EXECUTIVE SUMMARY

In 1996, a steam flood remediation of multicomponent NAPL was performed in a test cell located at Operable Unit 1, Hill AFB, Utah by Praxis Inc. The NAPL was composed of a heterogeneous mixture of weathered and degraded petroleum hydrocarbons, chlorinated solvents, and base/neutral and acid extractable compounds (BNAEs), with lower concentrations of polychlorinated biphenyls (PCBs), pesticides, dioxins, and furans. Prior to the remediation, a pre-flood partitioning interwell tracer test (PITT) was performed to estimate the amount of NAPL present and its distribution. Following the steam flood, a post-flood PITT was performed to assess the results of the remediation effort.

The methods of inverse modeling and first temporal moment analysis were used to interpret data from both the pre-flood and post-flood PITTs. Comparison of initial and final PITT recovery results were used to indicate the amount of NAPL removed by the steam flood and give some indication of the effectiveness of the technology. A complete discussion of the first moment analysis of the pre-flood tracer recovery data is presented in Appendix A. A report providing a full discussion of the inverse modeling calculations and results for the pre-flood PITT is found in Appendix B. Appendix C contains a complete discussion of the method of moments and the inverse modeling calculations applied to the post-flood tracer recovery data.

Field data were provided by Applied Research Associates, Inc. The first step in the data analysis process consisted of evaluating the available field data and selection of a pair of non-partitioning and partitioning tracers to use for NAPL volume and saturation estimation. For the pre- and post-flood PITTs, tracer response data of methanol and 2,2-dimethyl-3-pentanol were used for hydraulic conductivity and NAPL saturation distribution calculations.

Using the method of moments, pre-flood PITT data analysis indicated the following results:

- A tracer swept pore volume of 2,453 gallons.
- A NAPL volume of approximately 124 gallons in the tracer swept volume.
- A non-uniform distribution of NAPL with average NAPL saturation ranging from 1 to 8%.
- An average NAPL saturation over the tracer swept volume of 5%.

Using the method of inverse modeling, the following results from the pre-flood PITT data analysis were found to be in good agreement with the results from the method of moments:

- A tracer swept pore volume of 2,164 gallons.
- A NAPL volume of approximately 104 gallons in the pore space between the rows of the injection and extraction wells.

- A non-uniform distribution of NAPL with average NAPL saturation ranging from 0 to 10%.
- An average NAPL saturation over the tracer swept volume of approximately 5%.

The total NAPL volume of 124 gallons from the method of first moment analysis represents the NAPL volume in the saturated zone of the entire test cell. The total NAPL volume of 104 gallons from the method of inverse modeling represents the NAPL volume in the pore space of the simulation domain. The irregularly shaped boundary of the test cell (see Figure 2) results in a simulation grid that only represents the rectangular portion of the test cell between the rows of the injection and extraction wells. Therefore, the 104 gallons of NAPL predicted from inverse modeling represents the NAPL volume in the pore space between the rows of the injection and extraction wells, and not the NAPL volume in the groundwater saturated zone of the entire test cell, predicted by the method of moments.

The results of inverse modeling indicate that the NAPL is non-uniformly distributed in the test cell ranging from 0 to 10% in saturation. The average NAPL saturation is higher in the intermediate layers of the test cell (5.3%-5.7%) compared to the top (4.2%) and bottom (4.1%) layers of the test cell. This kind of variation is also consistent with the results from the method of first moment analysis.

Using the method of moments, post-flood PITT data analysis produced the following results:

- A tracer swept pore volume of 1,960 gallons.
- A NAPL volume of approximately 121 gallons in the tracer swept volume.
- A non-uniform distribution of NAPL in the swept volume with average NAPL saturation ranging from 3.1 to 12.2%.
- An average NAPL saturation over the entire tracer swept volume of approximately 6.2%.

Using the method of inverse modeling, post-flood PITT data analysis produced the following results:

- A tracer swept pore volume of approximately 1,777 gallons.
- A NAPL volume of approximately 132 gallons in the tracer swept volume.
- A non-uniform distribution of NAPL in the swept volume with average NAPL saturation of up to 13%.
- An average NAPL saturation in the tracer swept volume of approximately 7.4 %

In this case, the inverse modeling gives a slightly higher value than that of the method of first moment analysis. Nonetheless, the two results differ only by 10%. The possible reason for this difference is the fact that the matches of the tracer response curves between the actual data and model predictions in some of the extraction wells and monitor points are not very good. Therefore, the NAPL volume estimate from the inverse modeling in this particular case are less reliable compared to the results from the method of first moment analysis, but the inverse modeling provides valuable additional information on the distribution of the NAPL and it also yields an estimate of the variations of the hydraulic conductivity within the test cell.

Since the post-steam tracer partition coefficients were not measured, the partition coefficients used in the post-steam PITT calculations were assumed to be identical to the partition coefficients used in the pre-steam PITT calculation. Thus, the results of the post-steam PITT calculations are uncertain.

The steam would be expected to distill some of the lighter compounds of the NAPL. Some condensation of these volatile components would be expected to occur after displacement to colder regions of the cell. This would result in a heavier NAPL behind the steam front and a lighter NAPL ahead of the steam front. Unfortunately, no information whatsoever is available on the final composition of the NAPL or the tracer partition coefficients for this post-steam PITT. These partition coefficients could have been measured in the laboratory using post-steam cores as recommended by us before the test. Because we do not have these data a quantitative performance assessment is not possible.

The tracer partition coefficients would be expected to decrease after steam distillation and removal of the lighter components of the NAPL. However, if smaller partition coefficients were used to explain the measured retardation factors, this would result in a larger volume of NAPL measured in the second PITT than what was measured during the first PITT. Therefore, it seems likely that the NAPL was redistributed spatially by the steam without significant mass removal.