

# Use of a Drive Point Sampling Device for Detailed Characterization of a PCE Plume in a Sand Aquifer at a Dry Cleaning Facility

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## ABSTRACT

Contamination of groundwater by chlorinated solvents is a ubiquitous problem in North America. The EPA estimates that 33 percent of the 32,000 sites in CERCLIS are contaminated with solvents and that of the 1,199 Superfund sites currently listed, 60 percent have a medium to high likelihood of having DNAPL contamination present. Increasingly large sums of money are being spent to characterize and clean up these sites with very little success. One of the primary reasons for the lack of success in remediation of chlorinated solvent contamination of groundwater is inadequate characterization of solute concentrations in three dimensions and inadequate assessment of the presence and location of DNAPL residual sources in the aquifer. Conventional monitoring techniques used at such sites depend on drill rigs to install nests of monitoring wells. These techniques are expensive, time consuming and produce large volumes of potentially hazardous drilling waste. The cost in time and money of installing such monitoring points usually precludes the installation of the large number of points necessary for an adequate characterization of the plume. In unconsolidated deposits drive point sampling devices can be employed to provide more data more quickly with less cost and less waste than conventional techniques. The University of Waterloo has developed a drive point sampling device for such purposes. The device has been successfully tested at two Region I Superfund Sites and was used to investigate a tetrachloroethene plume that had contaminated water supply wells near a dry cleaner in Angus, Ontario. At the Angus site a two man field crew using portable equipment undertook 23 profile holes in three transects, collecting samples at 25 centimeter intervals to a depth of 12 meters. The resulting data provide a detailed three dimensional view of the plume that allows an assessment of the location of the residual DNAPL source(s) from the downgradient concentration data.

## 1.0 Introduction

This paper describes a drive point groundwater quality profiling tool developed at the University of Waterloo and presents the results of an investigation of tetrachloroethene contamination of groundwater in a sand aquifer in Angus, Ontario. The data produced using the profiler at the Angus site are compared to data developed using other monitoring techniques, including conventional monitoring wells. The profiler has been successfully tested at several superfund sites in EPA Region I and these field trials are the subject of a forthcoming paper.

### 1.1 *The Problem*

Conventional groundwater monitoring techniques are too expensive and time consuming to allow the collection of the large numbers of samples required to adequately define the distribution of groundwater contaminants in three dimensions. This problem is especially acute at sites contaminated with chlorinated solvents.

Contamination of groundwater by chlorinated solvents is a ubiquitous problem in North America. The U.S. EPA National Groundwater Supply Survey reported that the most commonly detected contaminants were chlorinated solvents (Westrick, 1990). The Superfund Chemical Analysis Results report indicated that 7 of the 20 most frequently detected organic contaminants at Superfund sites are chlorinated solvent compounds (U.S. EPA, 1993). While Superfund sites

receive the most attention and money, these sites are only a small fraction of the total number of contaminated sites. The Comprehensive Environmental Response, Compensation and Liability Information System lists over 32,000 sites and the EPA estimates that one third of these are contaminated with solvents (U.S. EPA, 1991).

Chlorinated solvents in groundwater pose special problems due to several unique characteristics. These compounds are quite mobile and persistent in the subsurface and some are believed to be human carcinogens. Additionally, chlorinated solvents exist in their pure form with densities greater than that of water and viscosities lower than that of water. These latter two characteristics cause the pure phase chlorinated solvents to sink relatively rapidly below the water table and to behave independently of groundwater flow. The movement of DNAPL is controlled primarily by capillary pressure distributions in the porous medium. Thus, relatively minor textural variations may have profound effects on the movement and distribution of DNAPL. This behavior results in complex distribution patterns of the pure phase solvents in the subsurface (Mercer and Cohen, 1990, 1993; Kueper and Poulsen, 1992; MacKay and Cherry 1989; Schuille, 1988) which then act as long term sources of dissolved phase contamination of groundwater.

Of the 1,199 Superfund sites currently listed EPA estimates that 60 percent have a medium to high likelihood of having dense non aqueous phase liquid (DNAPL) contamination present below the water table (U.S. EPA, 1993). The DNAPL contamination, however, is only rarely directly encountered in site investigations. In EPA Region I there are 66 Superfund sites with groundwater contamination by DNAPL chemicals but at only 9 of these sites has DNAPL been directly observed. At 5 of these 9 sites the DNAPL observed was either coal tar or PCBs which are much less mobile and more visually obvious than chlorinated solvents. In spite of the large amount of money expended, the Superfund program has enjoyed very little success in the remediation of sites contaminated with chlorinated solvents. The primary reasons for this lack of success are the presence of DNAPL source zones in the aquifer below the water table and site characterization investigations that are inadequate or inappropriate for the location and delineation of the DNAPL in these source zones (Harmon et. al., 1993).

Investigations at chlorinated solvent sites are typically conducted by installing a series of clusters of monitoring wells at a number of locations in and around the plume. The wells are typically constructed of 2 inch diameter PVC or stainless steel with 5 foot long screened sections. Installation of these wells generates considerable quantities of drill cuttings and water which must be handled as a hazardous waste. The cost of these installations and the time required to install them typically limit the number of screens to a relative few. Because transverse vertical hydrodynamic dispersion is typically a weak process and transverse horizontal dispersion is only slightly less so (MacKay et. al., 1986) plumes are often confined to a specific zone in the aquifer. Experience has shown that these zones may be only on the order of two or three meters in the vertical dimension and may only be approximately as wide as the source (Rivett et. al., 1992). In situations in which dense non aqueous phase liquids act as the source of contamination, the location of the source(s) is usually unknown. Compiling an adequate body of groundwater quality data in three dimensions is essential for the detection and characterization of groundwater contamination and is no less important in remedial planning and implementation. Locating the source area may be accomplished by conducting detailed three dimensional profiles and working

back in the direction of increasing concentrations. Such profiling requires sampling techniques that allow the collection of a large number of samples quickly and inexpensively with little disruption of the landscape.

In aquifers composed of unconsolidated deposits, such as sands and gravels, drive point sampling tools may be employed to great advantage. Many such drive point tools have been used effectively in a number of settings (Pickens et. al., 1981; Cherry et. al., 1983, Cherry et. al. 1993 ). Several drive point sampling devices are currently commercially available including Geoprobe® and HydroPunch®. These latter two tools are designed to be driven to a specific depth or depth interval and to be sampled once prior to withdrawal of the tool rather than to collect a series of samples at multiple depths in the same hole. The University of Waterloo has recently developed and field tested a drive point groundwater quality profiling device for the purpose of obtaining detailed concentration versus depth profiles in unconsolidated deposits without the use of a drill rig.

## 2.0 The Waterloo (Ingleton) Profiler

The device collects point samples rather than samples over a screened interval of a foot or more, as in the case of conventional monitoring wells. Driving, purging and sampling are accomplished quickly, allowing many samples to be collected in a relatively short period of time.

### 2.1 Physical Description

During the development of the profiler several prototype designs have been employed. There are currently two versions of the profiler, a light weight version employing schedule 80 black steel pipe as the drive casing (described by Broholm, et. al., 1994) and a more robust version employing drill rod as the drive casing. Sampling at the Angus site was accomplished using the lightweight version of the profiler.

In both cases the profiler consists of a stainless steel drive point with six 5/32 inch diameter circular ports fitted with 25 mesh stainless steel screen (see Figure 1). All six ports empty into a common reservoir in the profiler tip. Stainless steel tubing (1/8 inch outside diameter tubing with 0.020 inch thick walls) is coupled to fittings threaded into the reservoir using Swagelok® couplings. The stainless steel tubing serves as the conduit for water from the ports to the ground surface. The tubing is protected, and the tip is driven, by means of AW drill rod or schedule 80 black steel pipe that is threaded onto an adapter in the profiler tip with standard drill rod thread or NPT pipe thread respectively. The adapter is fixed to the tip using three set screws and the joint between the two is sealed using an "O ring". The drill rod and the tip have an outside diameter of 1 3/4 inches. In the case of the drill rod version the inside diameter of the threaded drill rod couplings is 5/8 of an inch.

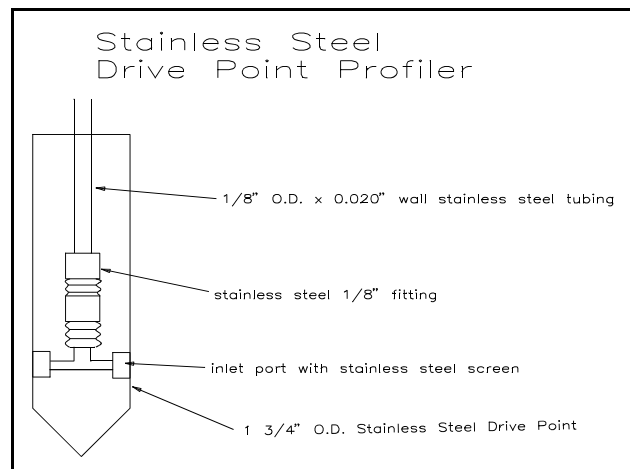
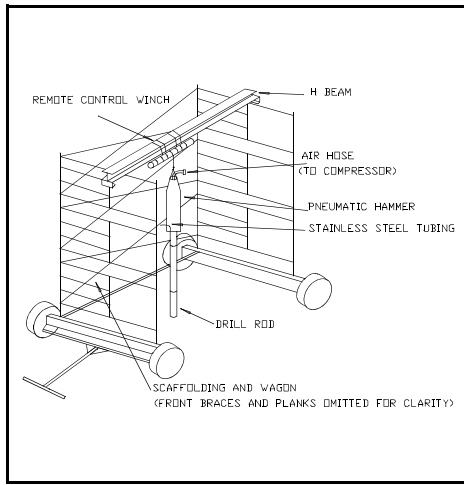


Figure 1 - Drive Point Profiler Tip

## 2.2 Driving Procedure

The lightweight version is usually



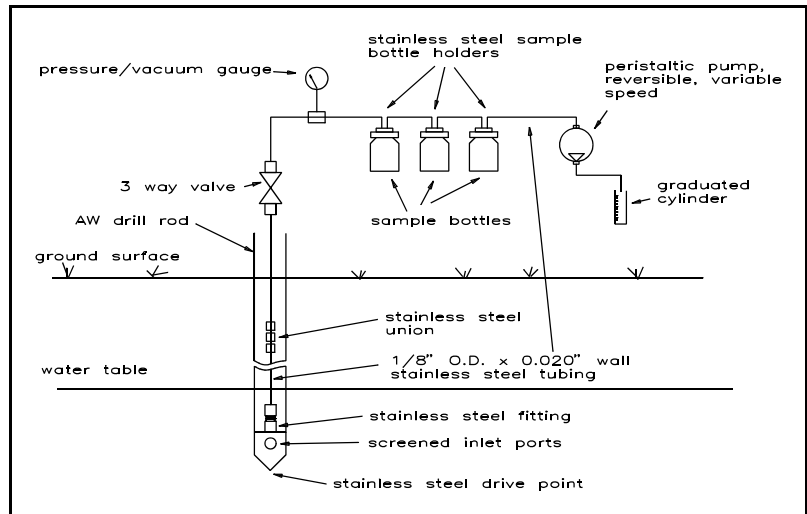
**Figure 2** - Field driving configuration schematic

advanced using a Bosch electric jackhammer whereas the drill rod version is advanced using a pneumatic piercing tool (air hammer) driven by a gasoline powered air compressor delivering a minimum of 180 cfm at 100 psi . The air hammer is raised and lowered, and the profiler retrieved, by means of a battery powered, 3 ton capacity winch attached to a steel "H" beam. The work area consists of three tiers of scaffolding erected on two sets of wheels (Figure 2). Planks provide shelf space and support the crew while working aloft. Target sampling depths are marked on the drill rod or pipe. Tubing and drill rod or pipe are added in five foot increments as required during driving.

During driving the purging and sampling pump is run in reverse (i.e., water is pumped down the tubing and out the ports) to purge the profiler of formation water from the previous depth interval and keep the ports clear. In some cases de-ionized water may be pumped down the tubing during driving to keep the ports clear. As the profiler approaches the depth to be sampled the pump is run forward to begin pumping water to the surface. In this way the introduction of foreign water to the zone to be sampled is minimized. The profiler tip and the stainless steel tubing are flushed with de-ionized water prior to driving at each location.

## 2.3 Sampling Procedure

. Groundwater is extracted from the profiler by means of a peristaltic pump ( Figure 3). This limits sampling to environments where the water table or potentiometric surface is within the suction limit (approximately 8 or 9 meters). Loss of volatiles due to application of suction is minimized if the sample is collected from a column of water that is not in contact with gases. The presence of a gas phase has proven to be a problem at some sites since the reduction in pressure can cause off-gassing of naturally occurring gases such as carbon dioxide. Barker and Dickhout (1988) and Baerg et. al. (1992) conducted research on biases caused by sampling method . The results of the research by Baerg et. al. indicate that the negative bias (i.e., a concentration lower than that actually occurring in the aquifer) in samples collected using a peristaltic pump is on the order of 12% for tetrachloroethene (PCE) and 7% for trichloroethene (TCE). Barker and Dickhout found that the negative bias for PCE was close to 37% and that for



**Figure 3** - Waterloo Profiler sampling configuration schematic

TCE was 25%. The difference in the magnitude of the negative bias between the work by Baerg and that by Barker and Dickhout is due to the fact that the latter were investigating gas charged water (i.e., high partial pressure of CO<sub>2</sub>) while Baerg was not. In either case the bias may be significant and the investigator should be aware that such biases probably exist. The magnitude of the bias is likely to be influenced not only by the partial pressures of dissolved gases but also by the volatility of the analyte and the head against which the sample is pumped to the surface. At many sites the advantage of being able to delineate plumes in detail and in particular to locate zones of high concentration over-rides the disadvantage posed by the sample bias. A modified version of the profiler which is expected to minimize or avoid sample bias has been developed and will soon be field tested.

Prior to sample collection the ports are developed and the profiler is purged. Development is accomplished by: 1) pumping water from the profiler until the water appears to be sediment free or; 2) alternately running the pump in forward and reverse to mobilize sediment around the screen and in the profiler. A large mesh screen is employed to allow sediment to enter the profiler and to be pumped out rather than to accumulate against the screen. The first approach is typically used when the flow rate is relatively high while the second approach is employed when the initial flow rate is relatively low.

The volume of purge water generated during sampling is very small. The volume of fluid contained in the profiler consists of approximately 5 milliliters (mL) in the reservoir in the tip and 5.6 mL for each 5 foot length of tubing that has been driven below the potentiometric surface. Thus, for example, the volume of water contained in the profiler over 50 saturated feet is 61 mL. However, as a result of the profiler being pumped out during driving there is no "stagnant" column of water in the profiler. The water entering the profiler comes directly from the formation. Therefore very little purging is required. In the field trials at Angus a minimum of 100 mL was purged. The volume of sample collected for analysis was 18 mL. In an aquifer with a porosity of approximately 0.35 the volume of water purged and sampled results in a sampled aquifer volume of 337 cubic centimeters (cc) or 20.57 cubic inches. If this volume is assumed to occupy a spherical shape then the minimum vertical sampling interval (to avoid overlap of sampled volumes) would be approximately 8.6 cm. However, in a typical anisotropic aquifer the shape of the sampled portion of the aquifer will be an ellipse (with the primary axis oriented horizontally) with the degree of flattening determined by the ratio of the horizontal to vertical hydraulic conductivities.

During sampling the sample bottles are fitted into stainless steel sampling caps in which an air tight seal is obtained by compressing an "O-ring" inside the sampling cap. The sampling caps are fitted with two 1/8 inch outside diameter stainless steel tubes. One of the tubes provides suction on the sample vial from the peristaltic pump while the other tube is connected to the sampling tube from the profiler through a three way valve arrangement as shown in Figure 3. By virtue of this arrangement the sample does not come in contact with the pump head tubing, rather the sample contacts only stainless steel, brass (in the 3 way valve) and may have minimal contact with the nitrile "O-ring" in the sampling cap. The three way valve is closed once the desired purge volume is obtained, preventing water from being syphoned back down the hole from the sample bottle when the pump is shut off. The purpose of the third valve position is to allow nitrogen to be forced down the profiler under pressure if the sample ports become plugged.

Nitrogen was used in initial prototype development field trials but has not been necessary with the current profiler configuration.

### 3.0 Investigation of a Chlorinated Solvent Plume in a Sand Aquifer at a Dry Cleaning Facility in Angus, Ontario

#### 3.1 Background

Angus, Ontario is a small village located in Essa Township just outside the main gate to Canadian Forces Base Borden. Many residents of Angus obtain their drinking water from relatively shallow drive point wells driven into the sand aquifer underlying Angus. In 1992 a tenant who had just moved into a duplex apartment building complained of a strange taste in the drinking water supplied by a drive point well at the apartment building. Subsequent water quality analyses performed by the Ontario Ministry of Environment indicated that the water contained as much as 27 mg/L of PCE, 5000 times the Canadian and U.S. drinking water standard of 0.005 mg/L. Further sampling of local water supply wells revealed contamination of other water supplies in narrow zone between one of the dry cleaners and the Pine River. Figure 4 is a map of the affected portion of the village of Angus.

Based on cores collected using the Waterloo piston coring tool (Star and Ingleton, 1992) the flow system of concern underlying Angus is comprised of two stratified sand and silty sand units separated by a silt layer underlain by a woody peat layer. The top of the silt layer is found between 4 and 5 meters below ground surface in the vicinity of the dry cleaner. The silt layer is approximately 0.8 m thick and is underlain by a peat layer approximately 0.10 m in thickness. Above the silt layer the sands vary from yellow fine to medium sand to grey very silty very fine sand. Below the silt layer the sands are bedded fine to medium and medium to coarse sand with

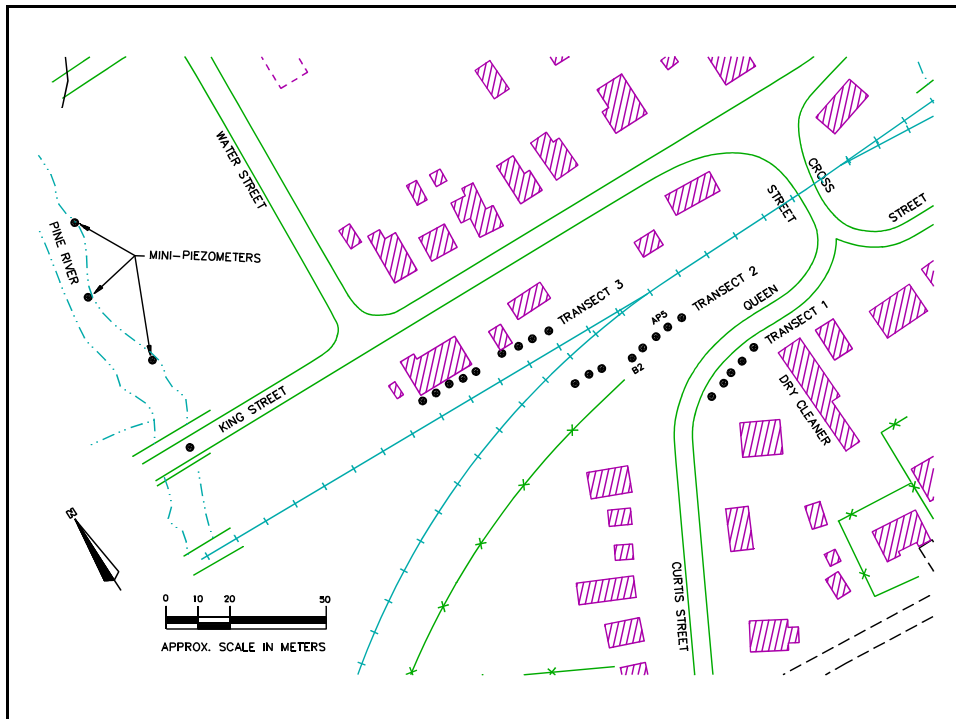


Figure 4 - Angus, Ontario profiling field site.

a few lenses and stringers of fine gravel. Shells are abundant in some layers in both the upper and lower sand units. A lower aquitard is believed to occur at approximately 15 to 16 meters below ground surface. In general the hydraulic conductivity is lower in the upper sand unit. Permeameter tests in the lower sand yielded permeability values

ranging from  $3 \times 10^{-2}$  cm/s to  $2 \times 10^{-3}$  cm/s (Broholm et. al., 1994). Groundwater flow direction in the lower sand is assumed to be generally northwest into the Pine River. Mini-piezometers placed in the bed of the Pine River confirm that groundwater discharges into this stream.

### *3.2 Drive Point Profiling Investigation*

The lightweight version of the Ingleton Profiler was used to determine the distribution of PCE solute concentrations. A total of 23 profile holes were undertaken in three transects across the plume (see Figure 4 for profiling locations). Samples were collected at 0.25 meter intervals except at B1 where a 0.20 meter interval was used. At all locations except B1 profiling was terminated at 12.0 meters below ground surface. The profile hole at B1 continued to 15 meters bgs. A total of 599 samples were collected for analysis using the profiler. Initially samples were collected only in the upper flow zone to the top of the silt layer to ensure that DNAPL was not perched on the silt layer. Following analysis of these upper sand unit samples the profiler was used to breach the silt layer and collect samples in the deeper sand unit. Sampling was not performed below the silt at AP1 and AP10. There was virtually no contamination above the silt layer in any location.

A Bosch electric jackhammer was used to drive the profiler. Driving times for the 0.25 meter interval were typically very short. In some locations the peat layer presented some difficulty in driving but in no case did the peat layer cause refusal of the profiler. Only formation water was pumped down the profiler in most cases. That is, the water remaining in the profiler following collection of a sample was pumped down and out of the ports during driving to prevent clogging of the ports and cross contamination of samples between depths. The pump was left running until the next target depth was reached. This caused air to be pumped out of the ports until the target depth was reached. In several cases the ports became plugged and distilled water was pumped down the profiler to open the ports. In these cases additional volume was purged prior to sample collection. Degassing of the samples during collection was evinced by excessive bubbling in the sample bottles during pumping. This degassing is likely to result in a negative sample bias due to partitioning of volatiles into the gas phase. We suspect that the degassing is due to a high partial pressure of carbon dioxide in the groundwater. The effect of degassing (i.e., the magnitude of the negative bias) was evaluated by collecting samples from conventional monitoring wells using a bailer, a peristaltic pump and canister samplers developed at the University of Waterloo (Baerg et. al., 1992). This evaluation is described in section 4.0.

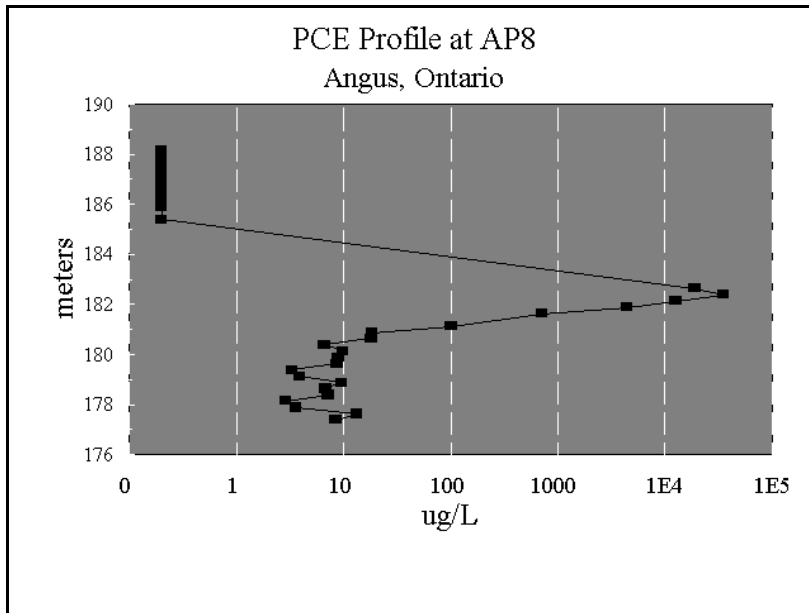
In most cases 100 mL of water were purged through the profiler prior to sample collection. The flow rate of water from the profiler varied dramatically. Typically the upper sand unit yielded much slower flow rates than the lower sand. Water could not be obtained from the silt and peat units using the profiler. The time required to collect a sample in the lower sand unit typically ranged from 6 to 15 minutes including driving, purging and sampling time. Twenty-six field days averaging approximately 10 crew hours per day were required to complete the profiling investigation. Twenty to thirty samples were commonly collected in a day including unpacking, setting up, sampling, and packing up the equipment. In the case of transect 3 all of the equipment was carried across the railroad tracks from Queen Street and back again each day, a distance of 50 to 100 meters. Assuming a crew rate of \$100/hour and equipment rental of \$400/day the total cost of collecting 599 samples is \$36,400 or approximately \$61/sample. If the

cost of feeding and housing the field crew is included in the estimate, a cost of approximately \$70 per sample is obtained.

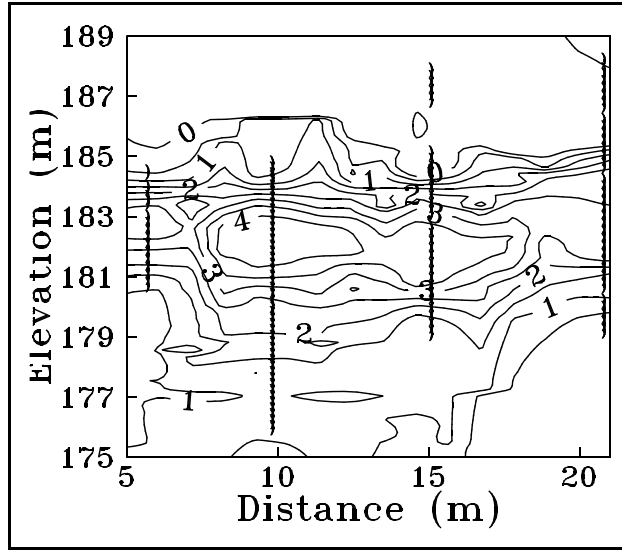
### 3.3 Results

The contamination appears to occur almost exclusively in the lower sand unit below the silt and peat layers. An example of the concentration profiles of PCE plotted versus depth is shown on Figure 5. Cross sectional views of the log of the contaminant concentration are shown for transects 1 and 2 in Figures 6 and 7 respectively. The majority of the mass of the plume is contained in a zone that is approximately 3 meters thick in the vertical dimension and is found between the elevations of 181 and 184 meters. At B1 fine sand and silty fine sand are found between the elevations of 181.24 and 183.24 meters. A plot of hydraulic conductivity versus depth developed from permeameter tests run on cores collected from B1 by Broholm et. al. (1994) is presented as Figure 8. A low hydraulic conductivity value is found at an elevation of 181.77 m (9.075 m depth). This low value corresponds to the silty fine sand mentioned above. Courser sand and some fine gravel are found both above and below this interval. Concentration gradients are quite steep vertically as is evident from the figures. At AP7 the concentration increases by an order of magnitude from 26 ppb to 303 ppb over a vertical distance of 25 cm and increases further from 303 ppb to 6,250 ppb over the next 25 centimeters. The highest

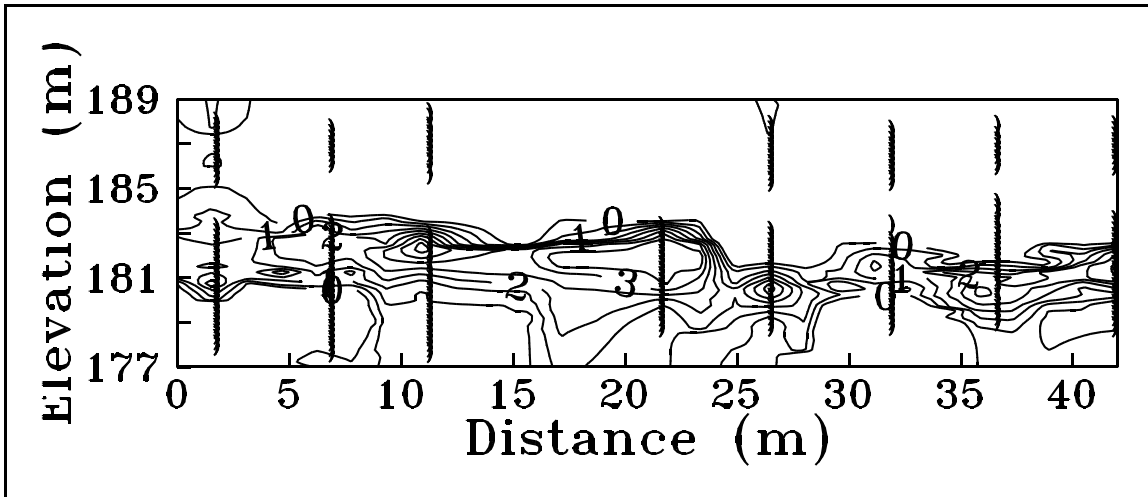
concentration observed at the site is 42,318 ppb at B1 on transect 1



**Figure 5** - PCE Concentration vs depth at AP8

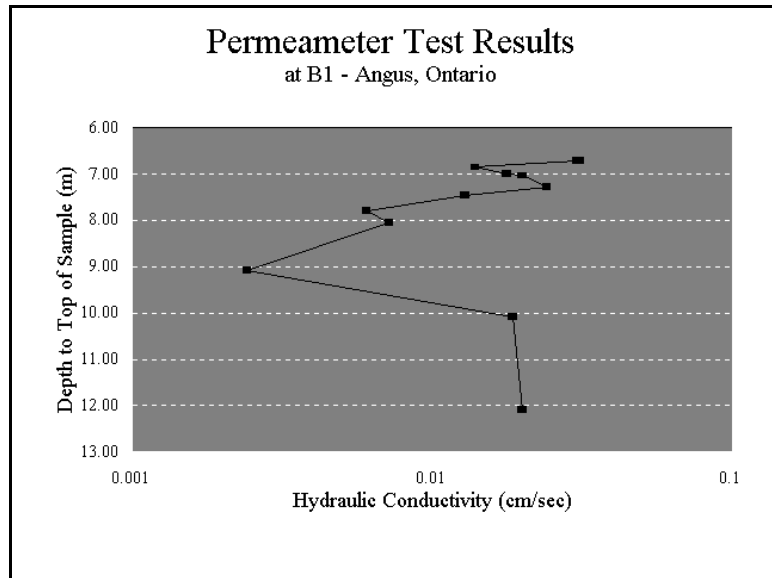


**Figure 6** - Log transformed PCE concentrations ( $\mu\text{g/L}$ ) on transect 1



**Figure 7** - Log transformed PCE concentration ( $\mu\text{g/L}$ ) on Transect 2

at an elevation of 182.44 m. At transect 2 the core of the plume yields a concentration of 35,389 ppb at an elevation of 182.38 meters at AP8. This is approximately 2.5 meters below the inferred bottom of the upper aquitard. The bottom of the aquitard is inferred from profiler purge rate data obtained during sample collection. Concentrations generally decline to a few ppb or to lab background levels with depth. This does not appear to be the case in the core of the plume. For example at AP8 the concentration fluctuates between 3.3 and 13.3 ppb to the bottom of the profiling hole. Concentrations also remain elevated above the drinking water standard at B1 to a depth of 15 meters below ground surface, although concentrations do drop off sharply below an elevation of 181 meters.



**Figure 8** – Hydraulic conductivity versus depth

The horizontal concentration gradients are also quite steep. For example, between AP8 and AP9 peak concentrations drop from 35,389 to 924 ppb over a horizontal distance of 5 meters and drop to 471 ppb over the next 5 meters to the west to AP18. By contrast, the concentrations do not appear to drop off as sharply to the east. AP7 is 35 meters east of AP8. The peak concentration at AP7 is 6,250 ppb, thus the decrease in concentration from AP8 to AP7 is much smaller and the distance between them is much greater than that between AP8 and AP9. The reason for this is not clear. Further field studies will be undertaken to assess the possible causes of this occurrence

#### **4.0 Comparison of Waterloo (Ingleton) Profiler Results with Other Monitoring Devices at the Angus Site**

##### *4.1 Objectives*

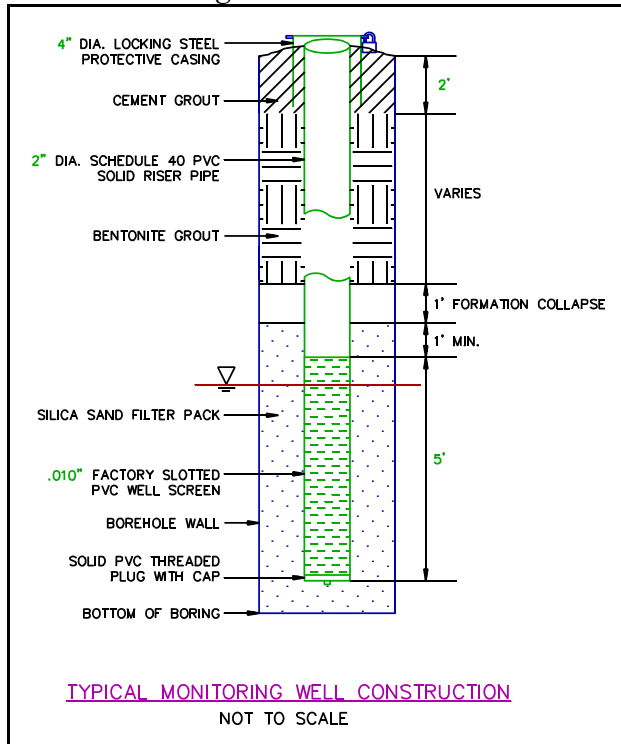
The objectives of the comparison of the profiler data to other monitoring techniques were: 1) to determine if the concentrations obtained using the profiler are comparable to concentrations obtained using conventional techniques that are accepted by the regulatory and legal communities and; 2) to determine how the method of investigation affects the resulting picture provided by the data.

##### *4.2 Installation of Monitoring Points*

Additional monitoring points were installed at profiling locations B1, B2 and AP5. At each location a pair of conventional 2 inch diameter PVC monitoring wells were installed along with drive point piezometers. At B1 and B2 bundle piezometers were also installed. Each of these

devices are described below.

#### 4.2.1 Monitoring Wells



**Figure 9** - Typical monitoring well construction

The monitoring wells were installed as standard consulting industry wells the typical construction of which is shown in Figure 9. Each well was equipped with a five foot length of 0.010 inch slot size schedule 40 PVC screen (the actual open length of which is 4.75 feet). Wells at B1 and B2 were installed using 7.25 inch O.D. hollow stem augers. The wells in each pair were completed in separate boreholes. A silica sand pack was placed around each well screen and for a distance of 1 foot above the screened interval. Approximately 1 foot of native formation material was allowed to collapse on top of the sand and the remainder of the borehole annulus was grouted with a bentonite grout. Wells were completed flush with the ground surface using steel protective casings cemented in place. Each well produced one 55 gallon drum of drill cuttings, a 55 gallon drum of water during development and another 30 gallons of water

from purging. In many situations this material must be handled as hazardous waste with the attendant costs of sampling, handling and disposal. At best, two monitoring wells could be completed in one (10 hour) day. A hollow stem auger drill rig typically costs \$100/hr, a crew per diem of \$200/day and well construction materials cost \$1,663 for the six wells. Thus the installation of six wells costs \$6,063 or \$1,010.50 for each data point exclusive of waste handling and disposal.

#### 4.2.2 Drive Point Piezometers

The drive point piezometers consist of a 1 foot long screened section in a stainless steel tip with 0.5 inch O.D. polyethylene tubing rising to the ground surface inside 0.75 inch diameter schedule 80 black steel pipe. Piezometers were driven using the Bosch electric jackhammer and scaffolding used to drive the profiler. Eight piezometers were installed at B2 and AP5 (four at each location at various depths) in just over four hours including setting up and packing up the equipment. Six piezometers were installed at B1 in the fall of 1992.

#### 4.2.3 Bundle Piezometers

Bundle piezometers (MacKay et. al., 1986) consist of 13-1/8 inch O.D. PTFE tubes bound to a 1/2 inch O.D. PVC center stalk. The bottom ends of the PTFE tubes are covered with a nylon screen. It is assumed that the contact time between the sample and the nylon screen during sampling is so short as to result in a negligible effect on the sample. The bundles were installed by driving 2 inch O.D. casing with EW drill rod thread. The casing was equipped with an

aluminum knock-out point and was driven using a pneumatic piercing tool mounted on a CanTerra drill rig. The casing was driven to the desired depth, the bundle piezometer was lowered down the casing, the point was knocked out and the casing was withdrawn allowing the formation to collapse around the bundle.

#### *4.3 Sampling*

The conventional monitoring wells were sampled using three different methodologies: 1) a PTFE bottom draining bailer with check valves located on the top and bottom; 2) a peristaltic pump using the same sampling cap configuration used with the profiler and; 3) stainless steel canisters. Both the bundle piezometers and the drive point piezometers were sampled using a peristaltic pump and the sampling cap configuration used with the profiler.

Monitoring wells were purged of 114 liters (> 3 well volumes) of water prior to sampling. The first 76 liters were removed with a gasoline powered centrifugal pump and the last 38 liters were purged using an inertial pump. The bailer sample was collected first followed by the peristaltic pump sample and finally the canister sample. An additional liter of water was pumped through the peristaltic pump prior to sample collection with that device.

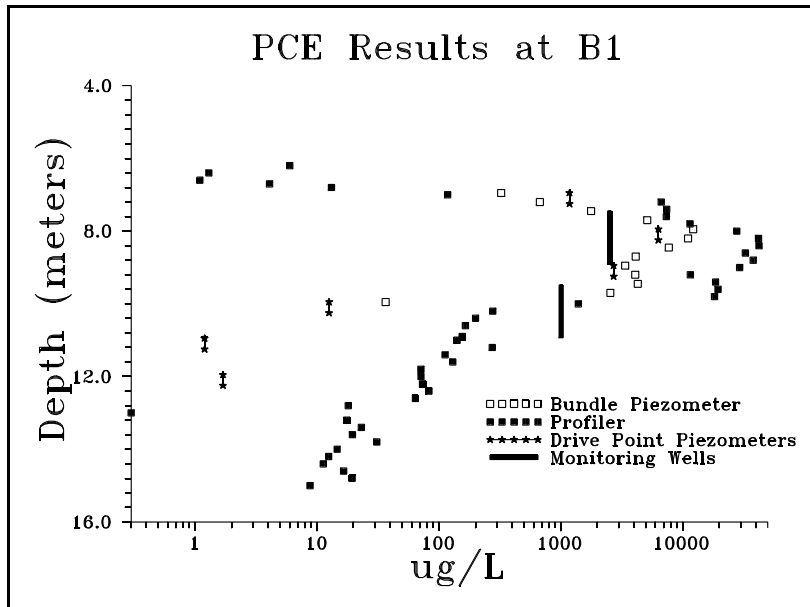
Three liters (> 3 well volumes) of water were purged from the drive point piezometers prior to sampling and 100 mL of water were purged from each tube in the bundle piezometers prior to sampling.

With the exception of the canister sampling system all samples were collected in 40 mL glass vials with PTFE lined septa and screw-on plastic caps. All samples were kept refrigerated prior to analysis. Samples were analyzed by gas chromatography using an electron capture detector following pentane extraction. Samples were forced out of the canisters into a gas tight syringe under pressure so that the sample pressure was not reduced during extraction.

All sampling of conventional monitoring wells, bundle piezometers and drive point piezometers was performed in December 1993. Profiling at B1 occurred in November 1992 and profiling at B2 and AP5 occurred in August 1993. Thus there is a substantial time lag between the profiler samples and the samples described in this section.

#### *4.4 Results*

Plots of the data obtained from the four types of monitoring devices are shown as Figures 10, 11 and 12 for locations B1, B2 and AP5 respectively. A bundle piezometer was not installed at AP5, therefore Figure 12 presents data from only three monitoring devices.



**Figure 10-** Monitoring Data at B1

Monitoring wells and drive point piezometers are represented as lines which reflect the interval over which they are screened. In this manner the single concentration value provided by sampling these devices are ascribed to the entire interval over which the device is screened. Monitoring wells are represented by the highest concentration obtained in each well. In every case the highest concentration was obtained using the bailer.

A comparison of the water quality described by the profiler and that described by the bundle piezometers reveals that the contaminant distributions have changed. Earlier comparisons of the profiler with bundle piezometer data obtained from field trials at a heavily instrumented, controlled field site at Canadian Forces Base Borden indicate that, in the absence of a significant vertical component of the hydraulic gradient, the bundle piezometer and profiler data are very similar (Broholm et. al., 1994). It is therefore a reasonable assumption that the bundle piezometer data at the Angus site are indicative of the conditions in the aquifer at the time of sampling that would have been obtained with the profiler at that time. Thus the inference is that aquifer conditions have changed in the period between profiler sampling and sampling of the permanent devices. This inference is supported by a comparison of analytical results from samples collected two from drive point piezometers at B1 on July 16, 1993 and again on December 9, 1993. The concentrations obtained during the December sampling are 45% lower than the July results on average.

An examination of Figure 10 reveals that, while the magnitude of the concentrations reported for the bundle piezometer are markedly lower than those reported for the profiler, the shape of the plume at this location is nearly identical. The bundle piezometer at B1 is located hydraulically downgradient of the drive point piezometers and upgradient of the monitoring wells. The uppermost conventional monitoring well in the pair (MW1S) is represented by the uppermost long line on Figure 10. This well is screened between 7.45 m and 8.9 m below ground surface. The concentration reported for this well is 2,514.6  $\mu\text{g/L}$ . The bundle piezometer has six intakes in the interval screened by MW1S. The maximum concentration reported for the bundle in this interval is 12,187  $\mu\text{g/L}$ , the minimum is 1,774.8  $\mu\text{g/L}$  and the mean is 7,000  $\mu\text{g/L}$ . Not surprisingly, the monitoring well under-represents the maximum concentration (as reported for the bundle piezometer) by nearly a factor of 5 and over-represents the minimum concentration by a factor of 1.5. The monitoring well does not represent the mean concentration over the sampled interval. The well under-represents the mean value by a factor of 2.78. The apparent reason for this is that the zone of highest permeability in the screened interval is near the top of

the interval. This also happens to be the zone of lowest solute concentration. Thus, the zone providing the most water to the well has the lowest concentration and weights the average toward the low end. The volume of aquifer sampled (due to purge volume) using the monitoring well is approximately 326,000 cc or nearly 3 orders of magnitude larger than the volume sampled using the bundle piezometer or the profiler. The drive point piezometer located near the center of the MW1S screened interval reports a concentration of 6331.8  $\mu\text{g/L}$ , a value more than 2.5 times higher than the monitoring well concentration. It should be noted that use of the peristaltic pump, when compared to bailing, results in a negative sample bias ranging from 6% to 60% with a mean of 28.3%. This is based on the reduction in the magnitude of the concentration reported for the monitoring well sampled with a peristaltic pump relative to the mean concentration reported for all the samples (2 or 3) collected from that well with a bailer. This implies that the actual concentrations in the aquifer are 28% greater than those reported by the bundle piezometer and therefore the gap between the monitoring well concentration and the aquifer concentrations are that much greater.

Over the interval screened by the deeper well (MW1D) at B1 there are only 3 intakes in the bundle piezometer. The maximum concentration reported for the bundle piezometer was 4,295  $\mu\text{g/L}$ , the minimum was 36.7  $\mu\text{g/L}$  and the mean was 2,295.2  $\mu\text{g/L}$ . The concentration measured in the sample from MW1D was 1,007.6  $\mu\text{g/L}$ , less than half of the mean value for the bundle piezometer. Two drive point piezometers were placed in the screened interval for MW1D. These piezometers returned values of 12.6 and 1.2  $\mu\text{g/L}$  for the shallow and deep piezometer respectively. Again, the monitoring well concentration does not represent the maximum, minimum or average concentration over the interval that it is screened. It represents some unknown weighted (on the basis of permeability) average.

The conventional monitoring wells at B1 were installed with the knowledge of solute concentration distributions provided by the profiler. Even with this prior knowledge and placement of the well screens in the zones of highest concentration, the wells do not provide the quantity or quality of information provided by the multi-level, point sampling devices. The picture provided by these two well screens provides a much less clear and less detailed understanding of the plume anatomy. If the screens had been placed without prior knowledge of contaminant distribution, for example if one screen had been placed at the top of the aquifer (just below the peat) and the second screen had been placed at the bottom of the aquifer (at approximately 15 meters), it is likely that concentrations of 0 to 10  $\mu\text{g/L}$  would have been reported and the severity of the contamination would have been completely misjudged.

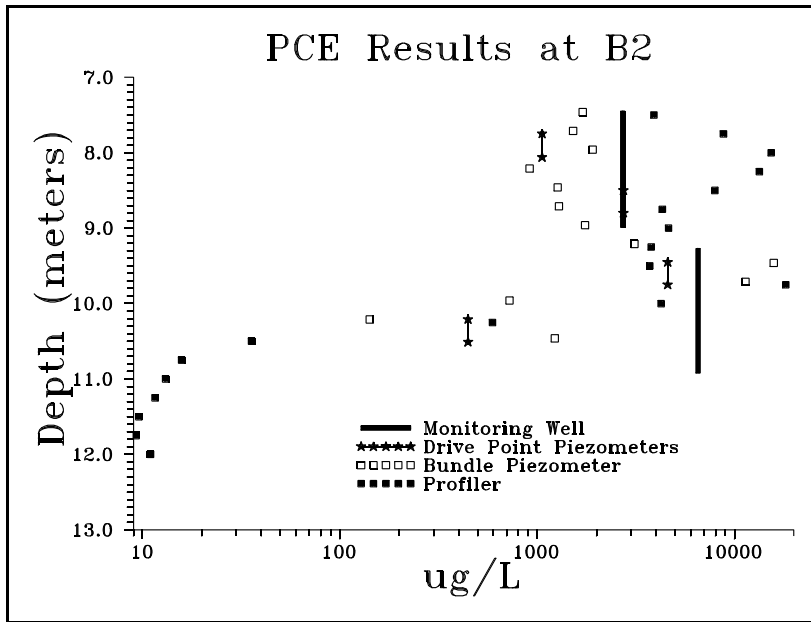


Figure 11 - Monitoring data at B2

Figure 11 presents the results of sampling at the B2 location. Here the bundle piezometer is located downgradient of the drive point piezometers and of the monitoring wells. The shape of the profile is not the same for the profiler data and the bundle piezometer, especially between 7.5 and 9.0 m bgs. It seems likely that the flow field is perturbed by the monitoring well installation, resulting in a "smeared" concentration profile downgradient in the bundle piezometer. The concentration reported for the shallow monitoring well is higher than

the concentrations in any of the bundle piezometer intakes over the same interval but is lower than all of the samples obtained with the profiler over that interval. In the interval screened by the deeper well the bundle piezometer shows an order of magnitude decrease in concentration over 0.75 m. In this case the monitoring well returns a concentration that is 10% higher than the mean of the bundle samples but is only 41% of the maximum and is 46 times the minimum concentration. Thus while the monitoring well serendipitously approximates the mean for the interval it does not accurately represent the distribution of solute concentration over the interval.

A bundle piezometer was not installed at AP5 (Figure 12). On the basis of the drive point piezometer results along with the monitoring well results, it appears that concentrations at this location have increased appreciably. One of the most striking features of this plot is that the depth interval occupied by the concentration spike is only 1.75 meters in thickness. Much of the rest of the aquifer at this location is characterized by PCE concentrations of less than 1  $\mu\text{g/L}$ . Placement of well screens is therefore extremely critical to detecting the plume, particularly the high concentration core of the plume. Based on the high concentration reported for the

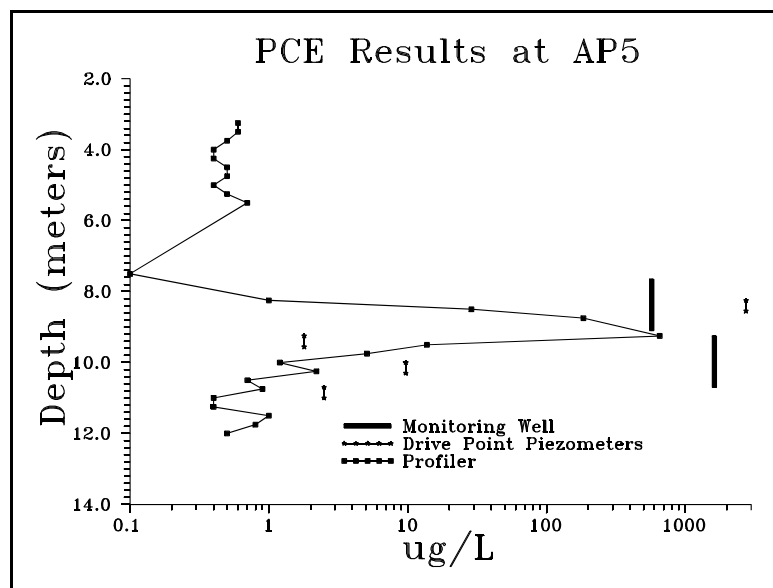


Figure 12 - Monitoring data at AP5

shallowest drive point piezometer it appears that the actual concentrations in at least a portion of the interval screened by the shallow monitoring well are substantially greater than that yielded from the monitoring well. The concentrations reported by the two shallowest drive point piezometers vary by nearly 3 orders of magnitude over a distance of 1.3 meters. The monitoring wells show no such variability.

## 5.0 Conclusions

Nearly 600 samples were collected with the drive point profiler. The average time required to collect samples was approximately 26 minutes per sample including daily set up and packing of equipment. An assumed charge rate of \$100/hour for the crew, a \$200 per diem for the crew and \$400/day for equipment rental results in a cost of \$70/sample. The cost of a field program producing 600 samples is less than the cost of a drilling program producing less than a tenth as many sampled intervals. No drill cuttings and minimal purge water were produced during the investigation. The profiler investigation could be made more efficient and less expensive by employing real time on-site GC analysis to guide the placement of profile holes.

Increases and decreases in concentration of an order of magnitude or more over a vertical distance of 25 cm indicate that cross contamination from one depth to another is negligible using the profiler with respect to determining the anatomy of the core of the plume. The issue of cross contamination is less clear at very low concentrations in the lower portions of the profile hole. In most situations the concentrations are not below the detection limit but nevertheless are very low. For example, at AP7 the profiler penetrated a zone with a concentration of over 6,000  $\mu\text{g/L}$  at 8.5 m bgs and subsequently returned concentrations below the detection limit at 11.0 and 11.25 meters bgs. The profiler data provide sharp resolution of the distribution of dissolved PCE contamination. The solute concentration data provide a picture of the anatomy of the plume which can be extrapolated to determine the location of the DNAPL source. This type of detailed delineation of plume anatomy will be useful at sites where plume remediation is by pump-and-treat or where *in-situ* treatment zones are used.

Negative sample biases due to suction pumping in gas charged water ranged from 6% to 60% with a mean of 28%. Even under these rather extreme conditions the profiler provided much more information on the distribution of contaminants than would be possible using conventional techniques at most sites. The data show that the distribution of solute concentrations is highly variable even over short intervals. Collection of this type of data offers one of the best hopes for delineating source areas at DNAPL sites and therefore offers better prospects of establishing and meeting realistic remedial goals.

Development of the profiler is continuing with a gas drive pump being used to overcome the suction limit and to minimize sample bias. A profiler tip modified to allow grouting of the hole during retrieval is being developed and field tested.

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