Persistent PCE In A Surficial Sand Aquifer Caused By Auger Cross-Contamination of DNAPL From An Underlying Aquitard

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An unexpected and persistent PCE plume was found in 1995 in the surficial sand aquifer in one of the Borden groundwater experiment areas. This plume was delineated in detail in 1998-2000 using detailed depth-discrete groundwater sampling along transects orthogonal to groundwater flow. Several lines of evidence indicate that the plume was caused by a small mass of PCE DNAPL introduced into the aquifer in 1991-1994 by augering into the underlying clayey aquitard where DNAPL occurs locally in thin sand beds. The plume extends 95 m (over 300 ft) to a small stream where nearly completely attenuation occurs. In recent years, direct push or rotosonic drilling can be used to avoid causing this type of contamination.

Introduction

The surficial sand aquifer at Canadian Forces Base Borden located 50 miles northwest of Toronto, Ontario has been used since 1981 for many field experiments in which chlorinated volatile organic chemicals were put into the aquifer to observe the long-term transport and fate. One of the experiment areas is known as the Forested Area, where the aquifer is a 3-4 m (10-13 ft) thick deposit of relatively uniform, medium-grained sand of glaciolacustrine origin. DNAPL experiments in the Forested Area have been conducted inside water-tight enclosures (cells) constructed of sealable-joint steel sheet piling driven through the sand aquifer into the underlying clayey aquitard. Two major PCE DNAPL experiments were conducted in these cells prior to 1995, the first involved infiltration of 231 L of free-phase PCE into a 3 m x 3 m cell in June, 1990 (Kueper et. al., 1993), and the second involved infiltration of 771 L of free-phase PCE into a 9 m x 9 m cell in July, 1991 (Brewster, et. al., 1995). Hydraulic tests and other evidence indicated that the two sheet pile cells were non-leaky and yet in 1995, and thereafter, PCE was found in the sand aquifer down-gradient of these cells. The study reported on here was conducted between 1998-2000, to determine the origin and fate of the PCE found in the sand aquifer outside the cells.

Approach and Field Methods

Figure 1 shows the location of the two sheet pile cells, the PCE plume delineated in this study and the monitoring transects for this delineation. Figure 1 also shows representative water table contours indicating the general direction of groundwater flow in the sand aquifer. The groundwater flows past the area of the cells to a small stream located 95 m (over 300 ft) down-gradient. The monitoring transects are positioned orthogonal to the general groundwater flow direction. One of the transects is up-gradient of the 9m cell and the other four are down-gradient.

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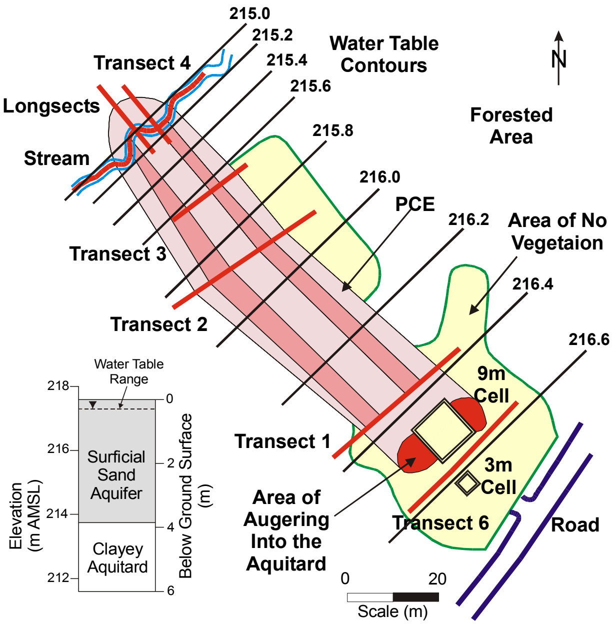

Figure 1: Plan view of Borden Forested Area showing 3m and 9m cells, road, forest area, stream, transects, general water table contours, two DNAPL augered areas, and resulting plume.

Detailed depth-discrete groundwater sampling was done along each of the down-gradient transects each year for 1998, 1999, and 2000, first using the Waterloo Profiler described by Pitkin et. al. (1999) and in later years primarily using multilevel bundle samplers as described by Cherry et. al., (1983). Cores were taken for many falling-head permeameter tests and borehole dilution tests for groundwater velocity were done at 10 locations.

Results and Discussions

Figure 2 shows the PCE concentration for the year 2000 sampling along the transect immediately down-gradient (17 m) of the 9m cell. No PCE was found on the up-gradient transect. Therefore, it is concluded that the source of the PCE is related to the 9m cell. Figure 1 shows the plume of PCE extending from the vicinity of the 9m cell to the small stream 95 m down-gradient. The other down-gradient transects exhibit generally similar concentration distributions to that of Figure 2, except that, towards the stream, the peak PCE values are generally lower. The high concentration zone on the east side of the plume is progressively deeper below the water table due to greater recharge in the area where all vegetation has been removed. The plume in plan view has two lobes originating from two areas associated with the 9m cell, one on the east side and one on the west side (Figure 1). These are areas where hollow-stem augers were used to acquire core samples from the underlying aquitard in which PCE DNAPL occurs. The DNAPL got into the aquitard shortly after the DNAPL was infiltrated into the 9m cell in 1991. It flowed down vertical fractures in the aquitard connecting to thin horizontal sand beds. The DNAPL flowed laterally in these sand beds beneath the sheet piling to the two areas beyond the 9m cell where the augering occurred in 1991-1994 (Morrison, 1998). PCE comprises essentially all of the contaminant mass in the aquifer at locations near the 9m cell, however, further down-gradient TCE appears, although PCE continues to be dominant. Near the stream, the PCE and TCE concentrations are much lower and the TCE/PCE ratio is much larger. The occurrence of TCE is attributed to reductive dechlorination. Only minimal amounts of c-DCE and VC were found. Figure 3 shows vertical profiles of PCE at two locations on Transect 1 where maximum PCE values occur. These profiles indicate that the PCE concentrations declined at nearly all depths from 1998 through 2000. The high PCE concentration zones are very small and therefore, closely spaced sampling, both vertically and laterally , was necessary to locate them. These small zones account for nearly all of the PCE mass flux.

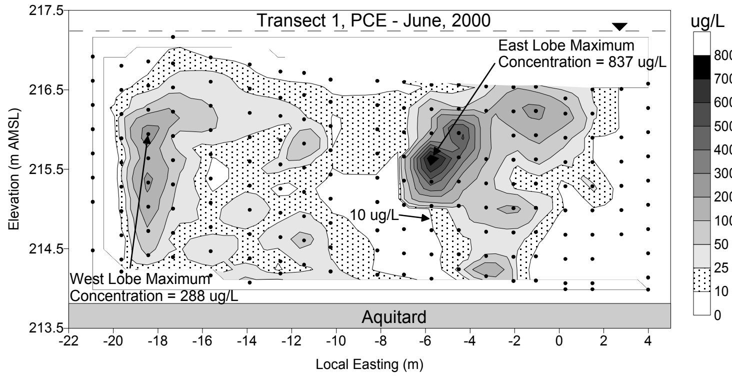

Figure 2: PCE concentration contours in Transect 1 for the year 2000

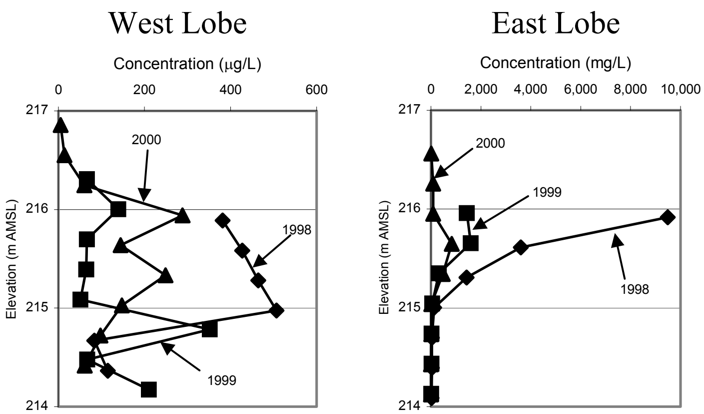

Figure 3: PCE Profiles (1998-2000) For Both Lobes for Transect 1 Showing Decrease With Time

Summary of Conclusions

The contaminant mass in the source zones causing the plume likely occurs as residual PCE DNAPL distributed as small globules. These globules are spaced sufficiently apart in the porous medium so that the plume caused by groundwater flow through the source zones has maximum concentrations far below PCE solubility (<0.25%) almost everywhere. Yet, the globules have provided sufficient mass for the source zones to persist since 1991-1994, when augering raised DNAPL from the aquitard up into the aquifer. Although considerable sampling was done in the two source zones in the aquifer, it was not possible to directly measure the DNAPL mass. Calculations based on the groundwater flow and the PCE distribution along the monitoring transect just down-gradient of the cell indicate that the integrated PCE flux, expressed as g/yr, was 151 in 1998, 75 in 1999, and 46 in 2000. This large decline suggests that very little mass remains in the source zone. Based on a mass decline projection, the source mass is expected to disappear within several years due to continued mass removal by natural groundwater flow. Once the source zone is removed, the plume is expected to be completely flushed out of the system within a few years. Thus, the augering will have caused aquifer contamination that lasted for nearly two decades. The plume occurrence could have been avoided if direct push or rotosonic drilling had been used to core the aquitard, but equipment for such drilling was rare in the early 1990s, and the risk posed by augering was not recognized.

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