

Field Demonstrations Using the Waterloo Ground Water Profiler

by Seth E. Pitkin, John A. Cherry, Robert A. Ingleton, and Mette Broholm

Abstract

Use of direct-push sampling tools for rapid investigations of contaminated sites has proliferated in the past several years. A direct-push device, referred to as a ground water sampling profiler, was recently developed at the University of Waterloo. This tool differs from other direct-push tools in that point samples are collected at multiple depths in the same hole without retrieving, decontaminating, and re-driving the tool after each sampling event. The collection of point samples, rather than samples from a longer screened interval, allows an exceptional level of detail to be generated about the vertical distribution of contamination from each hole. The benefits of acquiring this level of detail are contingent on minimization of vertical cross contamination of samples caused by drag down from high concentration zones into underlying low concentration zones. In a detailed study of chlorinated solvent plumes in sandy aquifers, we found that drag down using the profiler is minimal or non-detectable even when the tool is driven through high concentration zones of dissolved chlorinated solvent contamination. Chlorinated solvent concentrations, primarily PCE and TCE at or below a detection limit of 1 µg/L, were obtained directly beneath plumes with maximum concentrations up to thousands of µg/L. Minimal drag down, on the order of a few µg/L to 20 µg/L, may have been observed below chlorinated solvent concentrations of several tens of thousands to hundreds of thousands of µg/L. Drag down through DNAPL zones was not evaluated.

Introduction

A new direct-push ground water sampling device, referred to as the Waterloo Profiler, has been developed at the University of Waterloo for use in unconsolidated granular deposits. The tool offers the benefits of no drill cuttings, minimal purge water generation, and rapid sampling. Some direct push or drive point tools for ground water sampling require withdrawal of the tool from the hole to bring the sample to the surface or to decontaminate the tool and then re-insert it to collect deeper samples. This causes the collection of samples from multiple depths to be time consuming. The Waterloo Profiler is regarded as a continuous point sampler because numerous samples are collected at multiple depths in the same hole. At each depth, a small volume of water is drawn from a narrow depth interval into the tool through small screened ports. By sampling from narrow vertical intervals at a close vertical spacing, a nearly continuous profile of water chemistry is determined. The goal of such point sample profiling is to develop a clear understanding of the anatomy of plumes. The Profiler can generally be driven through silt or clay layers, but is not used to sample these low-permeability layers because of the long length of time required to obtain sufficient sample volume. Before using the Profiler, the general stratigraphy of the site should be determined by another method. However, based on flow rate, the Profiler can be used to distinguish low-permeability zones of silt or clay from zones of sand or gravel.

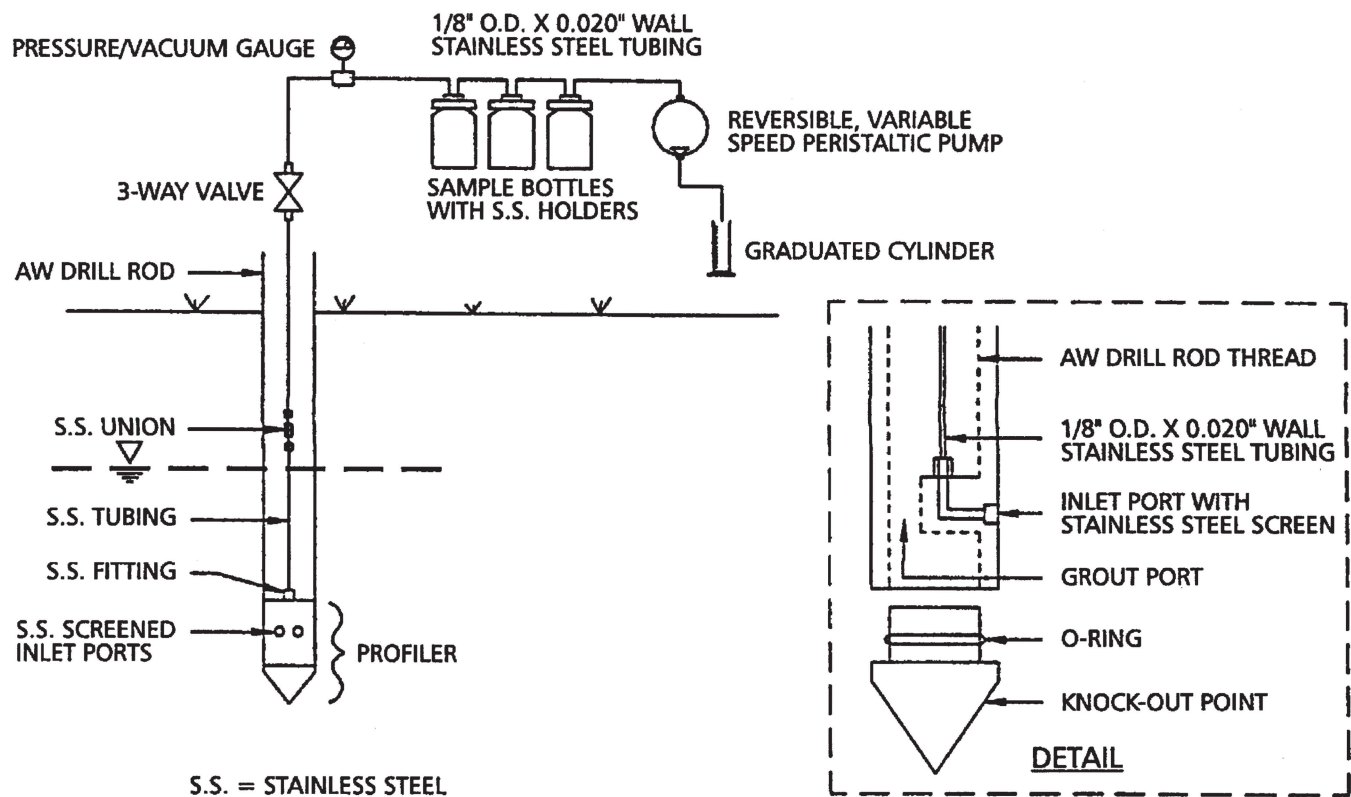


Figure 1. Components and operational arrangement of the Waterloo Profiler.

The effectiveness of the Waterloo Profiler is based on the premise that the device causes minimal drag down of contamination as it is driven down through high contaminant concentration zones into underlying zones of little or no contamination. In this context, drag down refers to any cross-contamination of the sampling system caused by advancing the tool through a zone of high dissolved phase contaminant concentration into a zone with lower concentrations. It does not refer to the movement of nonaqueous phase liquids along the outside of the probe rods. This paper describes the Waterloo Profiler and presents an assessment of drag down at six sites where profiles were obtained from chlorinated solvent plumes in sandy aquifers. At some sites no drag down was observed, and at other sites where the Profiler was driven through exceptionally high dissolved contaminant concentrations, trace drag down may have occurred.

The version of the Profiler described in this paper is best suited for use to depths up to 100 feet (30 m) in unconsolidated sand or gravel aquifers with a water table less than 26 feet (8 m) below ground surface, allowing samples to be drawn by peristaltic pumping or other suction means. A modified version of the Waterloo Profiler permits sampling at depths below the suction limit.

Profiler Components and Operation

The Profiler head consists of a 1.75-inch-diameter stainless steel drive point with six 5/32-inch-diameter circular ports fitted with stainless steel screens (Figure 1). Screen mesh sizes may be selected based on the grain size of the aquifer materials. The ports convey water into a common internal fitting in the tip. Stainless steel or

Teflon® tubing with an outside diameter of 1/8 inch (3 mm) is attached to the internal fitting using Swagelok® couplings. At five of the six sites in this study, stainless steel tubing serves to convey the water sample from the ports through the drill rod to the ground surface. At the sixth site, Teflon tubing was used in some holes and stainless steel in others. The Profiler head, which is 6 inches long, screws into conventional AW drill rods. The stainless steel tubing is coupled in 5 foot lengths, but the Teflon tubing is used in a disposable continuous length. The small storage volume in the Profiler and conduit tubing provides rapid transmission of the water sample to the surface. Sample bottles such as standard 40 mL VOA vials are fitted into stainless steel sampling caps in which an airtight seal is obtained by compressing an O-ring inside the sampling cap. The sampling caps are each fitted with two stainless steel tubes; one provides suction on the sample vial from the peristaltic pump while the other is connected to the sampling tube from the Profiler through a three-way valve arrangement (Figure 1). Thus, contact of the sample water with plastic or rubber tubing in the pump head or exposure to the atmosphere is avoided. Placing the sample containers in the sampling line upstream from the peristaltic pump minimizes the negative bias usually associated with suction-lift methods. Negative sample bias occurs when volatile organic compounds (VOCs) dissolved in the ground water partition into the atmosphere or head space in a sample vial. Positioning the sample vials upstream from the pump minimizes partitioning because no head space is allowed to exist in the sample vials (Baerg et al. 1992). Purging prior to sampling ensures that formation water exists in the vials at time of collection. The tubing is protected inside the

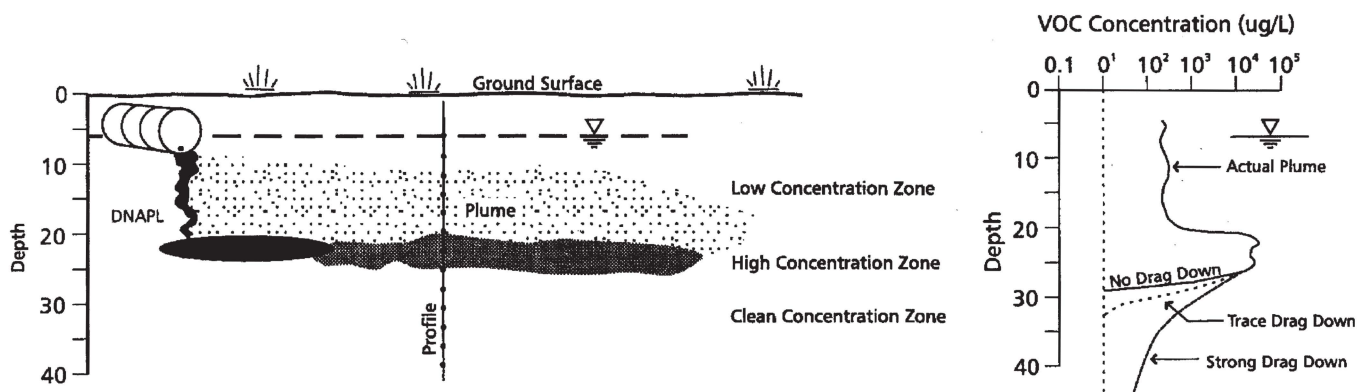


Figure 2. Schematic illustration of degrees of drag down induced by direct-push sampling devices.

Table 1
Summary of Site Contaminants and Hydrogeology

Site Name	Contaminants	Type of Release	Aquifer Materials	Hydraulic Conductivity (cm/sec)	Depth to Water Table (feet)	Fraction of Organic Carbon	Depth of Investigation (feet)
Borden	PCE	Field experiment	Sand	$10^{-2} - 10^{-3}$	10-12	0.002	25
Angus, Ontario	PCE	Tank rupture	Sand	$10^{-2} - 10^{-3}$	5-10	unknown	50
Savage Well, New Hampshire	PCE	Unknown releases at machine tool plant	Sand & gravel	$10^{-2} - 10^{-3}$	10-15	unknown	95
Pease AFB, New Hampshire (2 sites)	TCE, cis 1,2 DCE vinyl chloride	Outfall from underground disposal tank	Sand, silt, clay	$10^{-2} - 10^{-5}$	5	<0.001	45
Indiana	PCE, TCE, 1,1,1-TCA	Discharge to dry wells	Sand & gravel	$10^{-1} - 10^{-2}$	10-15	< 0.001	62
Florida	TCE cis 1,2 DCE	Spills	Sand	$10^{-1} - 10^{-2}$	10-15	<0.001	90

AW drill rod (1.75 inches outer diameter) used to drive the tip. The outside diameter of the Profiler is constant along the length of the tool to minimize the potential for fluid flow in the aquifer along the length of the Profiler. A smaller diameter tip and rods have been used to achieve deeper penetration in some aquifers.

The Profiler can be driven by many types of direct-push equipment or conventional drill rigs using impact, vibration, or direct down pressure. For shallow investigations or in soft aquifers, it can be driven using portable equipment such as a hand-operated jackhammer or pneumatic piercing tool (air hammer). The Profiler has been used at more than 30 sites in North America, commonly to depths of 50 to 100 feet. While the Profiler is being driven, contaminant-free water, such as distilled water, is pumped down the tubing and out the small ports to purge the Profiler of formation water from the previous sampling interval and to prevent clogging of the ports. As the Profiler approaches the sampling depth, the pump is reversed to begin pumping water to the surface, minimizing the introduction of foreign water to the zone to be sampled. Or, the injection of distilled water can continue for a short time after reaching the new sampling level to ensure that the sampling ports are kept free of sediment.

Prior to sample collection, the ports are developed and the system is purged. The volume of purge water

generated during sampling is usually on the order of a few hundred milliliters per sample. Initially, the water pumped from the Profiler is distilled water left in the tubing when the water injection stopped. This water must be purged before the ground water sample is collected. The change from distilled water to ground water is typically marked by a change in water color or turbidity. In-line monitoring of electrical conductivity also indicates the transition from non-conductive distilled water to conductive ground water. Turbidity in coarse sediments such as sand and gravel usually diminishes within several minutes during purging. In aquifers with considerable silt and clay, the time required to obtain a sample of low turbidity is prolonged. However, turbidity is acceptable in samples for volatile organic analyses and sample filtering is not required in accepted sampling protocols. For metals and hydrophobic organic compounds, the desire for low turbidity samples must be balanced against the time required to collect the sample and the amount of purge water generated.

After sampling, the hole can be sealed by pumping grout down the inside of the rods and out the bottom by displacing a disposable stainless steel point (Figure 1). The grout is pumped down the rods while the rod assembly is withdrawn from the hole in a process known as retraction grouting. This process ensures a high degree of control because the tool is removed slowly as the grout fills

the hole continuously under pressure from the bottom upward.

Approach for Drag Down Evaluation

The Profiler has a uniform diameter throughout its length and consequently can be expected to maintain a good seal with the porous medium as it is driven downward. This seal minimizes flow of fluids along the length of the device. This sealing capacity is well-known from the experience of others using cone penetrometry (CPT) (Edge and Cordry 1989). Sorption of contaminants to the tool is minimized through the use of stainless steel at every point of contact with the sample. As the sample water flows upward through the tubing, some loss of contaminant mass by sorption may occur when disposable Teflon tubing is used. At the one site in this study (Florida) where Teflon tubing was used in many holes, new tubing was used in each hole. Use of new tubing should minimize sampling artifacts due to sorption/desorption, but these effects were not quantitatively evaluated as part of this study.

Figure 2 shows the drag down concept schematically. The goal of profile sampling is to sample the vertical profile of a plume with no distortion of the measured profile of the plume due to the drilling or sampling processes. Trace drag down refers to a result in which a low concentration of VOCs are measured for a short vertical distance below the actual bottom of the plume due to

cross-contamination of the sampling system. If strong drag down occurs, elevated concentrations of VOCs are measured for some vertical distance below the actual bottom of the plume. Drag down may confuse data interpretation about the true vertical distribution of VOCs.

The potential for drag down was evaluated at six sites of chlorinated solvent contamination, including an experimental site at Canadian Forces Base Borden (CFB), Ontario, a dry cleaning site (the Angus site) close to the Borden site, two Superfund Sites in EPA Region I, an industrial site in Indiana, and an industrial site in Florida. Table 1 summarizes the hydrogeologic features of the six sites and the type of the solvent releases. Pitkin (1994) provides more detail about the field sites. At the Borden site, a profile obtained using the Waterloo Profiler was compared to a nearby profile obtained from a permanent multilevel sampling system. In addition, the concentrations below the Borden plume were measured in one hole where the Profiler was driven through the plume core and in a second hole where the Profiler went through the plume inside a casing to isolate the Profiler from potential drag down effects. Drag down was assessed at the other five sites by interpretation of the profiles with and without comparison to other forms of sampling. In the absence of other data, drag down is deemed to be a possible occurrence, but not a conclusive occurrence, in any particular profile in which an analytical result above the

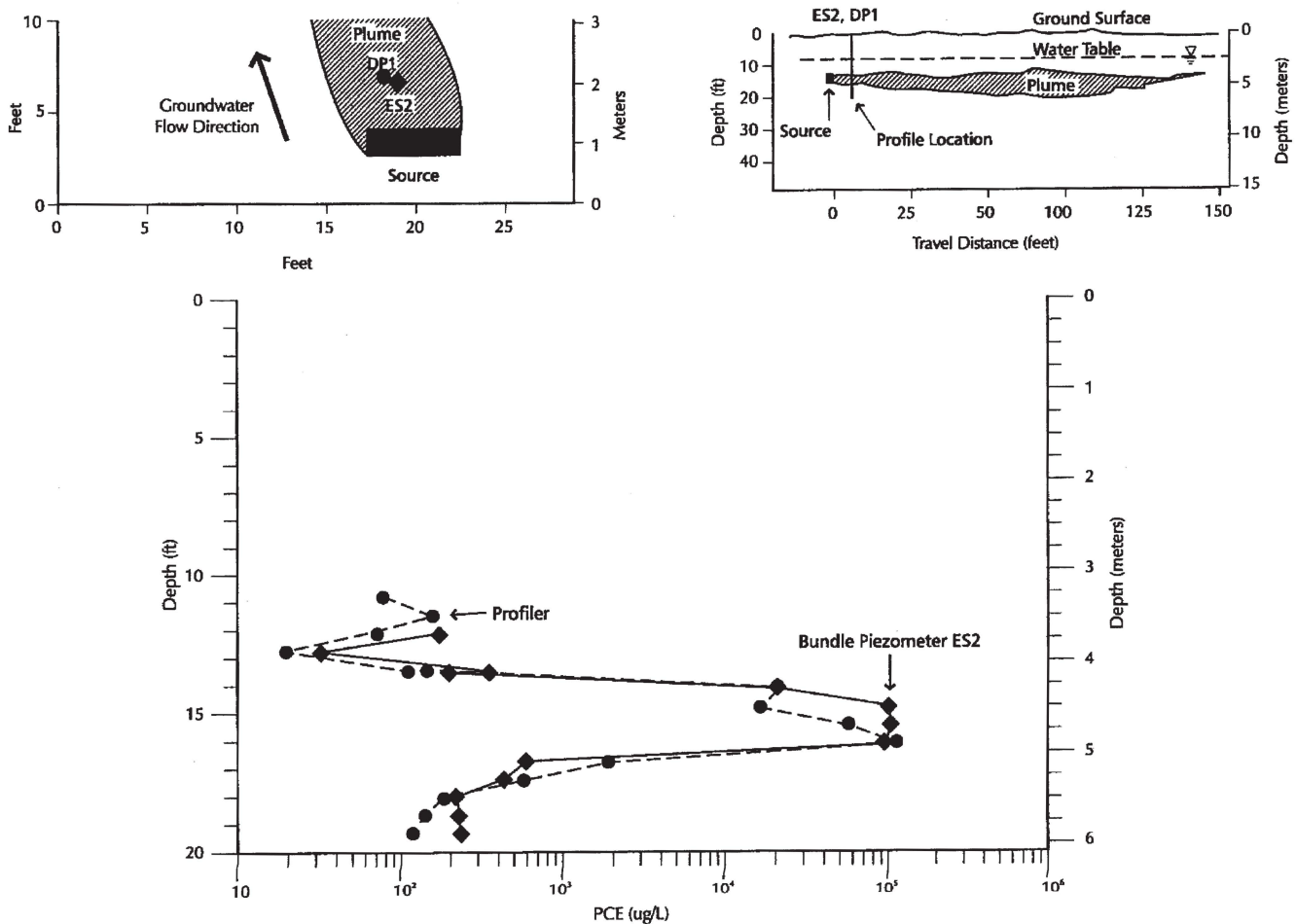


Figure 3. PCE profiles at bundle piezometer ES2 and Profiler location DP1 Emplaced Source Site, CFB Borden.

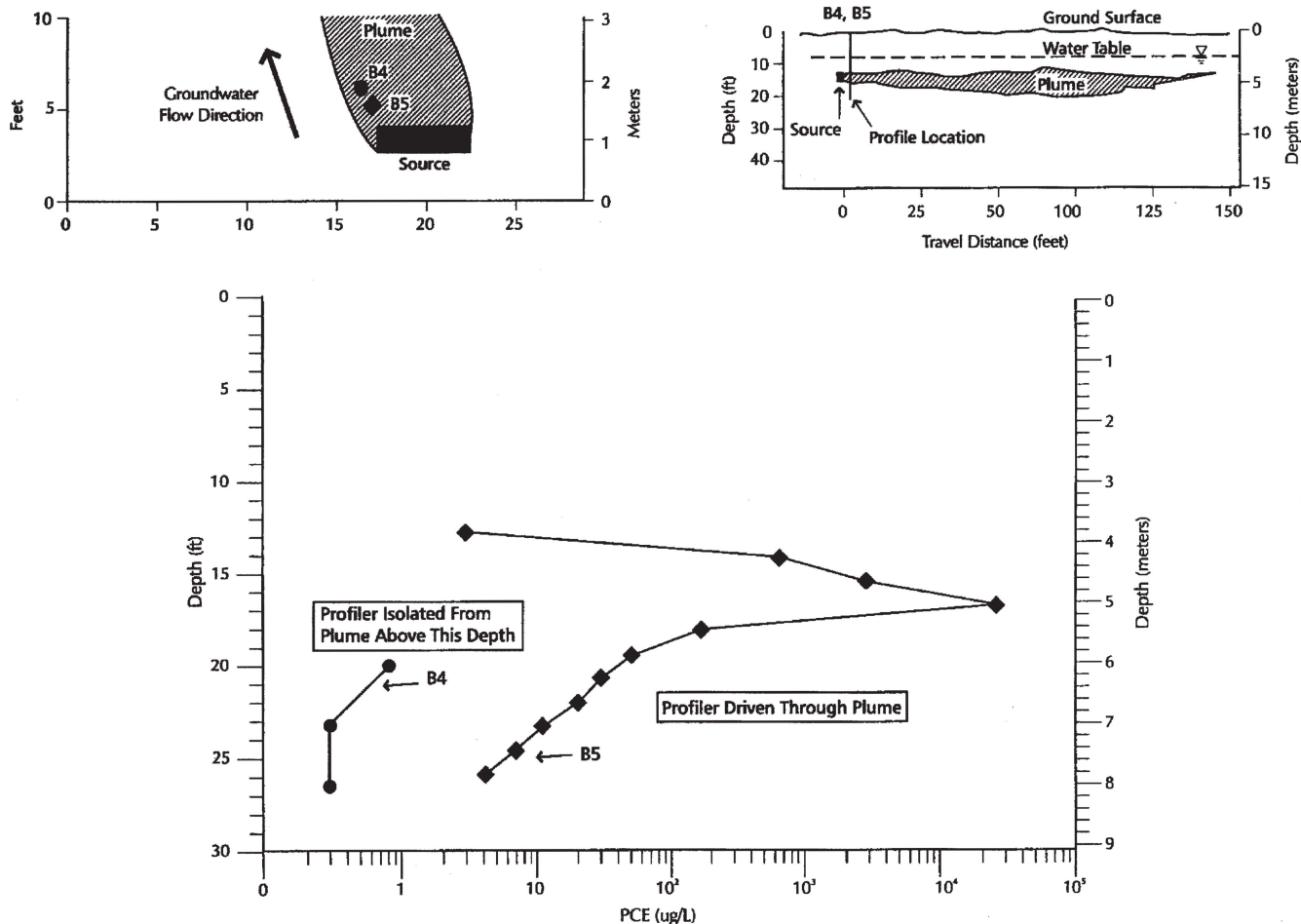


Figure 4. PCE concentrations determined by Profiler at Emplaced Source Site, CFB Borden.

detection limit is reported for the deepest sample collected. It is important to note that the deepest sample may not have penetrated below the plume.

The VOC analyses of ground water samples from two of the six sites (Borden and Angus) were conducted in a research laboratory at the University of Waterloo. Four different commercial laboratories performed the analyses of samples from the other four sites. As used in this paper, "detection limit" refers to the conventional "method detection limit" provided by the particular laboratory for reporting purposes, except for the Waterloo laboratory, which defined the detection limit as the smallest signal above background noise that the instrument can detect reliably. All values below 1 $\mu\text{g/L}$ were considered to be non-detection results for the Borden and Angus sites. Detection limits varied among laboratories during the study. In addition, different compounds had different detection limits using a given analysis. Detection limits were generally 1 $\mu\text{g/L}$ but were higher for particular analyses because of dilutions necessary to get one analyte into calibration range; this influences the detection limits of other analytes in the sample.

The Borden Experimental Site

The emplaced source site at CFB Borden is an intensely instrumented and well-characterized experi-

mental site at which Rivett et al. (1994) studied the nature of a solute plume emanating from a well-defined residual dense nonaqueous phase liquid (DNAPL) source. In 1990, a 43 ft^3 (1.2 m^3) volume of sand mixed with a three-component solvent DNAPL (TCM, TCE, and PCE) was buried below the water table to produce a downgradient plume under natural flow conditions (≈ 10 cm/day). The vertical profiles discussed later were obtained from within approximately one meter downgradient of the rectangular mass of residual DNAPL emplaced below the water table.

Figure 3 presents a profile obtained in 1992 using the Profiler (DP1) as well as results from an adjacent permanent multilevel sampling system (bundle)(ES2). The bundle was installed inside of a sealed pipe that was pushed to the bottom of the aquifer prior to the source being emplaced. Therefore, the bundle was not installed through the plume and the vertical profile from the bundle is accurate. The pipe was subsequently withdrawn, allowing the sand to collapse around the bundle. Data from the bundle and the Profiler show that concentrations decrease by approximately an order of magnitude over a short vertical distance (0.66 feet; 20 cm) at the bottom of both profiles. Given the steep concentration gradients and the nearly identical shapes of the profiles from the Profiler and the bundle piezometer, it can be concluded that no strong drag down (see Figure 2) was caused by the Pro-

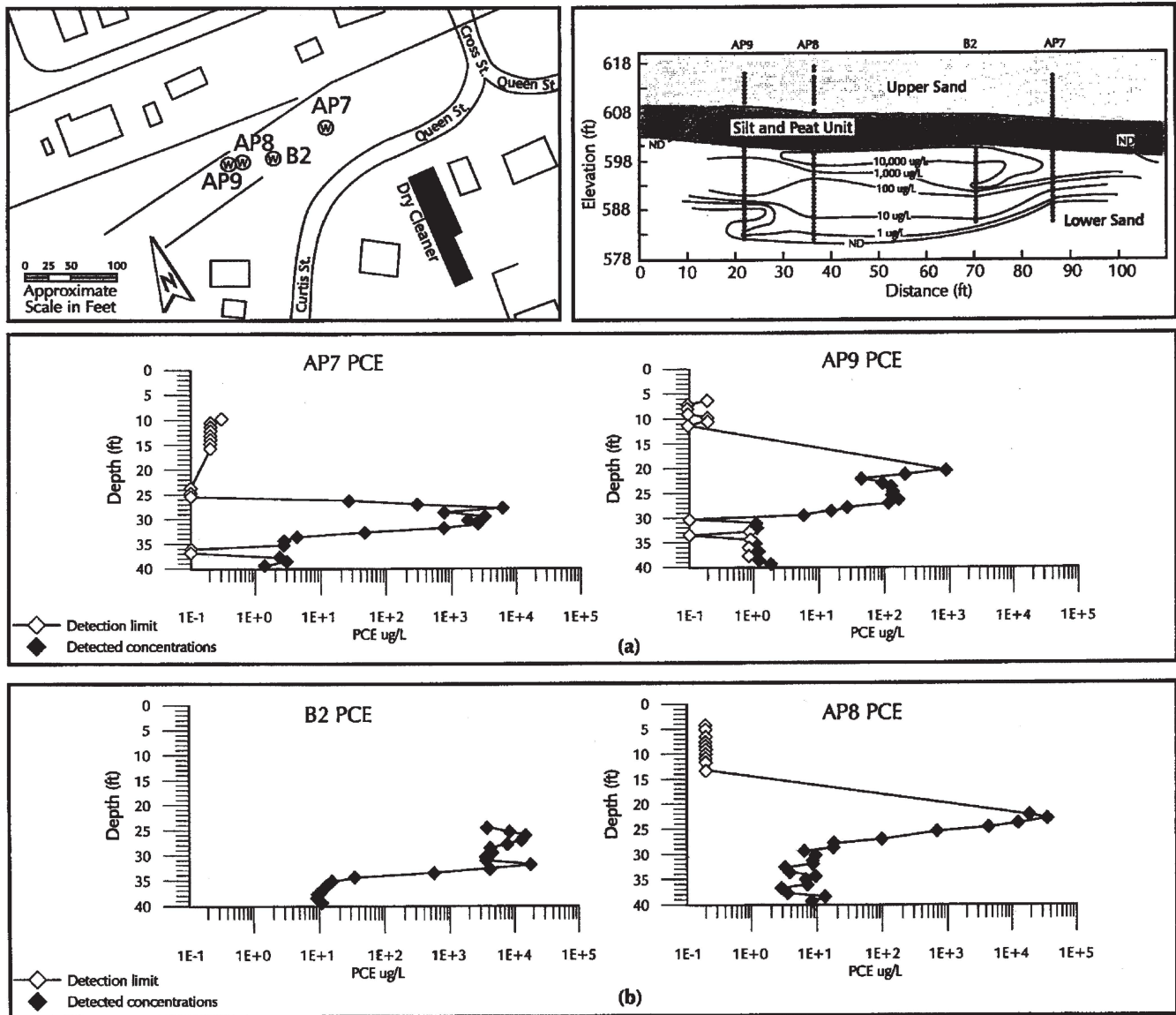


Figure 5. PCE Profiles along transect 2 in Angus, Ontario. (a) Profiles showing concentrations generally declining to lab background level or detection limits below moderate concentrations. (b) Profiles in which trace drag down may have occurred below high concentration plume cores.

filer, even when driven through PCE concentrations of 100,000 $\mu\text{g/L}$. In fact, the Profiler samples were characterized by slightly lower concentrations than the bundle at the bottom of the profile, probably due to local spatial variability of the plume. However, neither the bundle nor the Profiler yielded non-detectable concentrations at the bottom of the sampled interval so the potential for trace drag down could not be evaluated.

To further assess the potential for drag down, another set of profiles located close together was undertaken (profiles B4 and B5 in Figure 4) in 1994. These profiles were undertaken to a greater depth than were DP1 and ES2 in order to assess the degree of trace drag down at the bottom of the plume. Profile B5 is located approximately 0.09 foot (30 cm) downgradient of the emplaced source and B4 is located 0.12 foot (40 cm) further downgradient. At B4 the Profiler was prevented from coming into contact with high concentrations in the plume by collecting samples as described later. In contrast, the Profiler at B5

was driven in the normal manner through the plume before profiling the aquifer below the plume. It must be noted that a funnel and gate remedial system was installed a short distance downgradient of the study location in 1992. The funnel and gate system appears to have caused a downward shift in the position of the core of the plume and smearing of the concentration distribution; thus the peak concentrations and concentration distributions are substantially different between the 1992 data (DP1 and ES2) and the 1994 data (B4 and B5).

At B4, a 2½-inch outside diameter casing (BW casing) equipped with a disposable stainless steel point fitted with an O-ring was driven to a depth of 17.2 feet (5.3 m), which was approximately 1 foot (30 cm) below the high concentration zone. The Profiler tip was then used to knock out the disposable point before collecting samples below the bottom of the casing at a 3.3 foot (1 m) spacing. Figure 4 shows that Profiler samples at B4 yielded non-detectable concentrations at 23.2 feet (7.1 m). At

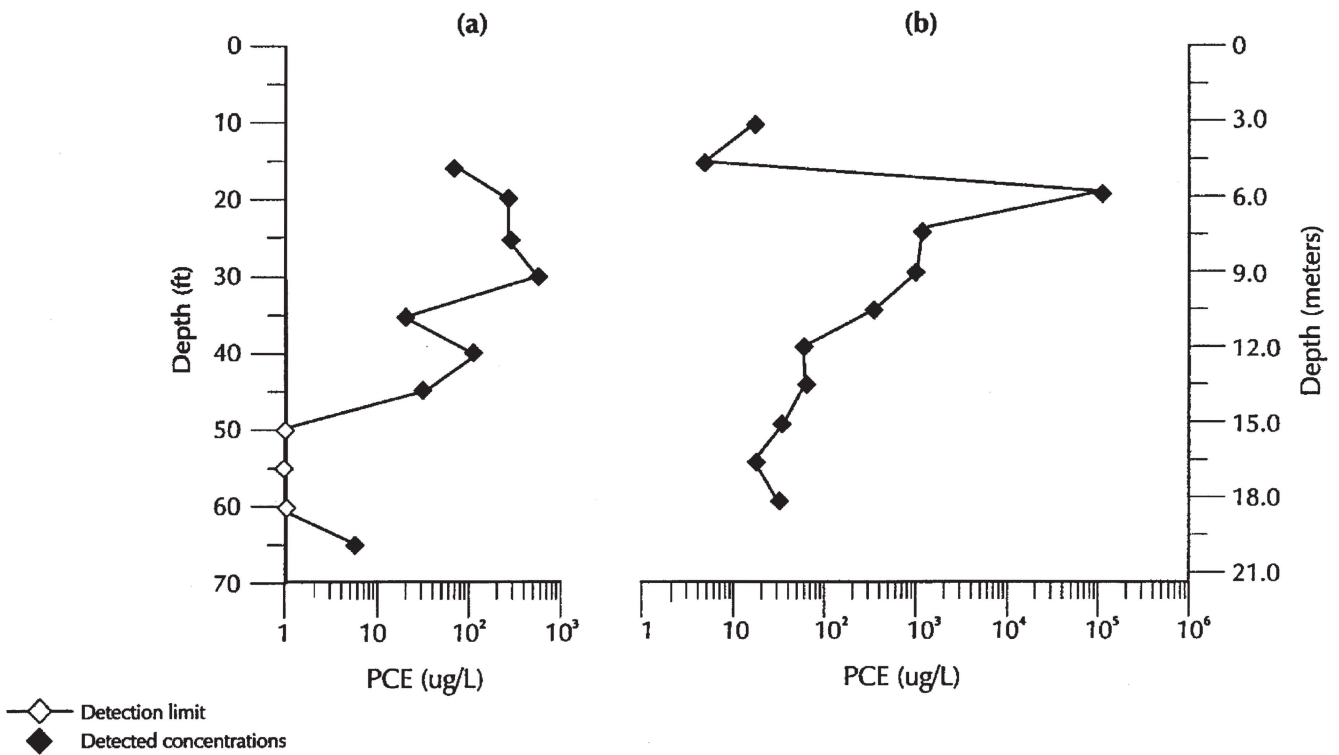


Figure 6. PCE concentrations determined by Profiler at Savage Well Superfund Site, New Hampshire. Conventional monitoring data confirm the presence of PCE throughout the entire thickness of the aquifer.

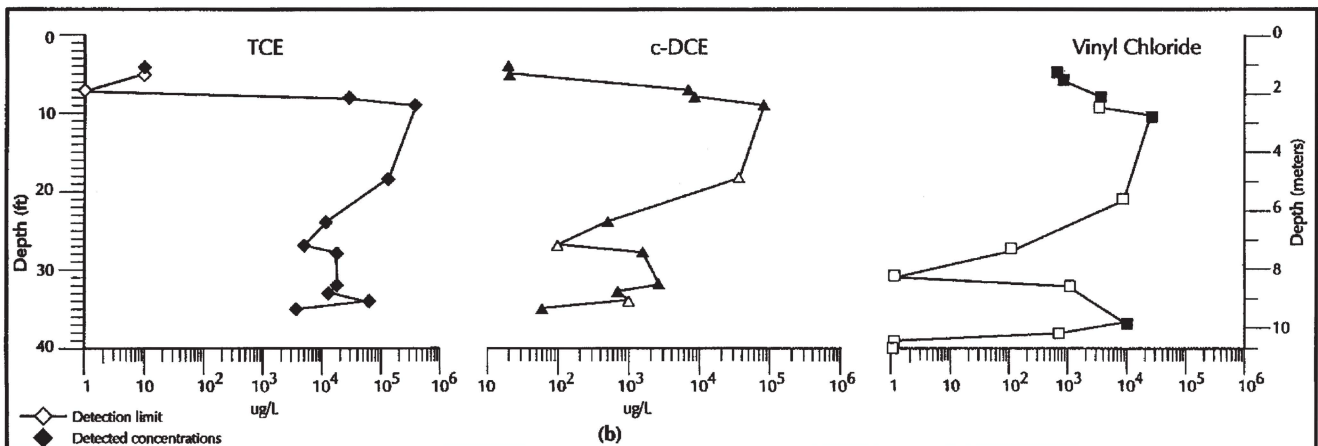
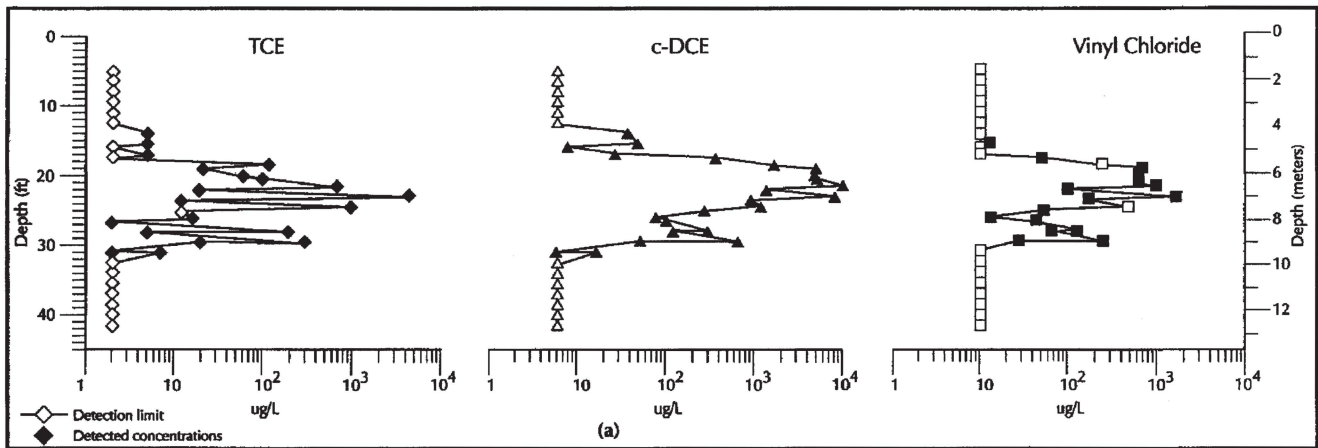


Figure 7 (a) Concentrations determined by Profiler at Site 73, Pease Air Force Base, Portsmouth, New Hampshire. (b) Concentrations determined by Profiler at Site 32 (P2), Pease Air Force Base, Portsmouth, New Hampshire. Monitoring well data from this location confirm the presence of TCE and cis-DCE at depth.

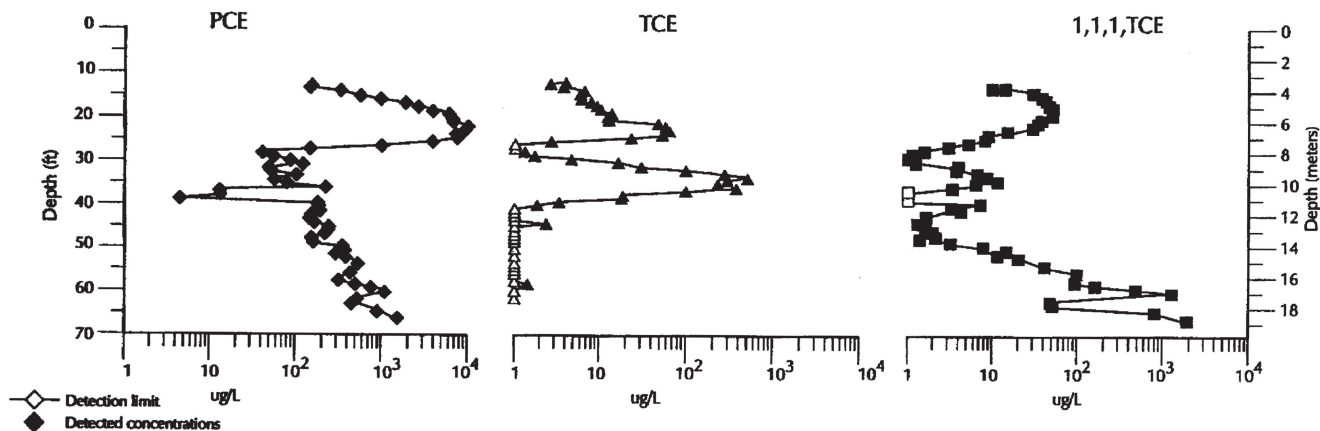


Figure 8. Concentrations determined by Profiler at the Indiana site.

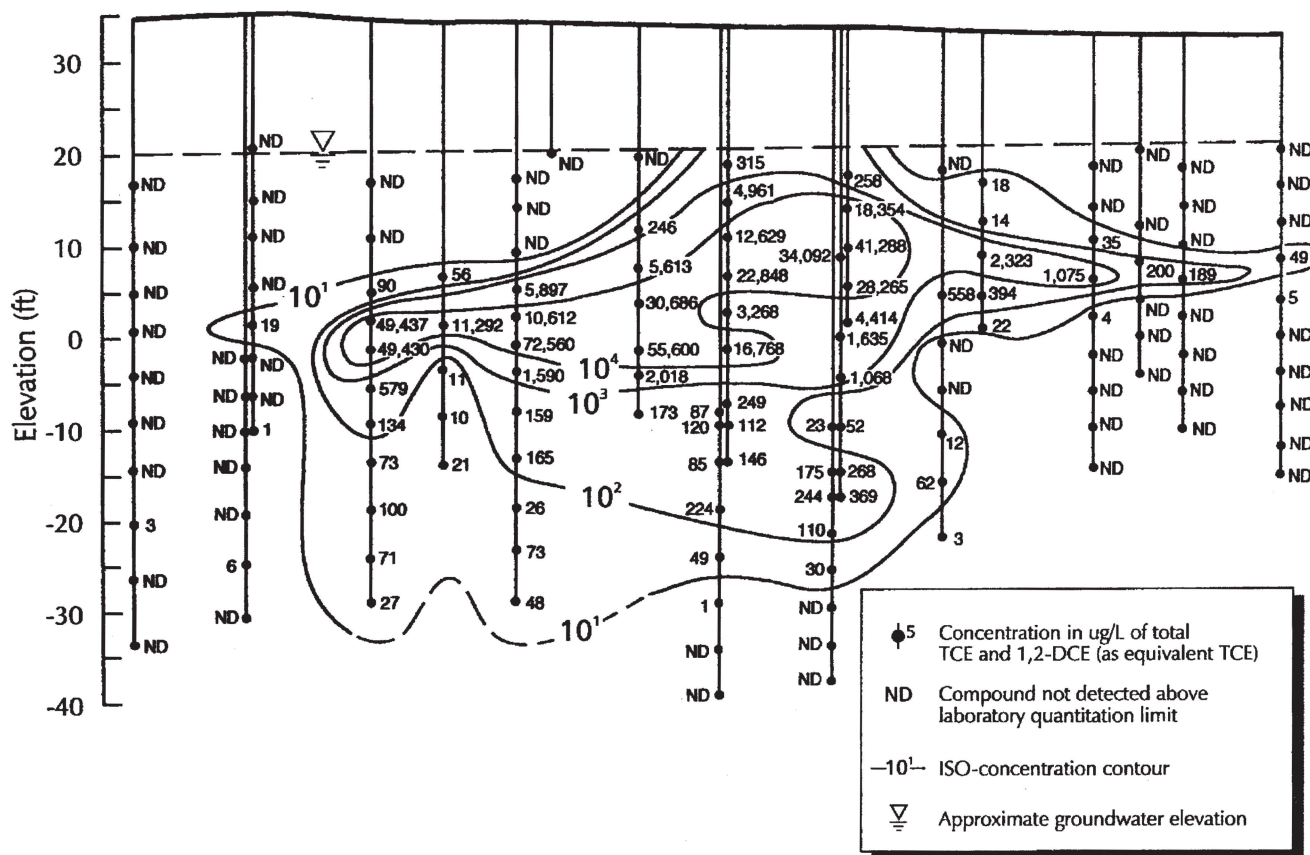


Figure 9. A transect across the Florida plume displaying results of 14 profiles.

this same depth, the profile at B5 produced by the normal Profiler method showed concentrations ranging from 6.7 to 13.3 $\mu\text{g/L}$. This indicates trace drag down ($< 14 \mu\text{g/L}$) over a vertical spacing of 8 feet (2.4 m) below the zone of high concentration, in this case 26,000 $\mu\text{g/L}$ PCE.

Profiler Results from the Five Industrial Sites

Figures 5 through 9 show profiles of solvent concentration versus depth for each of the five other sites. Twenty-one profiles were obtained from the Angus dry cleaning facility near the Borden site, which was the first site profiled after the Borden trials. The four profiles

shown in Figure 5 represent the range of general features of Angus profiles. The upper part of the aquifer has no detectable PCE. The top of a thin, high-concentration plume occurs at 20 to 25 feet (6.1 to 7.6 m) below ground surface. The upper two profiles in Figure 5a show non-detection results a short distance below the plume core, which indicates no apparent drag down. However, the bottom two profiles show values in the range of 3 to 13 $\mu\text{g/L}$ below the plume, slightly above the detection limit. The Angus profiles generally achieved non-detection levels below the plume at locations where the plume peak value was in the range of 1000 to 10,000 $\mu\text{g/L}$, but produced values slightly above the detection limit where peak values

were considerably above 10,000 µg/L. These slightly above detection limit values may represent trace drag down, but it is not certain that the zone immediately below the high-concentration part of the plume does not have an actual low-concentration fringe that could appear as trace drag down in the profiles.

Figure 6 shows two of 33 profiles obtained from the Savage Well site. Profile A shows non-detectable values below plume concentrations of 100 to 1000 µg/L, whereas profile B shows values slightly above the detection limit below a zone where the peak PCE level is exceptionally high (>100,000 µg/L). Occurrences of potential trace drag down at the Savage Well site are similar to those at Angus in that trace drag down may have occurred where the Profiler penetrated through dissolved PCE zones where peak concentrations are greater than 10,000 or 100,000 µg/L. However, conventional plume monitoring techniques at the Savage site indicate the presence of PCE throughout the entire aquifer thickness, so the trace concentrations at the bottom of the profile may reflect actual aquifer conditions.

Twenty-six profiles were obtained from the Pease site where TCE is the dominant contaminant and biotransformation has caused abundant occurrence of cis 1,2 DCE and vinyl chloride. None of the profiles at this site displayed evidence of drag down. Figure 7a shows results from a location where the plume is 15 feet (4.6 m) thick and has peak concentrations in the range of 1000 to 10,000 µg/L for TCE, cis DCE, and VC. Here the Profiler consistently produced non-detectable values for all compounds immediately below the plume. Within the plume there are large variations of the concentrations of compounds over small vertical distances, suggesting little or no drag down from one sampling level to the next. The Pease site profile shown in Figure 7b has a thicker plume and occurs in a geologically complex zone. It shows no bottom of the plume for TCE; however, VC shows non-detectable values below high VC occurrences. The overall interpretation of monitoring results from this location based on other sampling methods at the Pease site, including conventional monitoring wells, is that high TCE and cis DCE concentrations at depth represent actual contamination rather than drag down.

Only one profile was obtained from the Indiana site (Figure 8). Numerous non-detection TCE results were obtained below a zone with TCE in the range of 100 to 700 µg/L, indicating no apparent TCE drag down. The PCE and 1,1,1-TCA profiles are much different. For PCE the profile shows values less than 10 µg/L beneath the zone where the peak concentration exceeds 10,000 µg/L. The 1,1,1-TCA profile shows similar general trends, but at lower overall concentrations. The PCE and TCA profiles exhibit a gradual increase in the bottom part of the profiles. Based on the low concentrations at shallower depths, the non-detectable TCE below a depth of 40 feet (12.2 m), and the fact that significantly increasing concentrations cannot be caused by drag down, the deep PCE and TCA measurements are considered to be real and not a result of drag down. In addition, an adjacent monitoring well has

measured concentrations of these contaminants at a depth of 105 feet (32 m), substantially below the bottom of the profile hole.

In 1996, the Profiler was used at 90 locations at the Florida site of which 14 are shown in Figure 9, which is a perpendicular transect across a TCE/cis 1,2 DCE plume downgradient of DNAPL source zones. The detection limit is approximately 1 µg/L. At most of the locations where the Profiler penetrated much below the plume, non-detection results were obtained. However, non-detection results were not achieved at the locations where the plume has peak combined TCE and DCE that are extremely high, greater than approximately 50,000 µg/L. At these locations values in the range of 10 to 100 µg/L persisted at several sampling elevations below the high concentration zone. Profiles along another transect closer to the DNAPL source zone where TCE/DCE values are above 50,000 µg/L also show values in this range below the plume. These low values at the bottom of the plume below the extreme highs may be trace drag down. Like the Angus site, the apparent concentrations that may be trace drag down are on the order of 10^{-3} times the peak concentrations. However, it is unclear whether the high concentration plume area may have a low concentration fringe area and if the Profiler had been driven deeper, non-detects may have been obtained. The deepest samples collected yielded non-detectable results (Figure 9). In 1998 the Profiler was used at many more locations at the Florida site, but this time stainless steel tubing rather than Teflon tubing was used. No differences attributable to type of tubing were observed in the data; however, a detailed comparison was not done.

Conclusions

The Waterloo Profiler is a unique tool for the acquisition of detailed vertical profiles of solute concentrations in permeable unconsolidated deposits. These profiles provide an exceptionally detailed view of the anatomy of plumes. Extensive field testing indicates no detectable drag down when passing through chlorinated solvent concentrations of many hundreds or even thousands of µg/L. However, in some situations a few µg/L of drag down may have occurred after sampling in zones containing concentrations of tens of thousands or hundreds of thousands of µg/L. Even where trace drag down may occur, the detailed concentration profiles acquired provide a clear determination of the spatial structure of plumes.

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Biographical Sketches

Seth E. Pitkin is a senior geoscientist with Stone Environmental Inc., Montpelier, Vermont. He received a B.S. in geology from the Evergreen State College in 1984 and an M.Sc. in hydrogeology from the University of Waterloo in 1994. He has been involved in the investigation and remediation of numerous sites

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Mette M. Broholm is a research associate in the Department of Environmental Science and Engineering at the Technical University of Denmark (DK-2800 Lyngby, Denmark). She received an M.Sc. in chemical engineering from the Engineering Academy of Denmark in 1986 and a Ph.D. from the Department of Environmental Science and Technology at the Technical University of Denmark in 1998. Her research is focused on field and laboratory studies of the transport and degradation of organic contaminants in ground water. When the study described in this paper was conducted, she was a research associate at the University of Waterloo.