EXECUTIVE SUMMARY

This Dense Nonaqueous Phase Liquid (DNAPL) Source Delineation Project Final Report presents the results of four large-scale partitioning interwell tracer tests (PITTs) conducted at Operable Unit (OU) 2, Hill Air Force Base (AFB), Utah. This project represents the first full-scale field application of PITT technology to characterize the volume and extent of DNAPL in a shallow alluvial aquifer.

The disposal of chlorinated degreasing solvents in trenches at Hill AFB during the period 1967 to 1975 resulted in contamination of local groundwater. While current remedial operations at OU2 are controlling the off-site migration of contaminants from OU2, the site itself still contains large quantities of solvents that have accumulated as free-phase and residual DNAPL in an alluvial aquifer approximately 40 to 50 feet below ground surface. This DNAPL continues to act as the source of the dissolved-phase contamination. The DNAPL itself was determined to be primarily trichloroethene (approximately 60 percent), other chlorinated degreasing solvents (approximately 15 percent), and oil and grease (approximately 25 percent). A slurry wall constructed in 1996 to contain the DNAPL zone and prevent further off-site migration of dissolved-phase contamination left a significant volume of DNAPL outside the slurry wall. This result was due to the incomplete knowledge of the spatial distribution of DNAPL and served to emphasize the necessity of detailed characterization of DNAPL zones prior to remediation. Therefore, the primary objective of the DNAPL Source Delineation Project was to use partitioning-tracer testing to characterize the portion of the DNAPL-contaminated aquifer encompassed by the slurry wall. A secondary objective was to complete a preliminary characterization of that part of the DNAPL source zone outside the slurry wall by more traditional methods.

Designing and implementing a successful PITT required the development of a conceptual model of the DNAPL zone, referred to as the "geosystem." The geosystem is comprised of the geologic media, groundwater, DNAPL, and the clay formation underlying the DNAPL. Samples of DNAPL from OU2 provided important information on the physical-chemical properties of this immiscible liquid with respect to its original migration, trapping, and potential for remobilization during remediation. The complete geosystem constitutes the essential information for the design of a successful DNAPL remediation, operation irrespective of the technology employed. This information was incorporated into a multiphase, multicomponent model, referred to as a geosystem model.

The DNAPL Source Delineation Project was completed in five phases as follows:

- Phase I—Geosystem Characterization Activities
- Phase II—Geosystem Modeling and PITT Well-Field Design
- Phase III—PITT Well-Field Installation
- Phase IV—PITT Modeling and Design
- Phase V—Water Flood and PITT Implementation.

Phase I of this project involved the characterization of the paleochannel, and the alluvial aquifer contained within it, to the north and south of the previously-known source area. This phase was conducted using a number of investigation techniques, including ground-penetrating radar (GPR), cone penetrometer testing (CPT), and hollow-stem auger drilling and coring. During this process, additional free-phase DNAPL was discovered in the alluvium within the area encompassed by the containment wall, and outside and to the north of the containment wall. The pool of DNAPL outside of the containment wall was informally designated the Griffith Pool and is estimated to contain over 1,000 gallons of DNAPL. The first phase of the project culminated in the completion of a map of the paleochannel topography, that is, the surface of the clay of the Alpine Formation upon which is deposited the Provo Alluvium that contains the DNAPL contamination.

Phase II of the project involved the design of the PITT well fields. This design used an innovative and relatively inexpensive approach to conducting PITTs over large distances, referred to as the divergent-flow line-drive well pattern. This pattern uses a line-drive geometry for the well field in which a line of injection wells is positioned in the center of the well field and is flanked by two lines of extraction wells at opposite ends of the well field. Thus, the injection of the tracers results in the tracers flowing simultaneously in opposite directions towards the two lines of extraction wells. This innovation permits a particular volume of aquifer to be tested by partitioning tracers in half the time that would be required if the tracers were injected at one end of the well field and extracted at the other. This approach is now being used at other federal facilities undergoing partitioning-tracer testing and remediation.

Phase III involved the installation of 20 new injection and extraction wells and 5 new monitoring wells in the four arrays in which a PITT would be conducted. The new injection and extraction wells were 4-inches in diameter; the five monitor wells were 2-inches in diameter. These new wells, in addition to 13 existing wells, comprised the four well arrays used during the PITTs. The new wells, and the alluvial-sediment cores collected during their installation, were tested to determine the hydraulic properties of the aquifer. A conservative interwell tracer test (CITT) was conducted in each well array to provide design data for the PITTs, in particular, information on aquifer heterogeneities, swept pore volumes, and how each flow system responds to injection and extraction. Each CITT would mobilize and remove free-phase DNAPL remaining in the aquifer, thus improving the accuracy of the subsequent PITTs.

Cores from the newly completed wells were used in laboratory experiments to determine (1) appropriate partitioning tracers for use in the PITTs, (2) point estimates of DNAPL saturation using the NAPLANAL program, and (3) the potential for mobilization of DNAPL by capillary desaturation. These latter experiments indicated that the DNAPL appears be wetting some fraction of the alluvium such that the mobilization of residual DNAPL during waterflooding and the tracer tests would be unlikely. Additionally, the mixed-wet condition of the aquifer sediments indicates that whatever remediation technology is used in such sites would require changing the wettability to water-wet conditions as occurs during surfactant-enhanced aquifer remediation.

Information from the field and laboratory studies was incorporated into a revised geosystem model using the UTCHEM simulator (Phase IV). This revised model, incorporating hydraulic information obtained from the CITT, was then used to design PITTs for each well array.

The PITTs were conducted as Phase V of the project from June through November 1998. The completion of the four PITTs, encompassing a total swept pore volume of approximately 285,000 gallons in four different well patterns, was made possible only by the use of innovative and portable process technology. An electronic control system monitored and supervised the injection and extraction of fluids in the well array and controlled sampling from various monitoring locations. The system also logged and stored all system parameters, such as injection and extraction rates, the specific electrical conductivity of the effluent, and the various water pressures in the well array. Flow rates for each injection and extraction well were controlled by an automated flow-control system contained in a mobile trailer.

The production of the tracers at the extraction well arrays yielded tracer response curves, which were analyzed to determine the spatial distribution and total volume of DNAPL in the aquifer. The results are summarized in Table ES-1.

TABLE ES-1
Summary of PITT Results

Well Array	Tracer Recovery (%)	Swept Pore Volume (gal)	Average DNAPL Saturation (%)	Volume of DNAPL (gallons)	Relative Error (%)
1	101	53,150	0.59 ± 0.012	314 ± 61	19
2	103	64,500	1.0 ± 0.011	661 ± 71	11
3	109	81,200	0.10 ± 0.05	78 ± 43	55
4	91	86,000	0.09 ± 0.05	80 ±40	50
Total	**-**	**284,850**	**0.40 ± 0.08**	**1,130 ± 219**	**19**

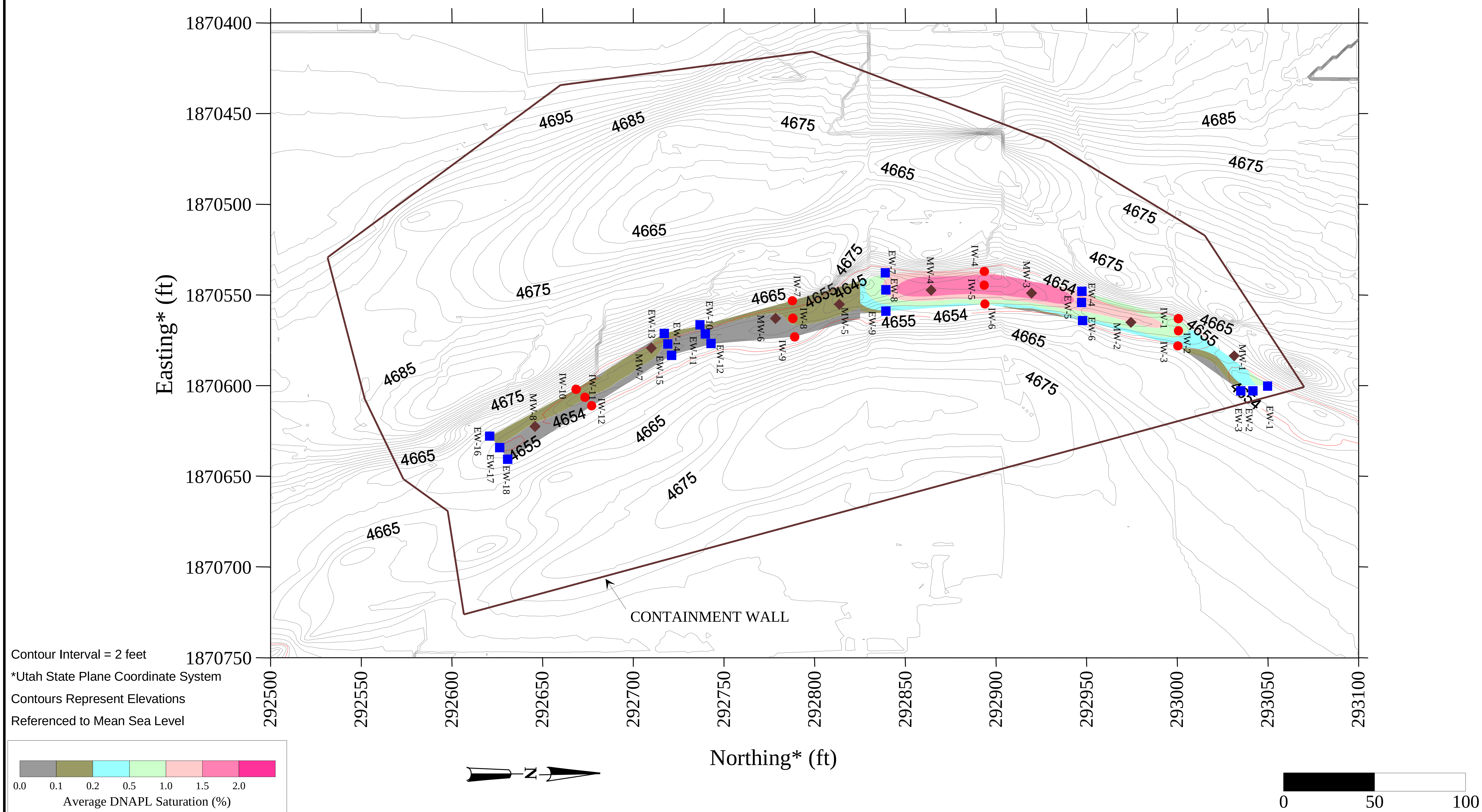
Notes:

DNAPL = Dense Nonaqueous Phase Liquid

These values indicate that the majority of the remaining DNAPL in place is in the northern end of the aquifer in well arrays 1 and 2, which constitute the deepest part of the paleochannel. A visual representation of the average DNAPL saturation distributed throughout the swept volume is presented in Figure ES-1. The plot also shows the surface of the Alpine Formation and the containment wall encompassing most of the source zone. The average DNAPL saturation, within the portion of the swept pore volume that is contaminated by DNAPL (i.e., below an elevation of 4,654 feet above mean sea level) is estimated to be 2 percent, with a range from 11 percent at the north end of the source zone to less than 0.4 percent in the southern portion.

Adding the results of the PITTs to the amount of DNAPL previously recovered from the source zone provides a new estimate of approximately 45,860 gallons of DNAPL originally residing within the area encompassed by the containment wall. An estimate of the DNAPL volume residing outside of the containment wall will be obtained from a PITT to be conducted there in spring 1999.

This project has demonstrated that it is practicable to determine the spatial distribution and volume of DNAPL in heterogeneous alluvium using partitioning tracers. As was also shown during a surfactant-enhanced aquifer remediation demonstration in well array 3 in 1997, partitioning tracers can measure the volume of DNAPL in a low-permeability sand unit situated immediately beneath an uncontaminated high-permeability sand. Thus, the PITT has proven itself to be a particularly reliable method for DNAPL source zone characterization even in the most heterogeneous alluvial environments.



HILL AIR FORCE BASE, UTAH

OU2
DNAPL Source Delineation
Project

Contour Plot of the Average DNAPL Saturation Within the Containment Area

Figure ES-1

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