.431	0.542	0.545	0.311	0.302	0.495	0.487	0.244	0.194	0.405	0.389
B	0.595	0.598	0.423	0.431	0.541	0.537	0.311	0.3	0.494	0.481	0.243	0.189	0.405	0.388
C	0.584	0.598	0.415	0.431	0.529	0.538	0.305	0.291	0.487	0.482	0.24	0.168	0.399	0.389
D	0.588	0.596	0.415	0.428	0.535	0.536	0.309	0.297	0.493	0.486	0.244	0.175	0.405	0.384
E	0.59	0.605	0.418	0.431	0.534	0.538	0.309	0.302	0.494	0.478	0.244	0.206	0.4	0.386
Mean	0.591	0.599	0.418	0.43	0.536	0.539	0.309	0.298	0.493	0.483	0.243	0.187	0.403	0.387
Significant difference? [†]		Yes		Yes		No		Yes		Yes		Yes		Yes
Percent difference?		1.5		2.9		0.5		-3.5		-2		-23		-3.8

*Mean of two replicate analyses

[†]Statistical analyses were conducted using paired t-tests

Table B6. Findings from the first standpipe study with explosives.

Sample	Mean* Concentration (mg/L)											
	HMX		TNB		RDX		1,3-DNB		TNT		2,4-DNT	
	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.673	0.700	1.92	1.94	5.94	5.88	0.132	0.132	1.40	1.38	0.104	0.104
B	0.683	0.696	1.95	1.96	5.92	5.92	0.134	0.133	1.40	1.40	0.104	0.105
C	0.690	0.738	1.96	1.94	5.94	5.95	0.133	0.131	1.40	1.38	0.104	0.103
D	0.682	0.682	1.93	1.93	5.91	5.93	0.132	0.132	1.40	1.40	0.106	0.105
Mean	0.682	0.704	1.94	1.94	5.93	5.92	0.133	0.132	1.40	1.39	0.104	0.104
Sig. Difference? [†]		No		No		No		No		No		No
Percent difference		3.2		0		-0.2		-0.8		-0.7		0

* Mean of two replicate analyses

[†]Statistical analyses were conducted by using paired t-tests

Table B7. Findings from the holding time study with explosives (7-day holding time).

	Mean* Concentration (mg/L)													
	HMX		TNB		RDX		1,3-DNB		TNT		NB		2,4-DNT	
Sample	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap	Control	Snap
A	0.657	0.649	2.7	2.68	4.73	4.7	0.215	0.214	0.97	0.967	0.116	0.115	0.0736	0.0738
B	0.664	0.662	2.71	2.69	4.77	4.73	0.207	0.215	0.98	0.967	0.116	0.115	0.0741	0.0738
C	0.651	0.656	2.71	2.7	4.76	4.73	0.216	0.216	0.977	0.972	0.116	0.115	0.0743	0.0741
D	0.644	0.641	2.71	2.69	4.76	4.73	0.207	0.215	0.980	0.970	0.116	0.114	0.0741	0.0741
E	0.634	0.636	2.71	2.7	4.75	4.73	0.216	0.216	0.975	0.972	0.116	0.116	0.0741	0.0738
Mean	0.650	0.649	2.71	2.69	4.75	4.72	0.212	0.215	0.976	0.970	0.116	0.115	0.074	0.074
Sig. difference?		No**		No [†]		Yes**		No**		Yes**		Yes**		No**
Percent difference						0.6				0.7		0.9		

* Mean of two replicate analyses

** Paired t-test

[†]Wilcoxon Signed Rank test

Table B8. Findings from the Field Study at LAAP.

		Low-flow Sample Concentration (mg/L)*				Snap Sampler Concentration (mg/L)*			
		Sample A	Sample B	Sample C	Mean	Sampler A	Sampler B	Sampler C	Mean
Well 104	HMX	2.4	2.37		2.39	2.26	2.15		2.2
	TNB	9.38	9.3		9.34	8.86	8.42		8.64
	RDX	16.5	16.5		16.48	16.9	16.5		16.7
	1,3-DNB	0.447	0.45		0.448	0.471	0.464		0.468
	TNT	7.43	7.41		7.42	7.66	7.38		7.52
	Tetryl	0.183	0.183		0.183	0.173	0.163		0.168
	2,4-DNT	0.288	0.481		0.385	0.317	0.327		0.322
Well 105	HMX	0.432	0.441		0.436	0.471	0.474		0.473
	TNB	2.03	2.02		2.02	1.99	2.1		2.05
	RDX	4.16	4.18		4.17	4.04	4.19		4.12
	1,3-DNB	0.153	0.153		0.153	0.148	0.157		0.152
	TNT	0.724	0.714		0.719	0.647	0.673		0.66
	Tetryl	0.027	0.029		0.028	0.026	0.03		0.028
	2,4-DNT	0.068	0.062		0.065	0.106	0.064		0.085
Well 108	HMX	0.022	0.025	0.026	0.024	0.022	0.025	0.032	0.026
	TNB	0.921	0.944	0.938	0.934	0.972	1.018	0.956	0.982
	RDX	0.321	0.328	0.328	0.326	0.334	0.411	0.427	0.391
	1,3-DNB	0.025	0.013	0.008	0.015	0.008	0.023	0.024	0.018
	TNT	0.88	0.899	0.888	0.889	0.699	0.828	0.717	0.748
	Tetryl								
	2,4-DNT	0.045	0.045	0.047	0.046	0.03	0.023	0.021	0.025
Well 110	HMX	0.543	0.509		0.526	0.52	0.511		0.516
	TNB	0.359	0.343		0.351	0.329	0.328		0.329
	RDX	5.45	5.26		5.35	5.5	5.38		5.44
	1,3-DNB	0.054	0.034		0.044	0.043	0.044		0.044
	TNT	0.765	0.709		0.737	0.615	0.593		0.604
	Tetryl								
	2,4-DNT	0.054	0.049		0.052	0.048	0.049		0.049
Well 140	HMX	0.088	0.085		0.087	0.059	0.082		0.07
	TNB	0.003	0.005		0.004	0.004	0.004		0.004
	RDX	1.36	1.36		1.36	1.24	1.26		1.25
	1,3-DNB	0.032	0.029		0.03	0.026	0.025		0.025
	TNT	0.342	0.345		0.344	0.309	0.314		0.311
	Tetryl								
	2,4-DNT	0.019	0.016		0.017	0.014	0.019		0.016

*Mean of two replicate analyses

Appendix C. Snap Sampler Deployment and Sample Preparation



Figure C1. Snap Sampler deployment preparation.



Figure C2. Preparation of sampler bottles. (The first three photos show a VOA vial. The last photo shows a 125-mL plastic bottle.)

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14. ABSTRACT A series of laboratory and field studies were conducted to determine the ability of the Snap Sampler to recover representative concentrations of VOC and explosives in ground water. For the laboratory studies, statistical analyses of the data (for each analyte) were conducted to determine if the concentrations of analytes in samples taken with the Snap Sampler were significantly different from known concentrations of the analytes in samples collected from a standpipe (i.e., control samples). For the field studies, concentrations of analytes in samples taken with the Snap Sampler were compared with concentrations of the analytes in samples taken using the EPA's low-flow purging and sampling protocol. Again, statistical analyses were used to determine if there were statistically significant differences between the individual analyte concentrations in these samples. Two field trials were conducted for VOCs and one field trial was conducted for explosives. In the laboratory studies, the Snap Sampler recovered concentrations of VOCs that were comparable to those in the control samples after equilibrating the Snap Sampler for 3 days. Comparable concentrations of explosives were recovered after equilibrating the Snap Sampler for 24 hours. In the field studies, concentrations of VOCs and explosives were comparable to concentrations of these analytes in samples that were collected using low-flow purging and sampling.					
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