EXECUTIVE SUMMARY

The purpose of this report is to document laboratory and field investigations of the use of surfactant/alcohol mixtures to solubilize a complex non-aqueous phase liquid (NAPL) as a single-phase microemulsion (SPME). The SPME study was divided into three separate phases: Laboratory Precursor Selection, Field Implementation, and Numerical Simulations. This report summarizes the results of these phases. Many of the details associated with each phase can be found in the attached appendices.

The first phase of this study was to select a surfactant and cosurfactant, which together form the microemulsion precursor, which would produce a low-viscosity, single-phase microemulsion on contact with the complex, multi-component NAPL found at the field site. Eighty-six surfactants and a number of alcohols were screened, with enhanced NAPL solubilization and low-viscosity (< 2 cp) as the main acceptance criteria. The viscosity of the precursor solution was limited to preclude large hydraulic gradients across the test cell and excessive drawdown around the extraction wells. The precursor solution selected was the surfactant Brij 97® (polyoxyethylene (10) oleyl ether) at 3% by weight and *n*-pentanol at 2.5% by weight in water. This mixture was evaluated in the laboratory in both column and two-dimensional aquifer models using contaminated and uncontaminated media from the field site at Hill AFB.

The second phase of this study was field implementation of the SPME flushing technology in a test cell constructed at Hill AFB Utah. Field testing of the SPME technology was part of larger a study coordinated by researchers at the USEPA National Risk management Laboratory in Ada, Oklahoma. The study was funded through the Strategic Environmental Research and Development Program (SERDP) to conduct side-by side testing of a total of nine technologies. Each test was conducted in isolation test cells using evaluation methods that provided consistency among the results. The final comparison of the effectiveness of each technology will follow completion of the studies.

The SPME flushing field study was conducted in a 2.8 m by 4.6 m test cell that isolated a section of the surficial aquifer by penetrating a thick clay aquitard at a depth of eight meters below ground surface. The flow through the test cell was a line drive with four injection wells and three extraction wells located on opposite sides of the test cell. The extent of contamination within the test cell was assessed by collecting soil samples during well installation and analyzing for a selected group of target analytes present in the NAPL. The test cell contamination was also characterized by conducting a 10-pore volume tracer test with a group of partitioning and non-partitioning tracers. The test cell had an average NAPL saturation of about 0.06 prior to SPME flushing. Water samples were also collected and analyzed for the target analytes, however, nearly all the contaminants were below detection limits. Finally, before the SPME flood, contamination in the test cell was characterized using interfacial tracers. The method estimates the contact area between NAPL and water in the test cell. The interfacial tracer method, developed at the University of Florida, was tested for the first time in the SPME test cell at Hill AFB. The result indicated that the NAPL-water contact area can vary more than one order of magnitude within the test cell. This variability in NAPL-water contact area could have significant impacts on in-situ flushing extraction efficiency. If there are mass transfer limitations that are magnified with low NAPL-water contact area this will reduce flushing efficiency, or if the NAPL is simply non-uniformly distributed, as evidenced by a low NAPL-water contact area, this can lead to inefficiencies.

The SPME flood was conducted over a 18-day period by pumping nine pore volumes of the precursor solution with some flow interruption periods. During this time, more than seven thousand samples were collected for target analyte quantification from the network of multilevel samplers and the three extraction wells. The results were used to quantify the mass removed during the flushing phase of the study for comparison with initial estimates based on both core samples and partitioning tracers. The use of multiple methods of evaluation provides a more comprehensive assessment of the technology and therefore better comparison with other technologies tested in the SERDP project. During the SPME flushing study, samples of effluent (combined from the three extraction wells) were collected for a laboratory investigation of methods to minimize and reduce cost of waste management. The use of salt to separate the waste into oil and water rich phases for more economic disposal was investigated at a small pilot scale.

Following the SPME flood, a post-flushing partitioning tracer test was conducted. The method and tracers used were the same as the pre-flushing test. The average NAPL saturation in the test cell following the SPME flood was 0.018, producing a NAPL reduction of about 72%. After the tracer test was completed, post-flushing core samples were collected. The core samples were compared to average values obtained during the pre-flush sampling to estimate mass removal for each target analyte. The mass removal based on core estimates ranged from 64 to 96%, but the three largest constituents present in the NAPL, *n*-undecane, *n*-decane, and 1,3,5 trimethlybenzene, were removed more than 90%.

The final method used to evaluate the SPME effectiveness was a mass balance on the target analytes. Using estimates of initial mass from the core data and partitioning tracers, the mass recoveries were calculated. Using the partitioning tracers to estimate initial mass, the mass removal estimates ranged from 62 o 82%. When the core data are used to estimate the initial mass only two constituents, *n*-decane and *n*-undecane, can be compared for removal effectiveness and the removals for these were 93 and 105%, respectively. Once again, an apparent difference in the effectiveness is seen between the results based on tracers and soil cores. A pitch fraction model of the NAPL is proposed as a likely explanation for the differences observed. The methods outlined above demonstrate that the SPME process was capable of affecting significant mass removal of the complex multi-component NAPL.

Simulations of the SPME flushing study were conducted following the experiment. In this effort both the tracer tests and the SPME flushing results were used. The simulator UTCHEM was used. The model was capable of simulating the processes observed in the experimental data. It was evident that the model required the use of a mass transfer term to capture the observed behavior. While the model simulation may have limited use in helping to design experiments conducted in a controlled test cell, they can be very important for designing hydraulically controlled systems. Of greater utility are simulations to assess cost and efficiencies of the SPME process at larger scales than the test cell.