Accurate Assessment of Natural Attenuation using Depth Discrete Multi-level Monitoring: Evidence at Three Chlorinated Solvent Sites

M.A. Guilbeault[1], B.L. Parker[2] & J.A. Cherry[3]

Releases of PCE and TCE decades ago at 3 industrial sites in Florida, New Hampshire and Ontario formed suspended DNAPL source zones and dissolved phase plumes within sandy aquifers. Detailed multi-level monitoring of groundwater concentrations along transects orthogonal to flow was performed at these sites to examine natural attenuation. A direct-push sampler (the Waterloo Profiler) and permanent multi-level bundle samplers were installed at many locations using direct-push casing. Closely spaced vertical sampling was used to determine peak concentrations within the source areas and downgradient dissolved phase plumes, where conventional monitoring wells had failed to locate the high concentration zones. Continuous cores for stratigraphy and concentration profiles showed maximum concentration peaks that were extremely sharp. At the Florida site, continuous coring and depth discrete sampling adjacent to the wells revealed much higher maximum concentrations than those detected in the monitoring wells. The high resolution sampling showed that 90% of the VOC mass discharge occurs within less than 20% of the transect cross-sectional area at each site. The information acquired using depth-discrete methods allowed determination of the scale of concentration variability within chlorinated solvent plumes and showed that, in contrast with conventional well installations, such techniques are time efficient and essential to obtain the information necessary for reliable assessment of natural attenuation of chlorinated solvent plumes.

Introduction

Releases of trichloroethylene (TCE) as DNAPL at an industrial facility in Florida on a 20m thick marine sand aquifer have formed suspended DNAPL source zones causing a persistent dissolved phase plume in an unconfined sand aquifer. The releases began in 1964 and the TCE contamination was discovered in 1966. The facility is still in operation but the use of TCE was discontinued in 1977. The aquifer has a shallow water table and some thin discontinuous clay and bioclast layers. Conventional monitoring wells used between 1993-1996 were found to be inadequate for characterizing the nature of the contamination. This most recent study was undertaken in 1996-2000, using new direct-push, depth-discrete sampling techniques to determine the spatial variability of VOC concentrations for assessment of natural attenuation. A similar depth-discrete monitoring approach was also used at two other sites, one in Ontario and the other in New Hampshire where tetrachloroethylene (PCE) releases formed suspended DNAPL zones in unconfined sandy aquifers with shallow water table. The Ontario site is a dry cleaning facility where PCE was used from the early 1970s to the early 1990s when its use was discontinued after contamination was found in nearby residential wells. Previous work using

[1] Research Assistant Hydrogeologist, Department of Earth Sciences, University of Waterloo , Waterloo, Ontario, Canada, N2L 3G1, Canada, Ph. 519.888.4567 x6750, Fx. 519-883-0220, maguilbeault@uwaterloo.ca
[2] Research Assistant Professor, Department of Earth Sciences, University of Waterloo , Waterloo, Ontario, Canada, N2L 3G1, Canada, Ph. 519.888.4567 x5371, Fx. 519-883-0220, blparker@uwaterloo.ca
[3] Professor, Department of Earth Sciences, University of Waterloo , Waterloo, Ontario, Canada, N2L 3G1, Canada, Ph. 519-888-4567 x4516, Fx. 519-883-0220, cherryja@uwaterloo.ca

depth-discrete sampling immediately downgradient of the DNAPL source zones by Guilbeault (1999) delineated the PCE plume extending 190m to a river where it discharges as described by Conant (2001). At the New Hampshire site, also known as the Savage Well Superfund Site, a former tool and dye factory released PCE DNAPL from degreasing operations between 1957 and 1983. These releases caused a dissolved plume that was discovered in 1983 in a municipal supply well 1km downgradient of the facility. The site lies on an unconfined glacio-fluvial sand and gravel aquifer. Monitoring using a network of conventional wells began in 1983 and reconnaissance direct-push sampling was done in 1995.

Field Methods

To evaluate the degree of attenuation immediately downgradient of the suspected DNAPL source zones, Guilbeault (1999) used depth-discrete sampling methods to characterize the cross-sectional distribution of PCE or TCE along vertical transects orthogonal to flow. At each site, a transect with very detailed sampling was done a short distance downgradient of the source zone. Groundwater samples were obtained along vertical profiles using the Waterloo Profiler described by Pitkin et al. (1999) and permanently installed multi-level bundle samplers of the type described by Cherry et al. (1983), which were driven or installed using direct-push Enviro-Core rigs. These devices were used at a total of approximately 80 locations within the study areas to obtain groundwater samples at a vertical spacing as close as 15cm (6in.). Soil physical properties were measured on continuous cores extracted at more than 18 locations at the different sites using the Waterloo Piston Corer described by Starr and Ingleton (1992). Also, VOC concentrations were measured on very small soil samples taken at 5cm (2in.) intervals along continuous cores using a small diameter stainless steel sampling device with the procedure described by Parker (1996). These field tools were combined with a new analytical system for rapid on-site analysis using rapid GC analysis with SPME extraction. This coupling of direct-push methods and the new on-site analytical system provided time efficient and cost effective characterization.

Results and Discussion

The VOC concentration distribution along transects within 10m, 5m and 30m of the suspected DNAPL source zones at the Ontario, New Hampshire and Florida sites respectively, showed maximum concentrations below solubility of TCE or PCE. Figure 1 shows the transect 30m downgradient of the Florida source zones, indicating three high concentration zones caused by three separate source zones on the property. Maximum concentration peaks along vertical profiles with close spacing were extremely sharp and showed concentrations variability of up to 1.5 orders of magnitude within 15cm. At all three sites, depth-discrete data showed rapid peak concentration decline within short distances downgradient of the source zones. The very fine scale of monitoring also allowed calculation of plume mass discharge values of 18, 80 and 33 kg/year for the Ontario, New Hampshire and Florida sites, respectively and allowed identification of small high concentration zones where most of the mass discharge occurs. These zones were not identified by the network of conventional wells at the Florida and New Hampshire Sites. Conventional wells were not used at the Ontario site, but would have had a low probability of detecting the zones given their small size.

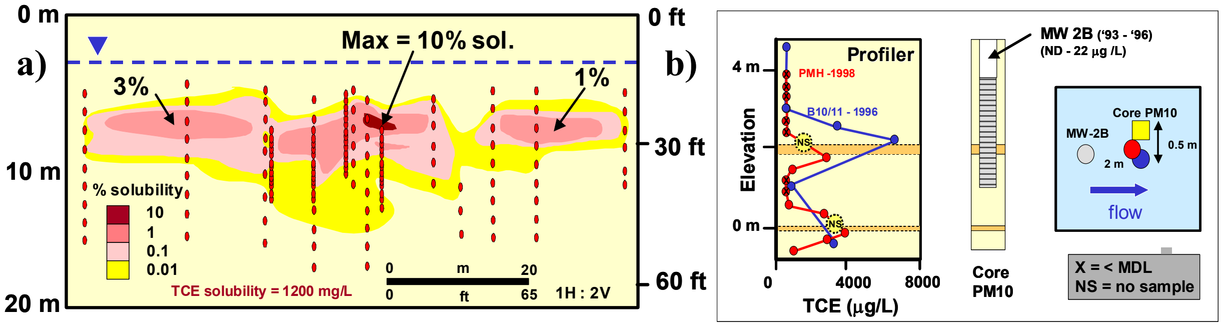

Figure 1. (a) VOC concentration transect from the Florida Site showing internal variability of plume and (b) misleading data from conventional well revealed by depth-discrete sampling which shows peak concentrations were not detected in monitoring well.

Summary of Conclusions

The very fine scale of depth-discrete sampling revealed the spatial variability of VOC concentrations within the plume and allowed determination of the sampling scale necessary to locate the high concentration zones. Maximum concentrations were distributed in several zones of locally high concentrations (local maxima) at each site. The peak concentrations undergo large decline in the first 20m downgradient from the source zones due to local dispersion but the decline with distance farther downgradient is much less. Depth-discrete monitoring at the Florida site showed the deficiencies in using conventional monitoring approaches such as large screened wells to assess natural attenuation. Concentrations obtained in 3m screened wells were several orders of magnitude lower than peak concentrations from vertical profiles adjacent to the wells. Depth-discrete monitoring using extremely low volume sampling tubes minimized purge water and direct-push techniques eliminated the need to handle contaminated groundwater and soil during sampling and installation. Continuous soil coring using direct-push methods allowed determination of small scale geological heterogeneities which control DNAPL distribution in the source zone. Given the heterogeneous distribution of DNAPL in source zones in sandy aquifers, the plumes retain large internal concentration variability that is unreliably characterized using conventional wells alone. Depth-discrete methods are efficient and essential to obtain the spatial detail required to characterize high concentration zones in the transverse dimensions orthogonal to groundwater flow. Delineation of these zones is necessary to obtain accurate estimates of mass discharge that are needed for proper assessment of natural attenuation.

References

Cherry, J.A., Gillham, R.W., Anderson, E.G. & Johnson, P.E. 1983. Migration of contaminants in groundwater at a landfill: A case study. 2. Groundwater monitoring devices. *Journal of Hydrology* 63: 31-49.

Parker, B.L. 1996. *Effects of molecular diffusion on the persistence of dense, immiscible phase liquids in fractured porous geologic media*. Ph.D. thesis, Dept of Earth Sciences, Univ. of Waterloo, Waterloo, ON, Canada

Guilbeault, M.A. 1999. *Suspended DNAPL source zones in three sandy aquifers: plume anatomy, mass discharge and sampling scale considerations*. M.Sc. thesis, Dept of Earth Sciences, Univ. of Waterloo, Waterloo, ON, Canada

Pitkin, S.E., Cherry, J.A., Ingleton, R.A. & Broholm, M. 1999. Field demonstrations using the Waterloo Groundwater Profiler. *Ground Water Monitoring and Remediation* 19(2): 122-131

Starr, R.C. & Ingleton, R.A. 1992. A new method for collecting core samples without a drilling rig. *Ground Water Monitoring Review* 12(1): 91-95

Conant, B.J. 2001. *A PCE plume discharging to a river: investigations of flux, geochemistry, and biodegradation in the streambed.* Ph.D. thesis, Dept of Earth Sciences, Univ. of Waterloo, Waterloo, ON, Canada