

EXECUTIVE SUMMARY

A comprehensive, field-scale evaluation of in-situ cosolvent flushing for enhanced remediation of NAPL-contaminated aquifers was performed at a field site at Hill AFB, Utah. The experiment was conducted in a hydraulically-isolated test cell (about 4.3 m x 3.5 m) constructed in a surficial sand-gravel-cobble aquifer, underlain by a deep clay confining unit. This surficial aquifer was contaminated with a multi-component NAPL as a result of jet fuel and chlorinated solvents disposal during the 50's and 60's.

Analysis of soil cores taken from the test cell prior to cosolvent flushing indicated the following: (1) the NAPL was located in a 1.5-meter smear zone immediately above the clay confining unit; (2) the largest amounts of NAPL were near the water-table position prior to test cell installation (5.8 m BGS); and (3) NAPL penetrated about 0.5 m into the confining unit via sand stringers near the aquifer-aquitard interface. Soil core analysis was also used to estimate NAPL saturation within the test of 1.6 to 3.8%. A series of non-reactive and reactive tracer tests were conducted to characterize hydrodynamic properties and NAPL distribution. A non-reactive tracer test was first conducted to characterize the hydrodynamic characteristics of the saturated zone within the test cell; these data were used to guide the design of other tests in the cell. Results from this test showed a highly variable flow velocity distribution within the test cell. The first field test of inter-well partitioning tracers (IWPT) was conducted as an alternative to the traditional intrusive techniques (i.e. soil coring) to quantify both the residual NAPL volume and distribution within the test cell. Data from the IWPT test estimated an average NAPL saturation of 4.6 to 5.4 % (\approx 250 L). The IWPT test data indicated that the NAPL saturation was highly variable within the test cell and increased with depth and from the eastern end (EW-1 side) to the western end (EW-3 side) of the cell.

The in-situ cosolvent flushing technique provides accelerated site clean up due to enhanced solubilization or mobilization of NAPL, and enhanced desorption of sorbed contaminants. The field-scale cosolvent flushing test consisted of pumping about 40,000 L (approx. nine pore volumes) of a ternary cosolvent mixture (70% ethanol, 12% *n*-pentanol, and 18% water) through the test cell over a period of 10 days, followed by flushing with water for another 20 days. Behavior of the cosolvents and solubilized NAPL constituents during the cosolvent and subsequent water flood was monitored with aqueous samples from 3 extraction wells and 60 multi-level sampling points. Extraction well fluids with alcohol concentrations $>1\%$ were transported off Base for incineration while all other fluids were disposed through the industrial wastewater treatment plant at Hill AFB.

The NAPL removal effectiveness achieved by cosolvent flushing was assessed using the following data: (1) NAPL constituent mass removal, based on extraction and analysis of pre- and post-flushing soil core samples; (2) cumulative NAPL mass removed for several target contaminants, as determined from analysis of the fluids generated at the extraction wells; (3) NAPL constituent mass decreases, based on pre- and post-flushing analysis of groundwater samples for target analytes; and (4) NAPL constituent mass removal, based on analysis of pre- and post-flushing IWPT tests. The results obtained by these methods are consistent, indicating that on the average $>85\%$ mass of several target contaminants was removed as a result of the cosolvent flushing; NAPL removal effectiveness was greater (90-99%) in the upper 1-meter zone, in comparison to about 70-85% in the bottom 0.5-m zone near the clay confining unit.

At the end of the field study, $<1\%$ of the injected cosolvent volume remained in the test cell along with approximately 40 L (0.8% saturation) of NAPL based on post-flushing IWPT test results. It is suspected that the remaining cosolvent will easily biodegrade whereas the remaining NAPL mass behaves more like a pitch (high molecular weight components with very low aqueous solubilities).