RCRA FACILITY INVESTIGATION REPORT
VAPOR MIGRATION MODELING VALIDATION STUDY AND VOC SURFACE FLUX AND AMBIENT AIR MONITORING AT THE FORMER LIQUID OXYGEN PLANT SITE

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LIST OF ABBREVIATIONS

1,1-DCE	1,1-dichloroethene
AOC	Area of Concern
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
B515	Building 515
Boeing	The Boeing Company
bgs	below ground surface
Cal-EPA	California Environmental Protection Agency
cDCE	cis-1,2-dichloroethene
cm/s	centimeters per second
CPS	counts per second
CTL	Component Test Laboratory
DOE	United States Department of Energy
DTSC	Department of Toxic Substances Control
FSDF	Former Sodium Disposal Facility
g/cc	grams per cubic centimeter
H&A	Haley & Aldrich
IPA	isopropyl alcohol
J	estimated value
LOX	Liquid Oxygen
NASA	National Aeronautics and Space Administration
PCE	tetrachloroethene
pcf	pounds per cubic foot
ppt	parts per trillion
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RL	Reporting Limit
SRAM	Standardized Risk Assessment Methodology
SSFL	Santa Susana Field Laboratory
SWMU	Solid Waste Management Unit
TCE	trichloroethene
tDCE	trans-1,2-dichloroethene
VOC	volatile organic compound
µg/L	micrograms per liter
µg/kg	micrograms per kilogram
$\mu g/m^3$	micrograms per cubic meter
$\mu g/m^2/min$	micrograms per meter square per minute

1.0 INTRODUCTION

The report describes the collection of air, vapor flux, soil vapor, soil matrix and groundwater data primarily for select volatile organic compounds (VOCs) that will be used in refining and validating vapor migration models that are part of the human health and ecological risk assessment of impacted environmental media at the Santa Susana Field Laboratory (SSFL). The SSFL is jointly owned by The Boeing Company (Boeing) and the federal government (administered by the National Aeronautics and Space Administration [NASA]) and is operated by Boeing. A portion of the SSFL that is owned by Boeing was leased to the U.S. Department of Energy (DOE). The SSFL is located in the southeast corner of Ventura County, 29 miles northwest of downtown Los Angeles, California. The location of the SSFL and its surrounding vicinity is shown on Figure 1.

This report has been prepared for Boeing, NASA, and the DOE as part of the Resource Conservation and Recovery Act (RCRA) corrective action program being conducted at the SSFL. The investigation and cleanup of RCRA Facility Investigation (RFI) sites at the SSFL are conducted under the jurisdiction of the California Environmental Protection Agency (Cal-EPA), Department of Toxic Substances Control (DTSC). The SSFL RFI program is currently in the data evaluation, risk assessment, and reporting phases.

The sampling program conducted in support of the vapor migration model validation study was performed in accordance with DTSC-approved work plans (MWH 2005a and 2006). Based on DTSC's review and comments on previous surficial media chemistry data, a separate work plan was prepared to collect additional VOC vapor and ambient air samples at the Former Liquid Oxygen Plant (LOX) site. The LOX sampling program was focused on further characterizing VOC sources and was conducted in accordance with DTSC-approved work plans (MWH 2005a). The LOX sampling program was conducted concurrently with the model validation sampling program to ensure consistency of data collection and optimization of field mobilization and sampling efforts.

A detailed discussion of vapor migration modeling methodology was included in Appendix G of the *Standardized Risk Assessment Methodology (SRAM) Work Plan – Revision 2* (MWH 2005b). Cleanup decisions for individual Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs) will be based in part on the results of the risk assessment, which includes the use of validated vapor migration models.

2.0 BACKGROUND INFORMATION AND SAMPLING RESULTS - VALIDATION STUDY FOR VAPOR MIGRATION MODEL

The vapor migration model validation study, which is summarized in the following sections, was described in detail in the *RCRA Facility Investigation, Vapor Migration Modeling Validation Study Work Plan* (MWH 2005a) and *Santa Susana Field Laboratory, Vapor Migration Modeling Validation Study Work Plan Amendment* (MWH 2006). Based on the conceptual site model proposed for human health and ecological exposures at the SSFL and historical trichloroethene (TCE) data, the validation study focused on areas across the SSFL reflecting a broad range of subsurface conditions that are considered representative of those present throughout the SSFL. Sample locations were selected for this study based on an assessment of TCE impacts, as TCE is the chemical most widely detected and is found at the highest concentrations in soil and groundwater at the SSFL. The chemical, physical and toxicological properties of TCE are sufficiently representative of other VOCs present at the SSFL such that TCE can be used as the surrogate compound for the vapor migration model validation study.

The vapor migration model will use TCE data collected from soil borings, soil vapor probes, near-surface groundwater, and Chatsworth formation groundwater. The data generated from this program will allow for an evaluation of TCE in various environmental media and its relationship to surface vapor flux. Furthermore, chemical data and physical property measurements of soil will be used to evaluate and refine critical model inputs and assess the performance of the identified vapor migration models. Sample locations were based in part on the presence of TCE and its associated daughter products in near-surface and/or Chatsworth formation groundwater[1].

Prior to implementing the sampling associated with the validation study, surface vapor fluxes were estimated using the model to represent a range in both depth to groundwater

[1] The near-surface groundwater underlying the SSFL has been defined as groundwater that occurs in alluvial or colluvial deposits and/or weathered bedrock. The Chatsworth formation groundwater has been defined as the saturated portions of the unweathered bedrock underlying the site. Near-surface groundwater can be separated from Chatsworth formation groundwater by a vadose zone (i.e., perched) or the groundwater between these media can be vertically continuous, depending upon the location at the SSFL and other factors such as temporal and spatial variability in recharge.

and the dissolved TCE concentration. The model-predicted surface vapor fluxes were used in conjunction with other criteria to select representative sampling locations, which are shown on Figure 2. The model was used to predict locations where the combination of both depth to groundwater and dissolved TCE concentrations were sufficient to produce emissions at the ground surface that would be greater than the laboratory reporting limit (RL). The model predicted that TCE should be able to be detected above the RL within the following range of conditions:

- Where the depth to groundwater is approximately 20 feet below ground surface (bgs) and dissolved TCE concentrations are greater than approximately 50 micrograms per liter (µg/L)
- Where the depth to groundwater is greater than 100 feet bgs and dissolved TCE concentrations in groundwater are greater than 1,000 µg/L

Based on these preliminary modeling results, areas with a shallow depth to groundwater and high dissolved TCE concentrations were selected for the validation study to maximize the potential for detecting TCE in soil vapor and at the ground surface. Sample locations were also selected based on the presence of exposed soil or bedrock (i.e., areas not covered by asphalt, gunite, concrete or other engineered structures).

The areas selected for the validation study were divided into three groups: source areas, groundwater plume areas (i.e., also referred to as distal areas), and control areas (Figure 2). Control areas are locations where no subsurface sources of VOCs have been identified and surface flux measurements were expected to be representative of ambient or background conditions.

Within these three general areas, the RFI sites were further segregated based on the presence or absence of soil cover and near-surface groundwater. Ten sampling locations were selected for this validation study with four sampling locations each in the source and distal areas, and two additional sampling locations in control areas (i.e., areas that were believed to be unimpacted by TCE and other VOCs). These areas included:

- Two locations at VOC source areas with near-surface groundwater: one at the Compound A RFI site in the central portion of the SSFL and the other at the Former Sodium Disposal Facility (FSDF) RFI site[2] in the western SSFL

- Two locations at VOC source areas without near-surface groundwater: the Delta RFI site (southwestern SSFL), and the Component Test Laboratory III (CTL-III) RFI site (southeastern SSFL)

- Two locations above near-surface groundwater plumes (i.e., distal areas above groundwater containing dissolved TCE and where no measured or known VOC source is present): at the northern end of the CTL-III RFI site in the southeastern SSFL, and near the Building 515 area in the northern SSFL (Figure 2)

- Two locations above Chatsworth formation groundwater plumes: the B-1 RFI site in the northeastern SSFL, and the LOX RFI site in the northern portion of the SSFL

- A northern control area (near well RD-92) and a southern control area (near well RD-05A) on undeveloped portions of the SSFL (i.e., areas where no solvent use is known or suspected to have occurred)

Samples were collected and analyzed for TCE and at times five other chlorinated ethenes[3] that included tetrachloroethene (PCE), cis-1,2-dichloroethene (cDCE), trans-1,2-dichloroethene (tDCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride at the ground surface in a flux-chamber and in the subsurface. At sites where the soil thickness was greater than 3.5 feet, surface vapor flux, soil vapor, and soil matrix samples were co-located within about 20 feet of an existing groundwater monitoring well. Whenever possible, surface vapor flux and soil vapor/soil matrix data were collected within a few days of each other. Groundwater data were collected from most of the targeted wells during the quarterly monitoring event closest to the validation sampling dates. Details regarding sampling protocols and laboratory analyses were described in approved work plans (MWH 2005a, 2005b, 2006).

The specific sampling that was performed at each of the ten areas is provided in Table 1. All sample locations are shown on Figure 2. Surface vapor flux samples were collected

[2] It is worth noting that the FSDF was the site of an interim removal action that resulted in excavation of all soil and the upper portion of weathered bedrock. The excavated area was subsequently backfilled with clean soil. The sample location is near the center of the excavated area.
[3] The term "chlorinated ethenes" used throughout the remainder of this report refers to the six chemicals noted in the above paragraph.

by C.E. Schmidt with support from MWH. Data sheets from the surface vapor flux sampling events are provided in Appendix A. Soil vapor probes were installed by HydroGeoSpectrum at the direction of MWH. Leak tests were performed on the soil vapor probes during sampling by placing a cloth that was nearly saturated with a solution containing 70 percent isopropyl alcohol (IPA) over the sampling tubes emerging from the head of the probe(s) at the ground surface. Samples were analyzed for IPA to assess the quality of the sampling system. Although IPA was detected in a number of the soil vapor samples at the ten validation study sites, the concentrations of IPA were all below the threshold of 10 µg/L (or 10,000 micrograms per cubic meter [$\mu g/m^3$]). A memorandum summarizing the results of the leak testing with IPA during the July 2006 sampling event is provided in Appendix B. Soil borings were installed by BL Hall, also at the direction of MWH. Boring logs collected during installation of the soil borings are provided in Appendix C. Groundwater samples were collected by Haley & Aldrich (H&A) and the majority of the results are presented in the *Report on Quarterly Groundwater Monitoring, Third Quarter 2006, July Through September 2006, Santa Susana Field Laboratory* (H&A 2006b). Results of samples that could not be collected during the third quarter 2006 were obtained from prior quarterly or annual groundwater monitoring reports (H&A, 2006a and 2005). Data validation reports of the analytical laboratory results of surface vapor flux, soil vapor, and soil matrix samples, prepared by chemists from MEC^x, are provided in Appendix D. Neutron logs were collected by Colog, a division of the Layne Christensen Company, at the direction of MWH, from monitoring wells at the vapor validation study sites to assess water content in the vadose zone and the position of the saturated zone. The neutron logs are provided in Appendix E. The following sections describe the locations sampled and results[4] of the data that were collected.

2.1 TCE SOURCE AREAS

TCE source area sample locations were sited in areas containing TCE in the vadose zone and/or high dissolved TCE concentrations in near-surface groundwater or Chatsworth formation groundwater.

[4] The results presented in the text of this report are all primary sample results. Results of split or duplicate samples are presented in the tables that accompany the text.

2.1.1 Sample Locations with Near-Surface Groundwater

Near-surface groundwater is present in limited areas of the SSFL and is typically associated with alluvial drainages and the broad alluvial valley located in the western part of the SSFL (MWH 2003). Two source area sampling sites were located in areas containing TCE in near-surface groundwater at concentrations greater than 1,000 µg/L. The Compound A RFI site is located in the central portion of the SSFL and the FSDF RFI site is located in the western portion of the SSFL (see Figure 2). TCE sampling results for these two sites and the other eight validation study sites are presented in vertical profile on Figure 3. This figure also presents the results of the neutron logging of the groundwater monitoring wells.

Compound A

The thickness of soil at the Compound A sample location is less than one foot, hence soil vapor and soil matrix samples were not collected. In the vicinity of near-surface groundwater monitoring well ES-24, VOC concentrations in soil vapor were previously reported at less than 50,000 µg/m^3.[5] Surface vapor flux samples were collected on July 18, 2006 from two locations adjacent to near-surface groundwater monitoring well ES-24 and both locations were resampled on July 21, 2006. Analytical results are presented on Table 2. At location CFVF01, TCE concentrations ranged from 0.17 µg/m^3 to 0.46 (J [estimated value]) µg/m^3, which equates to a surface vapor flux ranging from 0.0064 micrograms per meter squared per minute[6] (µg/m^2/minute, see Table 2 for sample results) to 0.018 (J) µg/m^2/minute. At location CFVF02, TCE concentrations ranged from 0.33 µg/m^3 to 0.41 µg/m^3, which equates to a surface vapor flux ranging from 0.013 µg/m^2/minute to 0.016 µg/m^2/minute.

[5] Vapor sampling results presented in this report are given in units of micrograms per cubic meter (µg/m^3) to be consistent with results reported by the analytical laboratory. Vapor sampling results are also frequently reported in units of micrograms per liter (µg/L). Units of µg/m^3 can be converted to units of µg/L by dividing by 1,000.

[6] Vapor flux sample results are reported by the analytical laboratory in units of µg/m^3. Vapor flux samples are collected at a prescribed rate (sweep air flow rate (Q) of 5.0 liters per minute or 0.005 cubic meters per minute) for a specified period of time (30 minutes (t)) resulting in a volume. Furthermore, the flux chamber covers an area (A) of 0.13 square meters of the ground surface. This allows then, for a flux (F) to be calculated by taking the concentration of a chemical (C) reported by the laboratory in µg/m^3 and multiplying by the sweep air flow rate and dividing by the area of the ground surface covered by the flux chamber (F=Q*C/t, or 0.039*C).

The dissolved TCE concentration in a near-surface groundwater sample collected from ES-24 on August 30, 2006 was 5,700 µg/L. Other chlorinated ethenes were also detected in this sample as reported on Table 2. The depth to groundwater in ES-24 was measured on August 1, 2006 and was encountered at a depth of 20.30 feet bgs (H&A 2006). A neutron log was collected from ES-24 on August 3, 2006 and the log shows a sharp drop in the counts per second (CPS) from about 1450 CPS at about 18.5 feet bgs that continues to about 400 CPS at 20 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

FSDF

One surface vapor flux sample was collected July 18, 2006 in an area adjacent to the near-surface groundwater monitoring well RS-54 and a second sample was collected on July 21, 2006. Analytical laboratory results are shown on Table 3. At location FSVF01, TCE concentrations ranged from 0.17 µg/m^3 to 0.63 (J) µg/m^3, equating to a surface vapor flux for TCE that ranged from 0.0066 µg/m^2/minute to 0.024 µg/m^2/minute. One soil vapor probe and one soil boring were installed adjacent to the surface vapor flux sample location and well RS-54 (see Figure 2). Soil vapor samples were collected at depths of 4 feet and 7 feet bgs from soil vapor probe FSSV03 on July 27, 2006 and analyzed for chlorinated ethenes (Table 3). A duplicate sample was also collected from the soil vapor probe at the 7-foot depth. The TCE concentration in the samples from 4 feet and 7 feet bgs were about 211 (J) and 12,000 (J) µg/m^3, respectively. Concentrations of the other chlorinated ethenes for the FSSV03 sample location are also presented on Table 3. Two soil samples from soil boring FSBS01 were collected on July 27, 2006 and analyzed for TCE and physical properties[7] (Table 3). TCE concentrations in the soil matrix samples collected from the soil boring ranged from non-detect at 5 feet bgs to 18 micrograms per kilogram (µg/kg) at 8 feet bgs.

[7] Physical property measurements that were made on soil samples collected for this and the LOX studies included soil moisture, bulk density, specific gravity, porosity, percent saturation, and hydraulic conductivity. Further references in this report to physical property measurements include these six parameters.

The dissolved TCE concentration in a near-surface groundwater sample collected from RS-54 was 2,100 µg/L (February 23, 2006 sample event, see Table 3). More recent TCE analytical results are not available as the downhole sampling equipment was in need of repair and repairs were made early in 2007. Other chlorinated ethenes were also detected in this well as shown on Table 3. Depth to groundwater was measured on August 1, 2006 and was found to be approximately 17.5 feet bgs (H&A 2006). Near-surface groundwater is perched above the Chatsworth formation groundwater at this location as previously reported (MWH 2003). A neutron log was collected from RS-54 on August 3, 2006 and the log shows a sharp drop in the counts per second from about 3,450 CPS at about 18 feet bgs that continues to about 1,000 CPS at 20 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

2.1.2 Validation Sampling Locations without Near-Surface Groundwater

Two source area sampling sites were located in areas where near-surface groundwater is not typically present and where dissolved TCE concentrations in Chatsworth formation groundwater typically exceed 1,000 µg/L. One sampling location is near Chatsworth formation well HAR-07 at the Delta RFI site in the southwestern portion of the SSFL (Figure 2). The second sampling location is adjacent to Chatsworth formation well RD-46A at the CTL-III RFI site in the southeastern portion of the SSFL (Figure 2). These two locations were selected to represent source areas without near-surface groundwater and that provide a range in both depth to groundwater and the dissolved TCE concentration.

Delta RFI Site

The soil thickness near HAR-07 is less than two feet, hence soil vapor and soil matrix samples were not collected at this location. Historical soil vapor sample results from a sampling probe located approximately 10 feet south of HAR-07 and collected from a depth of 2 feet bgs showed TCE to be present at a concentration of 4,500 $\mu g/m^3$.

Surface vapor flux samples were collected on July 18, 2006 from two locations adjacent to HAR-07 (Figure 2) and these locations were resampled on July 21, 2006. Analytical laboratory results are presented on Table 4. At location DAVF01, TCE concentrations ranged from 0.15 (J) µg/m^3 to 0.16 (J) µg/m^3, which equates to a surface vapor flux for TCE that ranges from 0.0045 (J) µg/m^2/minute to 0.0062 (J) µg/m^2/minute. At location DAVF02, the TCE concentrations ranged from non-detect at <0.15 µg/m^3 to 0.23 (J) µg/m^3, which equates to a surface vapor flux for TCE of 0.0089 (J) µg/m^2/minute.

The dissolved TCE concentration in a groundwater sample collected from HAR-07 on August 15, 2006 was 6,700 µg/L. Other chlorinated ethenes were also detected and the data are provided on Table 4. The depth to groundwater in HAR-07 was measured on August 2, 2006 and was encountered at a depth of 47.54 feet bgs (H&A 2006). A neutron log was collected from HAR-07 on August 3, 2006 and the log shows a sharp drop in the counts per second from about 3,750 CPS at about 47 feet bgs that continues to about 800 CPS at 48 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

CTL-III RFI Site

Soil thickness near RD-46A at CTL-III is approximately 17 feet. Historical soil vapor samples collected in the vicinity of RD-46A from a depth of 13 feet bgs contained TCE concentrations of 2,000,000 µg/m^3. Concentrations of this magnitude are likely indicative of a source within vadose zone soils.

One surface vapor flux sample (CLVF03) was collected on July 17, 2006 from a location adjacent to RD-46A and a second sample was collected from this location on July 20, 2006 (see Figure 2). Analytical laboratory results are presented on Table 5. TCE concentrations ranged from 116 (J) µg/m^3 to 123 (J) µg/m^3, which corresponds to a TCE surface vapor flux of 4.5 (J) µg/m^2/minute to 4.8 (J) µg/m^2/minute.

In addition, one soil vapor probe and one soil boring were installed near the surface vapor flux sample location and monitoring well RD-46A (Figure 2). Three soil vapor samples

were collected from soil vapor probe CLSV89 on July 27, 2006 and analyzed for chlorinated ethenes (Table 5). TCE concentrations in the three soil vapor samples ranged from 552 (J) µg/m^3 at 5 feet bgs to 1.5x10^6 µg/m^3 at 10 feet bgs to 8.6x10^5 (J) µg/m^3 at 15 feet bgs. None of the other chlorinated ethenes were detected in the three soil vapor samples, however the detection limits were elevated due to the high concentrations of TCE detected. Three soil matrix samples and one duplicate sample were collected from soil boring CLBS85 on July 27, 2006 and analyzed for TCE and physical properties (Table 5). The TCE concentration in CLBS85 increased from 6.2 µg/kg at 6 feet bgs to 500 µg/kg at 11 feet bgs and then declined slightly to 370 µg/kg at 15.5 feet bgs. Analysis of the duplicate sample from 16 feet bgs reported a TCE concentration of 26 µg/kg.

The dissolved TCE concentration in a groundwater sample collected from RD-46A on August 23, 2006 was 3,200 µg/L. Other chlorinated ethenes were also detected and the data are shown on Table 5. The depth to groundwater in RD-46A was measured on August 1, 2006 and was encountered at a depth of 66.21 feet bgs (H&A 2006). A neutron log was collected from RD-46A on July 18, 2006 and the log shows a sharp drop in the counts per second from about 1,700 CPS at about 64 feet bgs that continues to about 350 CPS at 66-feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

2.2 LOCATIONS ABOVE GROUNDWATER PLUMES (DISTAL AREAS)

These sampling locations were sited in areas where no TCE releases have been previously reported or known to have occurred and above locations where TCE is dissolved in either near-surface or Chatsworth formation groundwater.

2.2.1 Locations Above Near-Surface Groundwater TCE Plumes

Two locations were sited above groundwater plumes containing primarily TCE dissolved in near-surface groundwater. One of the validation sampling sites is located north of the CTL-III RFI site in the southeastern portion of the SSFL adjacent to near-surface

groundwater monitoring well ES-03 (Figure 2). The second site is located in an area of concern east of Building 515 (B515) in the northcentral portion of the SSFL adjacent to near-surface groundwater monitoring well ES-21 (see Figure 2).

Area North of CTL-III (ES-3)

The soil thickness is less than three feet in the area north of the CTL-III RFI site, hence soil vapor and soil matrix samples were not collected at this location. However, analytical results of soil vapor samples collected from probes located to the southwest of this sampling location were non-detect for TCE (< 1,000 $\mu g/m^3$).

Surface vapor flux samples were collected on July 17, 2006 from two locations adjacent to near-surface groundwater monitoring well ES-03 and these two locations were resampled on July 20, 2006. Analytical results are presented on Table 6. At sample location CLVF01, TCE concentrations ranged from non-detect (<0.15 $\mu g/m^3$) to 0.15 (J) $\mu g/m^3$, which equates to a TCE surface vapor flux of 0.0057 (J) $\mu g/m^2$/minute. At sample location CLVF02, TCE was not detected in either of the two samples.

Samples of near-surface groundwater were collected from ES-3 on August 28, 2006 and analyzed for VOCs. The TCE concentrations in ES-3 during this sampling event was 270 µg/L. The depth to groundwater in ES-3 was measured on July 31, 2006 and was encountered at a depth of 14.34 feet bgs (H&A 2006). A neutron log was collected from ES-3 on August 3, 2006 and the log shows a sharp drop in the counts per second from about 1,200 CPS at about 63 feet bgs that continues to about 300 CPS at 66.5 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

B515 Area

The soil thickness is approximately 20 feet in the area of the B515 sampling location. Soil vapor samples have been collected at several locations in this area and TCE has been measured at concentrations that range from non-detect (<1,000 $\mu g/m^3$) to 17,000 $\mu g/m^3$ at 12 feet bgs.

One surface vapor flux sample was collected July 18, 2006 from a location adjacent to the ES-21 well and this location was resampled on July 21, 2006. Analytical results are presented on Table 7. At sample location BTVF01, TCE concentrations ranged from non-detect (<0.16 $\mu g/m^3$) to 0.036 (J) $\mu g/m^3$, which corresponds to a TCE surface vapor of 0.0042 (J) $\mu g/m^2$/minute.

In addition, one soil vapor probe and one soil boring were installed near the surface vapor flux sample location and monitoring well ES-21 (Figure 2). Soil vapor samples were collected from soil vapor probe BTSV11 at depths of 5, 10, 15 and 20 feet bgs on July 26, 2006 and analyzed for chlorinate ethenes (Table 7). TCE concentrations in the soil vapor samples ranged from 62 $\mu g/m^3$ (J) at 15 feet bgs to 2.7×10^5 $\mu g/m^3$ at 5 feet bgs. PCE and cDCE were also detected in the soil vapor samples and the results are shown on Table 7. Four soil matrix samples were collected from soil boring BTBS02 at depths of 6, 11, 16 and 20 feet bgs on July 27, 2006. All four samples were analyzed for physical properties and the 6- and 11-foot samples were analyzed for TCE (Table 7). TCE was not detected in either sample (method detection limit of 0.31 µg/kg).

Samples of near-surface groundwater were collected from ES-21 on August 30, 2006 and analyzed for VOCs. The TCE concentrations in ES-21 during this sampling event was 210 µg/L. The depth to groundwater in ES-21 was measured on August 2, 2006 and was encountered at a depth of 14.65 feet bgs (H&A 2006). A neutron log was collected from ES-21 on August 3, 2006 and the log shows a sharp drop in the counts per second from about 1,650 CPS at about 13 feet bgs that continues to about 300 CPS at 14 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

2.2.2 Locations Above Chatsworth Formation Groundwater Plumes

Two sites were sampled where TCE is dissolved in Chatsworth formation groundwater. One of the sites is located near the B-1 RFI site near Chatsworth formation groundwater monitoring well RD-72 in the northeastern portion of the SSFL (Figure 2). The sampling site is located downgradient of a TCE source area. Detailed descriptions of the source area can be found in the *Report of Results, Phase I of Northeast Investigation Area*

Groundwater Characterization (MWH 2004). The second site, which is located west of the LOX RFI site, is adjacent to the Chatsworth formation groundwater monitoring well RD-52A in the northern portion of the SSFL (Figure 2). RD-52A is approximately 350 feet west of a TCE source area located at the LOX RFI site. Detailed descriptions of the source area can be found in the MWH 2005a Work Plan. These two locations were selected to represent areas where near-surface groundwater has not been encountered or measured and also provide a range of dissolved TCE concentrations and depths to Chatsworth formation groundwater. Soil thickness averages approximately one foot at both sampling locations.

RD-72 (South of B-1 RFI Site)

Surface vapor flux samples were collected on July 17, 2006 from two locations adjacent to RD-72 (Figure 2) and both locations were resampled on July 20, 2006. Analytical results are presented on Table 8. At sample location B1VF01, TCE concentrations ranged from non-detect (<0.16 $\mu g/m^3$) to 0.037 (J) $\mu g/m^3$, which corresponds to a TCE surface vapor flux of 0.0066 (J) $\mu g/m^2$/minute. At sample location B1VF02, TCE was not detected in either sample (<0.38 $\mu g/m^3$).

Samples of Chatsworth formation groundwater were collected from RD-72 on August 17, 2006 and analyzed for VOCs. The TCE concentration in RD-72 during this sampling event was 210 µg/L[8]. The depth to groundwater in RD-72 was measured on August 1, 2006 and was encountered at a depth of 89.9 feet bgs (H&A 2006). A neutron log was not collected from RD-72 because the well has been retrofitted with a discrete-interval groundwater monitoring system that prevents any borehole logging devices from being deployed.

[8] It should be noted that the TCE concentrations in groundwater samples collected from this well have historically been higher (i.e., greater than 1,000 µg/L). A discrete-interval groundwater sampling system was placed in this well in 2001 and groundwater samples were collected from each of the open-intervals on a couple of occurrences. Subsequent samples have been collected from the first saturated open-interval and the concentration of TCE in this interval has been lower during recent sample events, while the concentration of cDCE has increased and was greater than 1,000 µg/L in the sample collected on August 1, 2006.

RD-52A (West of LOX RFI Site)

Historical soil vapor sampling results from probes installed near RD-52A have been non-detect for TCE. Two surface vapor flux samples were collected on July 17, 2006 from two locations adjacent to RD-52A (Figure 2) and both locations were resampled on July 20, 2006. Analytical results are presented on Table 9. At sample location LXVF01, TCE concentrations ranged from non-detect (<0.15 $\mu g/m^3$) to 0.018 (J) $\mu g/m^3$, corresponding to a TCE surface vapor flux of 0.0007 (J) $\mu g/m^2$/minute. At sample location LXVF02, TCE was not detected in either sample (<0.16 $\mu g/m^3$).

Samples of Chatsworth formation groundwater were last collected from RD-52A on March 15, 2005 and analyzed for VOCs. Samples were not collected during 2006 because there has not been sufficient volume in the well bore from which to obtain representative samples. The TCE concentration in RD-52A during the March 2005 sampling event was 110 µg/L. The depth to groundwater in RD-52A was measured on August 1, 2006 and was encountered at a depth of 126.94 feet bgs (H&A 2006). A neutron log was collected from RD-52A on July 18, 2006 and the log shows a sharp increase in the counts per second from about 900 CPS at a depth of about 119 feet bgs to about 3000 CPS at about 121 feet bgs. The neutron log then shows a sharp drop in the counts per second from about 3,200 CPS at about 125 feet bgs that continues to about 900 CPS at 127 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

2.3 CONTROL AREAS

Two locations were selected to represent ambient or background conditions (i.e., in areas where VOCs have not been previously reported or known to have been released). Additionally, these locations were also selected because groundwater sampling results have shown that TCE has not been detected for at least six years. These sampling sites were located adjacent to Chatsworth formation groundwater monitoring wells located on undeveloped land in the northcentral (i.e., Control North) and southern (i.e., Control South) areas of the SSFL (see Figure 2). The Control North validation sampling location

is adjacent to well RD-92, while the Control South validation sampling location is adjacent to well RD-05A.

Control North (RD-92)

The soil thickness is approximately 3.5 feet near RD-92, hence no soil vapor or soil matrix samples were collected. Surface vapor flux samples were collected on July 18 and July 21, 2006 from one location near RD-92 (Figure 2). Analytical results are presented on Table 10. At sample location NCVF01, the TCE concentrations ranged from non-detect (<0.16 $\mu g/m^3$) to 0.026 (J) $\mu g/m^3$, corresponding to a TCE surface vapor flux of 0.001 (J) $\mu g/m^2$/minute.

Samples of Chatsworth formation groundwater were collected from RD-92 on August 25, 2006 and analyzed for VOCs. TCE was not detected in the sample collected during this event (<0.26 µg/L). The depth to groundwater in RD-92 was measured on August 2, 2006 and was encountered at a depth of 54.97 feet bgs (H&A 2006). A neutron log was collected from RD-92 on July 18, 2006. The neutron log shows a sharp drop in the counts per second from about 2,000 CPS at about 54 feet bgs that continues to about 300 CPS at 55 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

Control South (RD-05A)

Surface vapor flux samples were collected on July 17 and July 20, 2006 from one location near RD-05A. Sample locations are shown on Figure 2 and the analytical results are presented on Table 11. At sample location BZVF01, TCE was not detected (<0.15 $\mu g/m^3$) in either of the two samples.

The soil thickness near RD-05A is approximately 14 feet, therefore both soil vapor and soil matrix samples were collected Three soil vapor samples were collected on July 27, 2006 from depths of 5, 10 and 13 feet bgs in soil vapor probe BZSV01 (see Figure 2). The soil vapor samples were analyzed for chlorinated ethenes (Table 11). A TCE concentration of 7.3×10^3 (J) $\mu g/m^3$ was reported for the soil vapor sample collected

at 5 feet bgs. TCE was also detected in the samples collected from depths of 10 feet and 13 feet bgs at concentrations of 123 (J) µg/m^3 and 975 (J) µg/m^3, respectively. PCE, cis-1,2-dichloroethene, trans-1,2-dichlorethene, and vinyl chloride were also detected in the soil vapor sample collected from 5 feet bgs (Table 11). These results were unexpected, as there is no known or suspected source of chlorinated ethenes in this area. Therefore, the soil vapor probes were sampled and analyzed for TCE again on November 1, 2006. Reported concentrations for the samples collected from 5, 10 and 13 feet bgs were 3.8x10^3 (J) µg/m^3, 1.9x10^3 (J) µg/m^3 and 3.2x10^3 (J) µg/m^3, respectively. Three soil matrix samples from soil boring BZBS01 were collected on July 27, 2006 and analyzed for TCE and physical properties (Table 11). TCE was not detected in any of the three soil samples.

Samples of Chatsworth formation groundwater were collected from RD-05A on August 3, 2006 and analyzed for VOCs. TCE was not detected in the sample collected during this event (<0.26 µg/L). The depth to groundwater in RD-05A was measured on July 31, 2006 and was encountered at a depth of 77.85 feet bgs (H&A 2006). A neutron log was collected from RD-05A on July 18, 2006. The neutron log shows a sharp drop in the counts per second from about 2,200 CPS at about 76 feet bgs that continues to about 400 CPS at 78 feet bgs. A copy of the neutron log is provided in Appendix E. A summary diagram of the TCE results, well construction and the neutron log is provided in vertical profile on Figure 3.

3.0 LOX AREA SAMPLING PROGRAM AND RESULTS

As described in Section 1.0, a separate work plan was prepared to collect additional vapor flux, soil vapor, soil matrix and ambient air measurements at the LOX site. The LOX sampling program was conducted in accordance with the DTSC-approved February 2005 work plan, *RCRA Facility Investigation Work Plan Addendum Amendment, Surface Flux and Ambient Air Monitoring, Former Liquid Oxygen (LOX) Plant Site (SWMUs 4.5 and 4.6)* (MWH 2005a). The LOX sampling program was conducted concurrently with the vapor model validation study sampling program discussed above in Section 2.0. Figure 4 shows the locations of the ambient air, surface vapor flux, soil vapor probes and soil borings installed during this sampling program. The specific sampling that was performed for the LOX study is provided on Table 12. Ambient air samples were collected by personnel from ERM, who also operated and retrieved the data from the meteorological station. Surface vapor flux samples were collected by C.E. Schmidt with support from MWH. Data sheets from the surface vapor flux sampling events are provided in Appendix A. Soil vapor probes were installed by HydroGeoSpectrum at the direction of MWH. During the July sampling events, leak tests were performed on some of the soil vapor probes during sampling by placing a cloth that was nearly saturated with a solution containing 70 percent IPA over the sampling tubes emerging from the head of the probe(s) at the ground surface. Samples were analyzed for IPA to assess the quality of the sampling system. IPA was detected in a number of the soil vapor samples during the July sampling event at concentrations above the threshold of 10 µg/L (or 10,000 $\mu g/m^3$). Analytical results from soil vapor probes containing IPA at concentrations greater than 10,000 $\mu g/m^3$ were qualified during data validation as estimated. The October 9, 2996 memorandum summarizes the results of the leak testing with IPA during the July 2006 sampling event is provided in Appendix B. These locations were resampled in late October/early November 2006 using a different leak testing protocol that was reviewed and approved by staff from DTSC. Additionally, leak tests were not performed on certain soil vapor probes within the LOX study and the analytical results from these locations were rejected during data validation. These

locations were also resampled in late October/early November 2006 using a different leak testing protocol that was reviewed and approved by staff from DTSC. The results of the leak testing program that was implemented during the late October/early November resampling event are provided in Appendix B. Details of the locations resampled because of either excessive concentrations of IPA in the soil vapor sample or the lack of a leak test are described in subsequent sections of this report.

Soil borings were installed by HydroGeoSpectrum and BL Hall, also at the direction of MWH. Boring logs collected during installation of the soil borings are provided in Appendix C. Data validation reports of the analytical laboratory results of ambient air, surface vapor flux, soil vapor, and soil matrix samples, prepared by chemists from MEC^{x}, are provided in Appendix D.

Seven ambient air measurements were collected on July 19, 2006 adjacent to the former LOX plant perimeter. A meteorological station was also established at the LOX area, the location of which is also shown on Figure 4. Surface vapor flux measurements were also collected on July 19, 2006 from four locations in the suspected VOC source area. One vapor flux sample was collected from each of the following three locations (i.e., LXVF04, LXVF05, and LXVF06) and four vapor flux samples plus a duplicate vapor flux sample were collected from one sample location, LXVF03. One soil boring and one soil vapor probe were co-located with each of the four surface vapor flux sample locations. An additional four soil vapor probes and four soil borings were installed in the general vicinity of the suspected VOC source area at LOX. A summary of the sample types collected during this study along with the sample location names is provided on Table 12. The laboratory results from the samples collected in this study are presented on Tables 13 through 20. The following sections describe the locations sampled and results of the data that were collected.

3.1 AMBIENT AIR SAMPLE RESULTS

Ambient air samples were collected from seven locations on July 19, 2006. The samples were analyzed for chlorinated ethenes and the results are presented on Table 13. PCE

was detected in all eight[9] samples at concentrations ranging from 0.038 (J) µg/m^3 to 0.22 µg/m^3. TCE was detected in six of the eight samples at concentrations of 0.027 (J) µg/m^3 to 0.13 (J) µg/m^3. The TCE sampling results are presented on Figure 5. Vinyl chloride was detected in one sample (LXAA04) at a concentration of 0.019 (J) µg/m^3. No other chlorinated ethenes were detected.

A meteorological station was established at the LOX area (see Figure 4) to record barometric pressure, wind speed and wind direction. Data were collected starting on July 12, 2006 and continued through July 19, 2006. The data collected are provided in Appendix F.

3.2 SAMPLE RESULTS AT LOCATIONS LXVF04, LXSA21, LXBS23

One surface vapor flux sample was collected on July 19, 2006 at LXVF04. This along with the other vapor flux, soil vapor and soil matrix sample locations are shown in greater detail on Figure 6. The vapor flux sample was analyzed for chlorinated ethenes and the results are presented on Table 14. TCE and 1,1-dichloroethene were detected in this sample at 0.17 µg/m^3 and 0.024 (J) µg/m^3, respectively. These values equate to a TCE surface vapor flux of 0.0065 µg/m^2/minute and a 1,1-DCE vapor flux of 0.0009 (J) µg/m^2/minute. No other chlorinated ethenes were detected in the sample.

One soil vapor probe and one soil boring were co-located with LXVF04. Soil vapor samples were collected from depths of 5 feet and 10 feet bgs from soil vapor probe LXSA21 on July 25, 2006 (Figure 6) and analyzed for chlorinated ethenes (Table 14). The data were rejected because a leak-test was not performed to allow for an assessment to be made as to the integrity of the soil vapor probes. This location was resampled on October 30, 2006 and results are presented on Table 14. PCE and TCE were detected at concentrations of 10 (J) µg/m^3 and 349 (J) µg/m^3, respectively in the sample collected at 5 feet bgs. PCE and TCE were also detected in the sample from 10 feet bgs at

[9] Results from LXAA01S01 and LXAA01BS01 are from the same sample location. LXAA01BS01 was collected because the sample canister used to collect sample LXAA01S01 appeared to have a faulty valve. Hence, it was determined that the analytical result provided by this sample may not have been representative of actual site conditions.

concentrations of 82 (J) µg/m^3 and 4.6x10^3 (J) µg/m^3, respectively. The other chlorinated ethenes were not detected.

Two soil samples were collected from soil boring LXBS23 on July 26, 2006 (Figure 6). Both soil samples (1.5 and 5.5 feet bgs) were analyzed for physical properties and the soil sample collected at 5.5 feet bgs was analyzed for chlorinated ethenes (Table 14). TCE was detected at a concentration of 0.37 (J) µg/kg. No other chlorinated ethenes were detected in this sample. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.3 SAMPLE RESULTS AT LOCATIONS LXVF05, LXSA22, LXBS24

One surface vapor flux sample was collected July 19, 2006 at LXVF05 (Figure 6) and analyzed for chlorinated ethenes. Analytical results are presented on Table 15. TCE and cDCE were detected in this sample at 4.6x10^3 µg/m^3 and 144 (J) µg/m^3, respectively. The corresponding surface vapor flux for TCE was 175 µg/m^2/minute and 5.5 (J) µg/m^2/minute for cDCE. No other chlorinated ethenes were detected in the sample.

One soil vapor probe and one soil boring were co-located with LXVF05. Soil vapor samples were collected from depths of 5 feet and 10 feet bgs from soil vapor probe LXSA22 on July 25, 2006 (Figure 6) and analyzed for chlorinated ethenes. The data were rejected because a leak-test was not performed to allow for an assessment to be made as to the integrity of the soil vapor probes. Therefore, this location was resampled on October 30, 2006 and results are presented on Table 15. TCE, cDCE and tDCE were detected at concentrations of 1.4x10^6 µg/m^3, 4.4x10^4 µg/m^3, and 2.1x10^4 µg/m^3, respectively in the sample collected at 5 feet bgs. TCE, cDCE, tDCE and 1,1-DCE were also detected in the sample from 10 feet bgs at concentrations of 1.6x10^6 (J) µg/m^3, 1.1x10^5 (J) µg/m^3, 3.2x10^4 µg/m^3, and 607 µg/m^3, respectively. PCE and vinyl chloride were not detected.

Soil samples were collected from depths of 1.5, 5.5, and 10.5 feet bgs from soil boring LXBS24 on July 26, 2006 (Figure 6). All three soil samples were analyzed for physical properties and the soil sample collected at 5.5 feet bgs was analyzed for chlorinated

ethenes. Results are presented on Table 15. TCE was detected at a concentration of 38 µg/kg, while cDCE was detected at a concentration of 1.6 (J) µg/kg. No other chlorinated ethenes were detected in this sample. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.4 SAMPLE RESULTS AT LOCATIONS LXVF06, LXSA23, LXBS25

One surface vapor flux sample was collected July 19, 2006 at LXVF06 (Figure 6) and analyzed for chlorinated ethenes. Analytical results are presented on Table 16. PCE, TCE, cDCE, and tDCE were detected in this sample at 0.12 (J) µg/m^3, 25 µg/m^3, 0.31 µg/m^3, and 0.60 µg/m^3, respectively. These values correspond to surface vapor fluxes for PCE, TCE, cDCE, and tDCE of 0.0047 µg/m^2/minute, 0.97 µg/m^2/minute, 0.012 µg/m^2/minute, and 0.023 µg/m^2/minute, respectively. Other chlorinated ethenes were not detected in the sample.

One soil vapor probe and one soil boring were colocated with LXVF06. Two soil vapor samples were collected from soil vapor probe LXSA23 on July 25, 2006 (Figure 6). Soil vapor samples were collected at 5 and 10 feet bgs and were analyzed for chlorinated ethenes (Table 16). The data from the soil vapor probe at 5 feet bgs were qualified as estimated (with a low bias) as IPA, used to check for leaks in the sampling system, was detected at concentrations exceeding the acceptable threshold. The concentrations of TCE and cDCE in the 5-foot sample were 7.0x10^5 (J) µg/m^3 and 2.2x10^4 (J) µg/m^3, respectively. In the sample collected from 10 feet bgs, TCE and cDCE were 6.5x10^5 µg/m^3 and 2.1x10^4 (J) µg/m^3, respectively. The soil vapor probe at 5 feet was resampled on October 31, 2006 and results are presented on Table 16. TCE, cDCE and tDCE were detected at concentrations of 2.4x10^6 µg/m^3, 9.2x10^4 µg/m^3, and 3.2x10^4 µg/m^3, respectively. PCE, 1,1-DCE and vinyl chloride were not detected.

Three soil samples and one duplicate sample were collected from soil boring LXBS25 on July 26, 2006 (Figure 6). All three soil samples (1.5, 5.5, and 10.5 feet bgs) were analyzed for physical properties and the soil sample collected at 5.5 feet bgs was analyzed for chlorinated ethenes (Table 16). TCE was the only chemical detected in the primary sample, at a concentration of 5.1 µg/kg, but was not detected in the duplicate

sample. No additional chlorinated ethenes were detected in either the primary or duplicate sample. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.5 SAMPLE RESULTS AT LOCATIONS LXVF03, LXSA25, LXBS27

Four surface vapor flux samples, plus one duplicate sample and an equipment blank sample were collected July 19, 2006 at LXVF03 (Figure 6) and analyzed for chlorinated ethenes. Analytical results are presented on Table 17. The four surface vapor flux samples were collected over a period of 8 hours to assess the impact on potential changes in surface vapor flux as a result of changing meteorological conditions. TCE concentrations and corresponding vapor fluxes at location LXVF03 varied as follows:

- 225 (J) $\mu g/m^3$ (8.7 $\mu g/m^2$/minute) in a sample collected between 07:32 and 08:02,
- 536 (J) $\mu g/m^3$ (21 $\mu g/m^2$/minute) in a sample collected between 09:32 and 10:02,
- 1.4×10^3 $\mu g/m^3$ (53 $\mu g/m^2$/minute) in a sample collected between 11:49 and 12:19,
- 412 $\mu g/m^3$ (16 $\mu g/m^2$/minute) in a sample collected between 15:03 and 15:33.

A graph of the TCE vapor flux over the time frames noted above is provided on Figure 8.

PCE concentrations and corresponding vapor fluxes at the same location varied as follows:

- 0.84 (J) $\mu g/m^3$ (0.033 $\mu g/m^2$/minute) in a sample collected between 07:32 and 08:02,
- 2.5 (J) $\mu g/m^3$ (0.096 $\mu g/m^2$/minute) in a sample collected between 09:32 and 10:02,
- 68 (J) $\mu g/m^3$ (2.6 $\mu g/m^2$/minute) in a sample collected between 11:49 and 12:19,
- 1.9 (J) $\mu g/m^3$ (0.074 $\mu g/m^2$/minute) in a sample collected between 15:03 and 15:33.

cDCE concentrations and corresponding vapor fluxes at the same location varied as follows:

- Non-detect (<5.6 $\mu g/m^3$) in a sample collected between 07:32 and 08:02,
- 7.9 (J) $\mu g/m^3$ (0.30 $\mu g/m^2$/minute) in a sample collected between 09:32 and 10:02,

- 40 (J) µg/m^3 (1.6 µg/m^2/minute) in a sample collected between 11:49 and 12:19,
- 7.1 (J) µg/m^3 (0.27 µg/m^2/minute) in a sample collected between 15:03 and 15:33.

tDCE concentrations and corresponding vapor fluxes at the same location varied as follows:

- Non-detect (<5.0 µg/m^3) in a sample collected between 07:32 and 08:02,
- 4.5 (J) µg/m^3 (0.17 µg/m^2/minute) in a sample collected between 09:32 and 10:02,
- Non-detect (<326 µg/m^3) in a sample collected between 11:49 and 12:19,
- 3.4 (J) µg/m^3 (0.13 µg/m^2/minute) in a sample collected between 15:03 and 15:33.

The remaining two chlorinated ethenes (i.e., 1,1-dichloroethene, and vinyl chloride) were not detected in any of the samples.

One soil vapor probe and one soil boring were colocated with LXVF03. Soil vapor samples were collected from depths of 5 feet, 10 feet and 15 feet bgs from soil vapor probe LXSA25 on July 25, 2006 (Figure 6) and analyzed for chlorinated ethenes (Table 17). All chlorinated ethenes were detected except 1,1-DCE. TCE concentrations detected were 5.6x10^6 (J) µg/m^3 at 5 feet bgs to 2.0x10^7 (J) µg/m^3 at 10 feet bgs to 7.4x10^4 (J) µg/m^3 at 15 feet bgs. Results for the other chlorinated ethenes are provided on Table 17. The probe at 10 feet bgs was resampled on October 31, 2006 and the TCE concentration was 1.5x10^7 (J) µg/m^3.

Five soil samples were collected from depths of 1.5, 3, 5.5, 8, and 15.5 feet bgs from soil boring LXBS27 on July 26, 2006 (Figure 6). All five soil samples were analyzed for physical properties and the samples collected at 3 and 5.5 feet bgs were analyzed for chlorinated ethenes (Table 17). In the sample collected from 3 feet bgs, TCE was detected at a concentration of 20 µg/kg. No other chlorinated ethenes were detected in the sample. In the sample collected from 5.5 feet bgs, PCE, TCE, cDCE and tDCE were detected as concentrations of 0.84 (J) µg/kg, 890 µg/kg, 41 µg/kg, and 2.5 µg/kg, respectively (Table 17). Vinyl chloride and 1,1-dichloroethene were not detected. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.6 SAMPLE RESULTS AT LOCATIONS LXSA27, LXBS26

One soil vapor probe and one soil boring were co-located near existing soil vapor probe location LXSV73. A soil vapor sample was collected from a depth of 13 feet bgs at LXSA27 on July 26, 2006 and analyzed for chlorinated ethenes. Analytical results are presented on Table 18. The data from the soil vapor probe at 5 feet bgs were qualified as estimated (with a low bias) as IPA, used to check for leaks in the sampling system, was detected at concentrations exceeding the acceptable threshold. TCE and cDCE were detected at concentrations of $1.7x10^5$ (J) and $7.6x10^3$ (J) µg/m^3, respectively. No other chlorinated ethenes were detected. The soil vapor probe at 13 feet bgs was resampled on October 31, 2006 and results are presented on Table 18. This resampling was conducted to reduce the uncertainty associated with the potential leaks in the sampling system as a result of the IPA detection. TCE, cDCE, tDCE and were detected at concentrations of $1.9x10^4$ (J) µg/m^3, $2.9x10^3$ (J) µg/m^3, and 656 (J) µg/m^3, respectively. PCE, 1,1-DCE and vinyl chloride were not detected.

Soil samples were collected from depths of 6.5 and 10.5 feet bgs from soil boring LXBS27 on July 26, 2006 (Figure 6). The soil samples were analyzed for physical properties and chlorinated ethenes and the results are presented on Table 18. TCE was the only chemical detected at a concentration of 5.3 µg/kg in the sample from 10.5 feet bgs. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.7 SAMPLE RESULTS AT LOCATIONS LXSA24, LXSV72, LXSV74

Three soil vapor probes, LXSA24, LXSV72 (LXSA26), and LXSV74 (LXSA28) were co-located near the existing soil vapor probe locations LXSV68, LXSV72, and LXSV74, respectively. The LXSA26 and LXSA28 soil vapor probes were originally identified for installation at the LXSV72 and LXSV74 soil vapor probe locations, but at different depths. However, during the field program, the new soil vapor probes and samples were described using the old LXSV72 and LXSV74 identifiers. Therefore, the data are described in the tables and figures using the LXSV nomenclature.

One soil vapor sample was collected from a depth of 17 feet bgs from soil vapor probe LXSA24 on July 26, 2006 (Figure 6) and analyzed for chlorinated ethenes. Analytical results are presented on Table 19. The analytical results were qualified as estimated (with a low bias) as IPA, used to check for leaks in the sampling system, was detected at concentrations exceeding the acceptable threshold. TCE, cDCE, tDCE and vinyl chloride were detected at concentrations of $1.7x10^4$ (J) $\mu g/m^3$, $3.9x10^3$ (J) $\mu g/m^3$, $1.1x10^3$ (J) $\mu g/m^3$, and 93 (J) $\mu g/m^3$, respectively. PCE and 1,1-DCE were not detected. The soil vapor probe at 17 feet was resampled on October 31, 2006 and results are presented on Table 19. This resampling was conducted to reduce the uncertainty associated with the potential leaks in the sampling system as a result of the IPA detection. PCE, TCE, and 1,1-DCE were detected at concentrations of $2.6x10^5$ (J) $\mu g/m^3$, $3.1x10^5$ (J) $\mu g/m^3$, and $4.7x10^4$ (J) $\mu g/m^3$, respectively. cDCE, tDCE and vinyl chloride were not detected.

One soil vapor sample was collected from soil vapor probe LXSV72 (LXSA26) on July 28, 2006 (Figure 6) and analyzed for chlorinated ethenes. The data were rejected because a leak-test was not performed to allow for an assessment to be made as to the integrity of the soil vapor probes. This location was resampled on October 31, 2006 and results are presented on Table 19. All six chlorinated ethenes were detected at the following concentrations: $1.1x10^3$ (J) $\mu g/m^3$ (PCE), $2.4x10^6$ (J) $\mu g/m^3$ (TCE), $4.1x10^5$ (J) $\mu g/m^3$ (cDCE), $3.9x10^5$ (J) $\mu g/m^3$ (tDCE), $3.6x10^3$ $\mu g/m^3$ (1,1-DCE), and $4.3x10^3$ $\mu g/m^3$ (vinyl chloride), respectively.

Soil vapor samples were collected from depths of 5 and 10 feet bgs from soil vapor probe LXSV74 (LXSA28) on July 28, 2006 (Figure 6). The analytical results were rejected because a leak-test was not performed to allow for an assessment to be made as to the integrity of the soil vapor probes. This location was resampled on October 31, 2006 and results are presented on Table 19. PCE, TCE and cDCE were detected in the sample collected at 5 feet bgs at concentrations of $1.3x10^3$ (J) $\mu g/m^3$ and $1.6x10^5$ $\mu g/m^3$ and $2.3x10^3$ (J) $\mu g/m^3$, respectively. TCE, cDCE, and tDCE were detected in the sample collected at 10 feet bgs at concentrations of $8.4x10^3$ $\mu g/m^3$, 369 (J) $\mu g/m^3$, and 143 (J) $\mu g/m^3$, respectively. PCE, 1,1-DCE and vinyl chloride were not detected. A summary

diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

3.8 SAMPLE RESULTS AT LOCATIONS LXBS28, LXBS29, LXBS30

Soil samples were collected from depths of 5.5, 10.5 and 15.5 feet from soil boring LXBS28, and from depths of 3.5 feet bgs from soil borings LXBS29 and LXBS30 on July 25, 2006 (Figure 6). All five soil samples were analyzed for physical properties and the sample from 5.5 feet bgs from LXBS28 was analyzed for chlorinated ethenes. TCE was the only chemical detected, at a concentration of 1,700 µg/kg. Physical property and chlorinated ethane results are presented on Table 20. A summary diagram of the TCE results from these sampling locations are provided in vertical profile on Figure 7.

4.0 PHYSICAL PROPERTY MEASUREMENTS SUMMARY

As noted in the prior sections of this report, a number of soil samples were measured for physical properties. Twelve soil samples from the vapor validation study and 20 soil samples from the LOX study were analyzed for hydraulic conductivity, moisture content, porosity, percent saturation, bulk density and specific gravity. The minimum, maximum and average values for the sites included in the vapor validation study, for the LOX area and for both sets of data are presented on Table 21. Individual sample results are reported on the prior tables presented and discussed in this report. A brief discussion of results for each physical property that was measured is provided below.

A total of 32 soil samples were analyzed for hydraulic conductivity by American Society for Testing and Materials (ASTM) Method D5084-03. Results shown on Table 21 are presented in units of centimeters per second. For the vapor validation study sites, the minimum value measured was 2.12×10^{-7} centimeters per second (cm/s) and the maximum was 9.59×10^{-5} cm/s. The geometric mean value for the 12 samples was 4.16×10^{-6} cm/s. For the LOX area, the minimum value measured was 7.61×10^{-8} cm/s and the maximum was 2.99×10^{-4} cm/s. The geometric mean value for the 20 samples was 1.96×10^{-5} cm/s. These combined results of the 32 samples show the minimum, maximum and geometric mean values to be 7.61×10^{-8} cm/s, 2.99×10^{-4} cm/s, and 1.09×10^{-5} cm/s, respectively. Four other hydraulic conductivity measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH, 2003) and those values showed a geometric mean of 2.1×10^{-5}cm/s.

A total of 32 soil samples were analyzed for moisture content by ASTM Method D2216-98. Results shown on Table 21 are presented in units of percent. For the vapor validation study sites, the minimum value measured was 4.6 percent and the maximum was 22.9. The average value for the 12 samples was 14.2 percent. For the LOX area, the minimum value measured was 2.6 percent and the maximum was 25.6 percent. The average value for the 20 samples was 12.8 percent. These combined results of the 32 samples show the minimum, maximum and average values to be

2.6 percent, 25.6 percent, and 12.8 percent, respectively. Four other moisture content measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH, 2003) and those values showed an average of 13.5 percent.

A total of 32 soil samples were analyzed for porosity by ASTM Method D854/2397 (mod). Results shown on Table 21 are presented in units of percent. For the vapor validation study sites, the minimum value measured was 32 percent and the maximum was 45 percent. The average value for the 12 samples was 39 percent. For the LOX area, the minimum value measured was 34 percent and the maximum was 56 percent. The average value for the 20 samples was 47 percent. These combined results of the 32 samples show the minimum, maximum and average values to be 32 percent, 56 percent, and 44 percent, respectively. Four other porosity measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH, 2003) and those values showed an average of 32 percent.

A total of 32 soil samples were analyzed for saturation by ASTM Method D854/2397 (mod). Results shown on Table 21 are presented in units of percent. For the vapor validation study sites, the minimum value measured was 7.0 percent and the maximum was 27.0 percent. The average value for the 12 samples was 18.2 percent. For the LOX area, the minimum value measured was 4.0 percent and the maximum was 31.0 percent. The average value for the 20 samples was 17.6 percent. These combined results of the 32 samples show the minimum, maximum and average values to be 4.0 percent, 31.0 percent, and 17.8 percent, respectively. Four other saturation measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH 2003) and those values showed an average of 66.5 percent.

A total of 32 soil samples were analyzed for bulk density by ASTM Method D2937-00e1. Results shown on Table 21 are presented in units of pounds per cubic feet (pcf) or grams per cubic centimeter (g/cc). For the vapor validation study sites, the minimum value measured was 91.3 pcf (1.47 g/cc) and the maximum was 116.7 pcf (1.87 g/cc). The average value for the 12 samples was 102.8 pcf (1.65 g/cc). For the LOX area, the

minimum value measured was 73.7 pcf (1.18 g/cc) and the maximum was 114.6 pcf (1.84 g/cc). The average value for the 20 samples was 94.1 pcf (1.51 g/cc). These combined results of the 32 samples show the minimum, maximum and average values to be 73.7 pcf (1.18 g/cc), 116.7 pcf (1.87 g/cc), and 97.36 pcf (1.56 g/cc), respectively. Four other bulk density measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH, 2003) and those values showed an average of 111.7 pcf (1.79 g/cc).

A total of 32 soil samples were analyzed for specific gravity by ASTM Method D854-02. Results shown on Table 21 are presented in unitless. For the vapor validation study sites, the minimum value measured was 2.65 and the maximum was 2.73. The average value for the 12 samples was 2.68. For the LOX area, the minimum value measured was 2.11 and the maximum was 2.74. The average value for the 20 samples was 2.65. These combined results of the 32 samples show the minimum, maximum and average values to be 2.11, 2.74, and 2.66, respectively. Four other specific gravity measurements of soil were previously reported in the Near-surface Groundwater Characterization Report (MWH, 2003) and those values showed an average of 2.67.

5.0 DISCUSSION OF SAMPLING RESULTS

A summary of observations of the results from the vapor migration model validation study and the LOX VOC surface flux and ambient air study includes the following:

1. At locations without TCE sources in soil:
   a. Data obtained during this study indicate that vapor flux at the ground surface from TCE in groundwater is measurable at rates greater than 0.01 $\mu g/m^2/min$ when groundwater is within approximately 20 feet of the ground surface and TCE concentrations in groundwater are greater than 1,000 µg/L. This observation is based on the results from the Compound A and FSDF sampling studies.

   b. Vapor flux at the ground surface is measurable at rates less than 0.01 $\mu g/m^2/min$ when groundwater is approximately 50 feet below ground surface and TCE concentrations are greater than 1,000 µg/L or where groundwater is within about 20 feet of the ground surface and TCE concentrations in groundwater are in the hundreds of micrograms per liter range. This observation is based on the results from the Delta, and North of CTL-III (ES-3) and B515[10] area sampling studies, respectively.

   c. It appears that the vapor flux at the ground surface at rates of 0.001 $\mu g/m^2/min$ or less may not be attributable to vapor transport from groundwater. This observation is based on the results from the B-1 (RD-72), LOX (RD-52A), North Control (RD-92) and South Control (RD-05A) sampling studies. Of the 12 vapor flux samples collected at these 4 locations, 9 of the results were non-detect for TCE and the 3 remaining results reported TCE at estimated concentrations within a factor of 3 of the method detection limit of ~0.015 $\mu g/m^3$. Note that TCE was detected in soil vapor at concentrations of between 1,000 and 10,000 $\mu g/m^3$ at the South Control (RD-05A) location, but this was the only location where TCE was not detected in the samples collected from the flux chamber. Note also that TCE was reportedly detected in 1 of 2 samples (at estimated concentrations below the method reporting limit) collected from the flux chamber at the North Control sampling location, but there is no known TCE source in soil or bedrock and TCE in groundwater is non-detect at <0.26 µg/L. Further information supporting this observation is presented in item 2c below.

[10] It should be noted that one vapor flux sample result from this location was non-detect for TCE and the other result reported TCE at estimated concentrations below the method reporting limit and above the method detection limit. The reported TCE concentration is similar in magnitude to the ambient air concentrations reported for the LOX VOC surface flux and ambient air study and may be indicative of TCE in ambient air that is unrelated to SSFL activities. This item is further discussed in this section of the report.

2. At locations with TCE sources in soil (CTL-III and LOX):

   a. Vapor transport solely from groundwater can not be independently assessed when a TCE source is present in soil. The vapor flux at the CTL-III source area is greater than 1 $\mu g/m^2/min$ and can likely be attributed to the position of the flux chamber being adjacent to a former pond where TCE entered the ground and still remains at elevated concentrations in the vadose zone soil. Furthermore, there is also appreciable mass present in the unsaturated bedrock (also indicative of a source) that may also be transmitting vapor to the ground surface. The presence of TCE mass in the vadose zone bedrock at this location was previously reported in *Technical Memorandum: Conceptual Site Model, Movement of TCE in the Chatsworth Formation* (Montgomery Watson, 2000).

   b. TCE vapor fluxes at the LOX source area were above 1 $\mu g/m^2/min$ (and at times 2 orders of magnitude above this rate) at three of the four locations where these measurements were collected. TCE in soil vapor is greater than 1,000,000 $\mu g/m^3$ at all four of these locations. However, the largest measured flux (175 $\mu g/m^2/min$ at LXVF05) was not co-located with the highest soil TCE vapor sample concentrations (2.0×10^7 $\mu g/m^3$ at LXSA25, co-located with LXVF03).

   c. Concentrations of TCE in ambient air at the LOX source area were all low, with no single value exceeding the method reporting limit of about 0.15 $\mu g/m^3$. The maximum concentrations detected were both upwind and downwind of the LOX source area and were both less than 25 parts per trillion[11] (ppt). Sample results from two locations were non-detect, and results from three other locations within the LOX source area were less than 13 ppt.

These results can be compared to ambient air values reported in technical references issued by regulatory agencies. EPA (2000) reports that TCE in ambient air ranged from 2 ppt to 740 ppt in measurements collected from 25 states between the years of 1985 and 1995. The Agency for Toxic Substances and Disease Registry (ATSDR) reports that the mean TCE concentration in ambient air in rural or remote areas was 30 ppt. The California Air Resources Board (1990) reports that the mean TCE concentration in ambient air of the South Coast Air Basin of southern California was 190 ppt.

Furthermore, results of specific monitoring locations of samples collected between 1989 and 2003 at monitoring locations in Simi Valley, Burbank and Los Angeles reported mean TCE concentrations in ambient air of 36 ppt, 93 ppt, and 257 ppt, respectively.

Comparison of the LOX ambient air sample results to ambient air values of TCE proximal to the SSFL, within southern California, and across the United States indicate that TCE in air at this source location at the SSFL is on the low range of measured values. These results are presented graphically on Figure 9. Hence, it is likely that the TCE values measured in ambient air at the LOX study area are indicative of non-site-related regional concentrations and are not locally affected by TCE in soils at this location.

[11] Concentrations in $\mu g/m^3$ can be converted to parts per trillion (ppt) by multiplying the concentration in $\mu g/m^3$ by a conversion factor of 24,450, and dividing by the molecular weight of the compound (the molecular weight of TCE is 131.40 g/mol) or, C in ppt=186*C in $\mu g/m^3$.

6.0 MODEL PREDICTIONS AND ASSESSMENT

The focus of the vapor validation study was to evaluate the applicability of the vapor migration model being used at the SSFL for predicting potential vapor transport from groundwater to the ground surface. The evaluation and discussion in this section of the report focuses on the performance of the model for assessing vapor transport from groundwater, although the model performance from soil vapor measurements is also presented, thus providing further context for the overall model.

Data collected during the validation field sampling was used to assess the applicability of the vapor migration models to SSFL site conditions, considering the co-located surface flux measurements, source conditions (including concentration data), and soil properties. Each subsurface sample was used as an input to the vapor flux modeling equations provided in Appendix G of revision 2 of the SRAM (MWH, 2005) to provide an estimated surface flux that was then compared to the co-located, measured surface vapor flux. The dataset of physical properties for soil and bedrock has been updated since published in revision 2 of the SRAM. The revised physical property data are presented in Appendix G of this report. Updates to the SSFL physical parameter tables include corrections to previous reported moisture contents and the addition of the soil data presented in Section 4.0 of this report. Revisions to soil and bedrock physical property input parameters used in the vapor validation modeling based on the revised datasets are summarized in Table 22.

A summary of all the input parameters used to model vapor transport are listed in Table 23. Table 24 presents the model-calculated flux results from groundwater along with the average and maximum detected flux measurements made at the SSFL. Table 25 presents the model-calculated flux results from soil vapor measurements along with the average and maximum detected surface vapor flux measurements made at the SSFL. Table 26 presents a summary of model-calculated flux from co-located groundwater and soil vapor measurements along with the average and maximum field-measured fluxes. These results are presented for the two locations at the SSFL where co-located

groundwater and soil vapor measurements were made (i.e., those locations with soil thicknesses greater than 3.5 feet) and where the measured flux is greater than ambient air concentrations. Table 27 provides a comparison of measured TCE concentrations in ambient air samples and flux chamber samples.

6.1 EVALUATION OF MODEL PERFORMANCE – VAPOR TRANSPORT FROM GROUNDWATER

The vapor transport model was used to predict fluxes from groundwater (see Table 24), which were then compared to the measured fluxes from locations identified in Section 2.0 of this report. Results are graphically presented on Figure 10 as a ratio of the model-calculated flux to the measured flux. A discussion of the results is presented below.

6.1.1 Source Areas

As shown in Figure 10, the model overestimates flux at three of the four source areas (Delta, Compound A, and FSDF) by factors ranging from 1.3 (Delta) to 111 (FSDF) when using the location-specific data and measured TCE concentrations in groundwater.

At the CTL-III source area, the model underestimates the measured flux by 3 orders of magnitude. As discussed in Section 5.0, available data from CTL-III indicates that TCE remains at elevated concentrations in the vadose zone soil and bedrock. When conditions such as these exist, the model should not be used to estimate the vapor flux from groundwater, but rather soil vapor data should be used. Model results produced using soil vapor data will be more representative of the potential fluxes because the measurements that are used as inputs to the model do not require the partitioning of VOCs in the aqueous phase (i.e., groundwater VOC results) to the vapor phase.

6.1.2 Areas Above Groundwater Plumes (Distal Areas)

As shown in Figure 10, the model overestimates flux at the two near-surface groundwater locations above plumes (CTL-III and B515) by factors ranging from 17 to 243. The model appears to underestimate the flux at the two Chatsworth formation groundwater locations (B-1 and LOX) by 2 to 4 orders of magnitude. However, 8 vapor flux samples

were collected from these 2 locations and TCE was not detected in 6 of the 8 flux samples. TCE was reportedly detected in 1 vapor flux sample at the B-1 location and 1 vapor flux sample at the LOX area and both results were reported at estimated concentrations below the method reporting limit. Furthermore, the concentrations of TCE reported in the samples are in the same range as the TCE concentrations in ambient air at the LOX source study area. The flux chamber sample results from the B-1 and LOX groundwater study areas likely reflect detections of TCE in ambient air that is unrelated to vapor transport from groundwater. The detections of TCE in the flux chamber samples could be associated with barometric pumping of ambient air into and through the surface sediments and rock.

6.1.3 Control Areas

The transport of vapors from groundwater at the control areas was not modeled because TCE was not detected in groundwater. However, TCE was reportedly detected in one of the two flux chamber samples collected at the North Control location. The detection was reported at 0.026 J $\mu g/m^3$, which is below the method reporting limit. Furthermore, the concentration of TCE reported in the sample is in the same range as the TCE concentrations in ambient air at rural or remote areas as reported by the ATSDR. The flux chamber sample result from this location likely reflects the detection of TCE in ambient air that is unrelated to vapor transport from groundwater.

While TCE was not detected in the flux chamber or groundwater samples at the South Control sampling location, TCE was detected in soil vapor samples ranging from 7.3×10^3 J $\mu g/m^3$ at 5 feet bgs to 3.2×10^3 J $\mu g/m^3$ at 13 feet bgs.

6.2 EVALUATION OF MODEL PERFORMANCE – TRANSPORT FROM SOIL VAPOR

The model was also used to predict vapor fluxes at the ground surface from soil vapor sampling results and location-specific information. These results are presented on Figure 11 and include estimates for the LOX soil source study area along with the locations for the vapor migration model that contained soil thicknesses greater than 3.5 feet.

The following summarizes the results of the model-predicted fluxes from the soil vapor measurements compared to the measured fluxes at each location:

- At the FSDF source area, the result from the primary sample collected at 4 feet bgs underestimated the flux by a factor of 3, although the result from the duplicate sample overestimated the flux by a factor of 11. The deepest sample result (from 7 feet bgs) overestimated the average measured flux by a factor of 11.
- At the CTL-III source area, the flux was underestimated using the vapor results from the sample collected at 5 feet bgs by a factor of 500. The model slightly overestimated the flux when using the results from the two deeper soil vapor samples collected at 10 and 15 feet bgs (by factors of 3 and 1.2, respectively).
- At the B515 plume, the flux was underestimated using the vapor results from the sample at 15 feet bgs by a factor of 5. The model overestimated the flux when using the results from the soil vapor samples collected at 5 feet, 10 feet and 20 feet bgs (by factors of 3056, 1.7 and 115, respectively). This variability may result from slight variations in water content within the soil profile that can not be accounted for in the model.
- At the LOX source area, the model-predicted flux was overestimated by factors ranging from 1.1 to 60.7 in all but three soil vapor samples. The flux was underestimated using vapor sample results from depths of 5 feet and 10 feet bgs at LXSA22 by factors of 6 and 11, respectively, and from the sample collected at 15 feet bgs from LXSA25 by a factor of 50.

The average model-predicted flux from the soil vapor measurements collected vertically at each sampling location was also calculated and divided by the average and maximum measured fluxes for the four locations discussed above. These results are also presented on Table 25. Application of the average fluxes for each sample location overestimates the average and maximum measured fluxes at all locations except one by factors ranging from 1.4 to over 900. The only location where the model underestimates the average and maximum measured fluxes (by a factor of 10) is at sample location LXSA22 at the LOX source area.

6.3 COMPARISON OF MODEL-CALCULATED FLUXES FROM GROUNDWATER TO FLUXES FROM SOIL VAPOR

Model performance was also evaluated by comparing the model-calculated flux from groundwater to the model-calculated flux from soil vapor samples collected just above

the soil-bedrock interface at locations where both types of measurements were available. These comparisons were made for the two locations with near-surface groundwater and are illustrated in Figure 12. This figure also depicts the average measured flux from these two locations. The primary difference between these two models includes the partitioning of vapors from groundwater to the vapor phase and transport of the vapors through bedrock (for the FSDF location). The model-estimated soil vapor flux using soil vapor and groundwater sampling results from the B515 and FSDF sampling locations (Figure 12) show that the estimates of flux from groundwater are 10 to 142 times higher than the estimated flux from the soil vapor samples.

6.4 PERFORMANCE SUMMARY OF THE VAPOR TRANSPORT MODEL

The following are the conclusions regarding model performance along with the supporting basis:

1. Low level concentrations of TCE in ambient air (i.e., less than 30 ppt) that are ubiquitous in southern California air as reported in regulatory agency documents (and not related to SSFL operations) affect the ability to interpret and attribute vapor fluxes that are measured at similar or lower values. Sporadic detections in flux chamber measurements at concentrations in ranges similar to ambient air cannot be distinguished from vapor transport from groundwater.

<u>Basis for Conclusion:</u>

- Concentrations of TCE in ambient air at the LOX source area were all less than 25 ppt, including monitoring stations both up- and down-wind. Two samples were non-detect for TCE. Comparison of these results to ambient air values reported in technical references issued by regulatory agencies (EPA, 2000, ATSDR, and CARB, 1990) report TCE in ambient air at similar or greater concentrations at locations proximal to the SSFL, within southern California, and across the United States. The values measured at the SSFL are on the low end of the range of measured values. These results are presented graphically on Figure 9. Hence, it is likely that the TCE values measured in ambient air at the LOX study area are indistinguishable from non-site-related regional concentrations.

2. The model, in its present form, estimates vapor fluxes from dissolved VOCs in groundwater at rates greater than measured fluxes.

Basis for Conclusion:

- VOC concentrations in near-surface groundwater can be used in the vapor migration model. The deepest soil vapor sample collected could be used and less-conservatively predicts soil flux compared to groundwater.
    - Compound A source data (ES-24) provide conservative groundwater-concentration-based flux estimates that are a factor of 11 greater than the average measured flux. This site has near-surface groundwater at 20 feet bgs with vapor migration through 19 feet of bedrock. (Figures 3 and 10, and Table 24). Note that this location does not have an appreciable thickness of soil (i.e., greater than 3.5 feet) overlying the groundwater source area.
    - FSDF source data (RS-54) provide conservative groundwater-concentration-based flux estimates that are a factor of 111 greater than the average measured flux. This site has near-surface groundwater at 17.5 feet bgs with vapor migration through 3 feet of bedrock (Figures 3 and 10, and Table 24). The deepest measured soil vapor result (at 7 feet bgs) over-predicts flux by a factor of 11. Note that this location had the source soils excavated and transported off-site for disposal and was backfilled with soils from a clean borrow source at the SSFL.
    - CTL-III groundwater plume data (ES-3, i.e., distal) provide conservative groundwater-concentration-based flux estimates that are approximately 17 times greater than the average measured flux. This site has groundwater at 14 feet bgs with vapor migration through 11 feet of bedrock (Figures 3 and 10, and Table 24). Note that this location does not have an appreciable thickness of soil (i.e., greater than 3.5 feet) overlying the groundwater source area.
    - B515 groundwater plume data (ES-21, i.e., distal) provide conservative groundwater-concentration-based flux estimates that are approximately 240 times greater than average measured flux (Figures 3 and 10 and Table 24). The groundwater-based flux estimates are greater than the soil vapor-based flux estimates by a factor of about 140 (Figure 12 and Table 26). Note that the deepest soil vapor sample above the saturated zone is at 10 feet bgs (15 and 20 feet are within the saturated zone). Although the shallower 5 foot sample predicts an even more conservative flux, the modeled results using the deeper soil vapor samples are also representative but closer to the modeled flux (i.e., within a factor of 5, see Figure 11 and Table 25).
- Chatsworth formation groundwater concentrations can be used in the vapor migration model.
    - Delta source data (HAR-07) provide estimated fluxes based on groundwater concentrations that are approximately equal to maximum measured flux. This site has groundwater at 48 feet bgs with vapor migration through 46 feet of bedrock (Figures 3 and 10, and Table 24).

- TCE was not detected in most vapor flux measurements at the B-1 (RD-72), LOX (RD-52A), North Control (RD-92) and South Control (RD-05A) sampling locations. Of the 12 vapor flux samples collected at these four locations, nine of the results were non-detect for TCE and the three remaining results reported TCE at estimated concentrations within a factor of 3 of the method detection limit of ~0.015 $\mu g/m^3$. These low level vapor fluxes (as reported by the laboratory and prior to conversion to a flux, see footnote 6) are indistinguishable from regional concentrations of TCE in ambient air. These detections are shown graphically on Figure 13, along with ambient air data from regulatory agency reports and from the LOX source area monitoring. Model-calculated fluxes at the B-1 and LOX groundwater areas are 2 to 4 orders of magnitude below the few measured values and regionally-measured ambient air results. Additional measurements will not be able to resolve this apparent discrepancy between low-level detections and the model estimates because of the inherent ability of the model to predict values orders of magnitude below the current capabilities of analytical instrumentation and the ubiquitous background concentration of TCE in ambient air.

3. At locations with elevated concentrations of VOCs in vadose zone soils, the model should use soil vapor data to obtain estimates of the vapor flux. In these instances, groundwater sampling results should not be used, as they produce estimates that are lower than the measured fluxes. When applying vapor sampling results to the model, the average flux from all samples in the vertical profile should be used because individual sample results from within the vertical profile both overestimate and underestimate the fluxes when compared to actual measurements. Alternately, the averaged flux overestimates the measured flux in all but one instance and hence is conservative in most cases (Table 25).

   - At the CTL-III source (RD-46A), using TCE concentrations in groundwater as input to the vapor migration data results in fluxes that are underestimated by a factor of about 1600 (Figure 10 and Table 24). TCE concentrations in soil vapor samples are near or greater than 1,000,000 $\mu g/m^3$ at depths of 10 feet and 15 feet bgs. Application of the model using the soil vapor sampling results produces estimates that are near or modestly above the measured vapor flux (Figure 11 and Table 25). Soil vapor data will be more representative of the potential fluxes as the transport mechanism is simpler to model through a single lithology and the availability of direct vapor measurements does not require a calculation to partition the vapor phase from the groundwater.

4. The data collected in this study provide the information necessary to apply the model appropriately to the various settings that are encountered at the SSFL.

6.5 MODEL SENSITIVITY ANALYSIS

The objective of the sensitivity/uncertainty analysis is to quantify the effect of vapor migration model inputs relative to the baseline. This analysis focused on evaluating the

sensitivity of SSFL-specific input parameters on the vapor migration model. The sensitivity analysis was conducted for specific SSFL site conditions and subsurface media data used as modeling input. The sensitivity analysis was conducted by sequentially varying site-specific inputs by +/- 50 percent and evaluating resulting changes in model output. The site-specific parameters that were evaluated include:

- Soil Air Content
- Weathered Bedrock Air Content
- Unweathered Bedrock Air Content
- Weathered Bedrock Thickness
- Weathered bedrock fractures

Moisture content and porosity were not evaluated as they are related to air content and ultimately it is the resulting change in the calculated air content that affects the model. Overall model sensitivity is discussed in the original source document prepared by Dr. David McWhorter that was used to develop the model algorithm and is provided in Appendix H. The results of the sensitivity analysis are presented in Table 28. Table 28 presents the flux results based on the changes for each of the inputs for each groundwater scenario as well as a ratio of the revised flux results to the baseline condition.

For the near-surface groundwater scenarios, the air content in soil and weathered bedrock were the most sensitive parameters. A 50 percent reduction in soil air content caused reductions in flux by factors up to 10. A 50 percent increase in soil air content caused increases in flux by a factor of 4. A 50 percent reduction in weathered bedrock air content caused reductions in flux by factors up to 10. A 50 percent increase in weathered bedrock air content caused increases in flux by a factor of 2.

For the Chatsworth formation groundwater scenarios, the air content of the unweathered bedrock was the most sensitive parameter. A 50 percent reduction in unweathered bedrock air content caused reductions in flux of over 10 orders of magnitude. A 50 percent increase in unweathered bedrock air content caused increases in flux of two to nearly four orders of magnitude. This large variability is to be expected as described in

detail in Appendix H. The thickness of the weathered bedrock showed mild sensitivity as well. Due to the greater depths to Chatsworth formation groundwater compared to near-surface groundwater, the Chatsworth formation groundwater scenarios indicated much higher sensitivities to the model.

Although this analysis shows that appreciable variances in a few parameters can create greatly disparate estimates of the modeled flux, the true conditions encountered at the site do not exhibit such fluctuations, particularly as it relates to the air content of the unweathered bedrock. Relationships between groundwater recharge and the unsaturated hydraulic conductivity of the rock matrix, measurements of water content in rock samples and borehole geophysical measurements all show that the air content in the unweathered bedrock is low and quantitation puts this value at about 0.3. Furthermore, the borehole geophysical logs show intervals where the air content is appreciably lower than this value due to the presence of finer-grained siltstones and shales that retain more water within the pore space. Finally, the analysis of the modeled and measured fluxes that are presented in this report demonstrate that the model conservatively predicts the flux relative to the measured values and hence accounts for location-specific uncertainties in these parameters.

6.6 APPLYING THE VAPOR MIGRATION MODEL AT THE SSFL

The work performed to validate the vapor migration model at the SSFL has demonstrated that its proper application produces results that are greater than measured values and hence they are conservative. This conclusion allows for the model to be applied site-wide to characterize the VOC inhalation pathway for the risk assessment process. However, the inputs to the model need to be applied in a methodical way to estimate fluxes that are conservative. Therefore, a procedure has been developed to ensure this outcome and it is provided below.

Procedure for Applying Vapor Migration Model at the SSFL

1. Evaluate the applicability of the conceptual site model to the location where the modeling is to be applied. Review source input, geologic and hydrogeologic conditions present at the site, particularly: the location where VOCs entered the ground, chemical sampling results, the presence and thickness of unconsolidated sediments and the occurrence of first-encountered groundwater.
2. Determine the type of environmental media samples from which volatile organic compound results are available (i.e., soil matrix, soil vapor, and/or groundwater).
3. For modeling indoor air concentrations from soil:
    a. select sample results in the following order for use as input into the Johnson-Ettinger model (the standard DTSC model version is used for soil): soil vapor, soil matrix.
    b. Generate a soil vapor input concentration utilizing all the available soil vapor and/or appropriate soil matrix data converted to soil vapor concentrations by calculating the upper 95 percentile confidence limit of the mean.
    c. Use location-specific inputs for depth and thickness and the other input parameters specified in Table 23 of this report when applying the vapor migration model.
4. For modeling indoor air concentrations from groundwater:
    a. Select sample results as follows for use as input into the SSFL-modified Johnson-Ettinger (1991) model (the subject of this vapor migration validation study): VOC concentrations in first-encountered groundwater.
    b. Use the maximum concentration detected over the most recent 3-year sampling timeframe in the vapor migration model to characterize current exposures.
    c. Use location-specific inputs for depth and thickness and the other input parameters specified in Table 23 of this report when applying the vapor migration model.
5. If the vapor migration model estimates are lower than the regional ambient air values (~30 parts per trillion), then conclude that the flux from the groundwater is indistinguishable from regional ambient conditions and do not include this estimate in the risk quantification. Include this finding in the conservatism/uncertainty discussion in the risk assessment.
6. Estimate indoor air cancer and non-cancer risks, as appropriate, from the modeled indoor air concentrations and present in risk summary tables for soil-related risks and groundwater-related risks.
7. Select the highest of the two potential sources of indoor air concentrations, soil matrix or groundwater, and include in the overall total risk estimate for each receptor.

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TABLES

TABLE 1
SAMPLE TYPES AND LOCATION NAMES FOR VAPOR MIGRATION MODEL VALIDATION STUDY
Santa Susana Field Laboratory
Ventura County, CA

Site	Site Type	Vapor Flux Location	Soil Vapor Location	Soil Boring Location	Groundwater Well
Compound A	Source Area	CFVF01/CFVF02	None	None	ES-24
FSDF	Source Area	FSVF01	FSSV03	FSBS01	RS-54
DELTA	Source Area	DAVF01/DAVF02	None	None	HAR-07
CTL-III	Source Area	CLVF03	CLSV89	CLBS85	RD-46A
CTL-III	Groundwater Plume	CLVF01/CLVF02	None	None	ES-03
RD-9/B515	Groundwater Plume	BTVF01	BTSV11	BTBS02	ES-21
RD-72	Groundwater Plume	B1VF01/B1VF02	None	None	RD-72
RD-52A	Groundwater Plume	LXVF01/LXVF02	NA	None	RD-52A
Control (North)	Control	NCVF01/NCVF02	None	None	RD-92
Control (South)	Control	BZVF01	BZSV01	BZBS01	RD-05A

Soil vapor probes and soil borings were not installed when the thickness of the soil was less than 3.5 feet.

TABLE 2
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SAMPLES FROM COMPOUND A
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
CFVF01S01	7/18/2006	VF	0	--	0.46 J	--	--	--	--
CFVF01S02	7/21/2006	VF	0	--	0.17	--	--	--	--
CFVF02S01	7/18/2006	VF	0	--	0.33	--	--	--	--
CFVF02S02	7/21/2006	VF	0	--	0.41	--	--	--	--
ES-24	8/30/2006	NSGW	30	0.52 J	5.7E+03	320	36	150	1.3

Sample Matrix:
VF = vapor flux
NSGW = near surface groundwater

VOC result units:
Vapor = µg/m3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes:
ug/L = micorgrams per liter
ug/m3 = micrograms per cubic meter
bgs = below ground surface

TABLE 3
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR, SOIL MATRIX AND GROUNDWATER SAMPLES FROM THE FSDF
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
FSVF01S01	7/18/2006	VF	0	--	0.63 J	--	--	--	--	--	--	--	--	--	--
FSVF01S02	7/21/2006	VF	0	--	0.17	--	--	--	--	--	--	--	--	--	--
FSSV03S01	7/27/2006	SV	4	< 27	211 J	< 16	< 14	9.7 J	< 10	--	--	--	--	--	--
FSSV03S02	7/27/2006	SV	7	26 J	1.2E+04 J	681 J	158 J	1.0E+03 J	< 58	--	--	--	--	--	--
FSSV03D01	7/27/2006	SV	7	37 J	1.2E+04 J	772 J	109 J	1.1E+03 J	26 J	--	--	--	--	--	--
FSBS01S01	7/27/2006	S	5	--	< 0.37	--	--	--	--	23	92	2.7	0.45	27	3.10E-05
FSBS01S02	7/27/2006	S	8	--	18	--	--	--	--	18	101	2.7	0.4	22	5.90E-07
RS-54	2/23/2006	NSGW	38	< 16	2.1E+03	34 J	< 14	2.4E+03	< 13	--	--	--	--	--	--

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux
NSGW = near surface groundwater

VOC result units:
Soil = µg/kg
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Note: Physical property measurements did not go thorough formal validation procedures
ug/kg = micrograms per kilogram
ug/L = micorgrams per liter
cm/s = centimeters per second
ug/m^3 = micrograms per cubic meter
pfc = pounds per cubic foot
bgs = below ground surface
FSDF = Former Sodium Disposal Facility

TABLE 4
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SMAPLES FROM DELTA
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
DAVF01D01	7/21/2006	VF	0	--	0.12 J	--	--	--	--
DAVF01S01	7/18/2006	VF	0	--	0.15 J	--	--	--	--
DAVF01S02	7/21/2006	VF	0	--	0.16 J	--	--	--	--
DAVF02S01	7/18/2006	VF	0	--	< 0.15	--	--	--	--
DAVF02S02	7/21/2006	VF	0	--	0.23 J	--	--	--	--
HAR-07	8/15/2006	CFGW	100	< 3.2	6.7E+03	1.1E+03	55	< 4.2	21

Sample Matrix:
VF = vapor flux
CFGW = Chatsworth formation groundwater

VOC result units:
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: bgs = below ground surface
ug/L = micorgrams per liter
ug/m^3 = micrograms per cubic meter

TABLE 5
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR, SOIL MATRIX AND GROUNDWATER SAMPLES FROM CTL-111
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
CLVF03S01	7/17/2006	VF	0	--	123 J	--	--	--	--	--	--	--	--	--	--
CLVF03S02	7/20/2006	VF	0	--	116 J	--	--	--	--	--	--	--	--	--	--
CLSV89S01	7/27/2006	SV	5	< 24	552 J	< 14	< 13	< 14	< 9	--	--	--	--	--	--
CLSV89S02	7/27/2006	SV	10	< 1.2E+05	1.5E+06	< 6.8E+04	< 5.8E+04	< 6.9E+04	< 4.3E+04	--	--	--	--	--	--
CLSV89S03	7/27/2006	SV	15	< 2.3E+04	8.6E+05 J	< 1.3E+04	< 1.2E+04	< 1.3E+04	< 8.5E+03	--	--	--	--	--	--
CLBS85D01	7/27/2006	S	16	--	26	--	--	--	--	--	--	--	--	--	--
CLBS85S01	7/27/2006	S	6	--	6.2	--	--	--	--	15	105	2.7	0.41	19	2.50E-07
CLBS85S02	7/27/2006	S	11	--	500	--	--	--	--	12	113	2.7	0.32	16	2.90E-06
CLBS85S03	7/27/2006	S	15.5	--	370	--	--	--	--	11	100	2.7	0.38	15	3.70E-06
RD-46A	8/23/2006	CFGW	140	< 13	3.2E+03	140	< 11	< 17	< 10	--	--	--	--	--	--

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux
CFGW = Chatsworth formation groundwater

VOC result units:
Soil = µg/kg
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Note: Physical property measurements did not go thorough formal validation procedures
ug/kg = micrograms per kilogram
ug/L = micorgrams per liter
cm/s = centimeters per second
ug/m^3 = micrograms per cubic meter
pfc = pounds per cubic foot
bgs = below ground surface

TABLE 6
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SAMPLES FROM AREA NORTH OF CTL-III
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
CLVF01S01	7/17/2006	VF	0	--	< 0.15	--	--	--	--
CLVF01S02	7/20/2006	VF	0	--	0.15 J	--	--	--	--
CLVF02S01	7/17/2006	VF	0	--	< 0.16	--	--	--	--
CLVF02S02	7/20/2006	VF	0	--	< 0.15	--	--	--	--
ES-03	8/28/2006	NSGW	27	< 0.32	270	83 J	16	0.49 J	< 0.26

Sample Matrix:
VF = vapor flux
NSGW = near surface groundwater

VOC result units:
Vapor = µg/m3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: bgs = below ground surface
ug/L = micorgrams per liter
ug/m^3 = micrograms per cubic meter

TABLE 7
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR, SOIL MATRIX AND GROUNDWATER SAMPLES FROM THE B515 AREA
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
BTVF01S01	7/18/2006	VF	0	--	0.036 J	--	--	--	--	--	--	--	--	--	--
BTVF01S02	7/21/2006	VF	0	--	< 0.16	--	--	--	--	--	--	--	--	--	--
BTSV11S01	7/26/2006	SV	5	< 1.2E+05	2.7E+05	8.4E+03 J	< 6.2E+04	< 7.4E+04	< 4.7E+04	--	--	--	--	--	--
BTSV11S02	7/26/2006	SV	10	6.5 J	310 J	10 J	< 6.0	< 7.0	< 4.5	--	--	--	--	--	--
BTSV11S03	7/26/2006	SV	15	1.3 J	62 J	< 3.2	< 2.9	< 3.2	1.1 J	--	--	--	--	--	--
BTSV11S04	7/26/2006	SV	20	72 J	4.2E+04 J	2.7E+03 J	739 J	< 217	< 140	--	--	--	--	--	--
BTBS02S01	7/27/2006	S	6	--	< 0.31	--	--	--	--	12	105	2.7	0.38	15	8.90E-06
BTBS02S01	7/27/2006	S	11	--	< 0.32	--	--	--	--	15	111	2.7	0.34	19	4.40E-06
BTBS02S03	7/27/2006	S	16	--	--	--	--	--	--	16	98	2.7	0.42	21	2.40E-06
BTBS02S04	7/27/2006	S	20	--	--	--	--	--	--	20	98	2.7	0.41	24	2.10E-07
ES-21	8/30/2006	NSGW	35	< 0.32	210	61	1.2	< 0.42	< 0.26	--	--	--	--	--	--

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux
NSGW = near surface groundwater

VOC result units:
Soil = µg/kg
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Note: Physical property measurements did not go thorough formal validation procedures
ug/kg = micrograms per kilogram
ug/L = micorgrams per liter
cm/s = centimeters per second
ug/m^3 = micrograms per cubic meter
pfc = pounds per cubic foot
bgs = below ground surface

TABLE 8
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SAMPLES FROM RD-72
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
B1VF01S01	7/17/2006	VF	0	--	0.037 J	--	--	--	--
B1VF01S02	7/20/2006	VF	0	--	< 0.38	--	--	--	--
B1VF02S01	7/17/2006	VF	0	--	< 0.16	--	--	--	--
B1VF02S02	7/20/2006	VF	0	--	< 0.16	--	--	--	--
RD-72	8/17/2006	CFGW	115	< 16	20 J	2.0E+03	< 14	61	< 13

Sample Matrix:
VF = vapor flux
CFGW = Chatsworth formation groundwater

VOC result units:
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes:
bgs = below ground surface
ug/L = micorgrams per liter
ug/m^3 = micrograms per cubic meter

TABLE 9
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SAMPLES FROM RD-52A
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
LXVF01D01	7/17/2006	VF	0	--	< 0.16	--	--	--	--
LXVF01S01	7/17/2006	VF	0	--	0.018 J	--	--	--	--
LXVF01S02	7/20/2006	VF	0	--	< 0.15	--	--	--	--
LXVF02S01	7/17/2006	VF	0	--	< 0.15	--	--	--	--
LXVF02S02	7/20/2006	VF	0	--	< 0.16	--	--	--	--
RD-52A	3/15/2005	CFGW	137	< 0.32	110	39	7.1	0.6 J	2.7

Sample Matrix:
VF = vapor flux
CFGW = Chatsworth formation groundwater

VOC result units:
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: bgs = below ground surface
ug/L = micorgrams per liter
ug/m^3 = micrograms per cubic meter

TABLE 10
LABORATORY RESULTS OF VAPOR FLUX AND GROUNDWATER SAMPLES FROM CONTROL NORTH (RD-92)
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
NCVF01S01	7/18/2006	VF	0	--	0.026 J	--	--	--	--
NCVF01S02	7/21/2006	VF	0	--	< 0.16	--	--	--	--
RD-92	8/25/2006	CFGW	105	< 0.32	< 0.26	< 0.32	< 0.27	< 0.42	0.26

Sample Matrix:
VF = vapor flux
CFGW = Chatsworth formation groundwater

VOC result units:
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: bgs = below ground surface
ug/L = micorgrams per liter
ug/m^3 = micrograms per cubic meter

TABLE 11
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR, SOIL MATRIX AND GROUNDWATER SAMPLES FROM CONROL SOUTH (RD-05A)
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
BZVF01S01	7/17/2006	VF	0	--	< 0.15	--	--	--	--	--	--	--	--	--	--
BZVF01S02	7/20/2006	VF	0	--	< 0.15	--	--	--	--	--	--	--	--	--	--
BZSV01S01	7/27/2006	SV	5	19 J	7.3E+03 J	447 J	57 J	< 69	8.5 J	--	--	--	--	--	--
BZSV01S01	11/1/2006	SV	5	--	3.8E+03 J	--	--	--	--	--	--	--	--	--	--
BZSV01S02	7/27/2006	SV	10	2.9 J	123 J	< 6.3	< 5.7	< 6.3	< 4.1	--	--	--	--	--	--
BZSV01S02	11/1/2006	SV	10	--	1.9E+03 J	--	--	--	--	--	--	--	--	--	--
BZSV01S03	7/27/2006	SV	13	2.9 J	975 J	49 J	15 J	< 6.7	< 4.3	--	--	--	--	--	--
BZSV01S03	11/1/2006	SV	13	--	3.2E+03 J	--	--	--	--	--	--	--	--	--	--
BZBS01S01	7/27/2006	S	6	--	< 0.32	--	--	--	--	9.2	91	2.7	0.42	13	2.00E-05
BZBS01S02	7/27/2006	S	11	--	< 0.33	--	--	--	--	4.6	117	2.7	0.32	7	1.40E-05
BZBS01S03	7/27/2006	S	16	--	< 0.34	--	--	--	--	15	101	2.7	0.43	20	9.60E-05
RD-05A	8/3/2006	CFGW	158	< 0.32	< 0.26	< 0.32	< 0.27	< 0.42	< 0.26	--	--	--	--	--	--

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux
CFGW = chatsworth formation groundwater

VOC result units:
Soil = µg/kg
Vapor = µg/m^3
Groundwater = µg/L

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: Physical property measurements did not go thorough formal validation procedures
ug/kg = micrograms per kilogram
ug/L = micorgrams per liter
cm/s = centimeters per second
ug/m^3 = micrograms per cubic meter
pfc = pounds per cubic foot
bgs = below ground surface

TABLE 12
SAMPLE TYPES AND LOCATION NAMES FOR LOX STUDY
Santa Susana Field Laboratory
Ventura County, CA

Group	Vapor Flux Location	Soil Vapor Location	Soil Boring Location	Remarks
Ambient Air				Ambient Air results. LXAA01 through LXAA07
LXSA21,LXBS23,LXVF04	LXVF04	LXSA21	LXBS23	Submitted to lab under LXSA21. Soil Vapor sample collected near LXSV38 and GPS'd as LXSV38
LXSA22, LXBS24,LXVF05	LXVF05	LXSA22	LXBS24	Submitted to lab under LXSA22. Soil Vapor sample collected near LXSV48 and GPS'd as LXSV48
LXSA23, LXBS25,LXVF06	LXVF06	LXSA23	LXBS25	Submitted to lab under LXSA23. Soil Vapor sample collected near LXSV69 and GPS'd as LXSV69
LXSA24	NONE	LXSA24	NA	Submitted to lab under LXSA24. Soil Vapor sample collected near LXSV68 and GPS'd as LXSV68
LXSA25, LXBS27, LXVF03	LXVF03	LXSA25	LXBS27	Submitted to lab under LXSA25. Soil Vapor sample collected near LXSV70 and GPS'd as LXSV70
LXSA27_LXBS26	NONE	LXSA27	LXBS26	Submitted to lab under LXSA27. Soil Vapor sample collected near LXSV73 and GPS'd as LXSV73.
LXSV72	NONE	LXSV72	NA	This sample was originally mislabeled as LXSV74 (S01 and S02). Sample location should have been labeled as LXSA26.
LXSV74	NONE	LXSV74	NA	This sample was originally mislabeled as LXSV72 (S01 and S02). Sample location should have been labeled as LXSA28.
LXBS28	NONE	NONE	LXBS28	
LXBS29	NONE	NONE	LXBS29	
LXBS30	NONE	NONE	LXBS30	

NA = No co-located sample associated.
GPS = Global Positioning System

TABLE 13
LABORATORY RESULTS OF AMBIENT AIR SAMPLES COLLECTED AT AND NEAR LOX
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Time (PM)	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
LXAA01BS01	7/19/2006	2:58 - 5:30	Air	0	0.16 J	0.13 J	< 0.43	< 0.39	< 0.43	< 0.28
LXAA01S01	7/19/2006	1:28 - 2:42	Air	0	0.093 J	0.027 J	< 0.12	< 0.1	< 0.12	< 0.074
LXAA02S01	7/19/2006	1:28 - 5:35	Air	0	0.038 J	0.028 J	< 0.18	< 0.16	< 0.18	< 0.11
LXAA03S01	7/19/2006	1:37 - 5:37	Air	0	0.089 J	0.03 J	< 0.17	< 0.15	< 0.17	< 0.11
LXAA04S01	7/19/2006	1:31 - 5:31	Air	0	0.065 J	0.066 J	< 0.16	< 0.14	< 0.16	0.019 J
LXAA05S01	7/19/2006	1:26 - 5:38	Air	0	0.075 J	< 0.22	< 0.16	< 0.14	< 0.16	< 0.1
LXAA06S01	7/19/2006	1:24 - 5:24	Air	0	0.085 J	< 0.19	< 0.14	< 0.13	< 0.14	< 0.091
LXAA07S01	7/19/2006	1:25 - 5:30	Air	0	0.081 J	0.13 J	< 0.14	< 0.13	< 0.14	< 0.092

VOC result units:

Air = $\mu g/m^3$

Result Data Qualifiers:

All non-detected result were preceded by "<"
J = estimated value
bgs = below ground surface

TABLE 14
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR AND SOIL MATRIX SAMPLES COLLECTED AT LOX LOCATIONS LXVF04, LXSA21 AND LXBS23
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
LXVF04S01	7/19/2006	VF	0	< 0.19	0.17	< 0.11	< 0.1	0.024 J	< 0.073	--	--	--	--	--	--
LXSA21S01	10/30/2006	SV	5	10 J	349 J	< 15	< 13	< 3.0	< 1.9	--	--	--	--	--	--
LXBS23S01	7/26/2006	S	1.5	--	--	--	--	--	--	6.7	79.51	2.7	0.53	10	9.06E-06
LXBS23S02	7/26/2006	S	5.5	< 0.53	0.37 J	< 0.89	< 0.44	< 0.49	< 0.98	8.5	99.19	2.69	0.41	12	1.79E-05

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux

VOC result units:
Soil = µg/kg
Vapor = µg/m^3

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Note: Physical property measurements did not go thorough formal validation procedures
pcf = pounds per cubic foot
cm/sec = centimeters per second
bgs = below ground surface

TABLE 15
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR AND SOIL MATRIX SAMPLES COLLECTED AT LOX LOCATIONS LXVF05, LXSA22 AND LXBS24
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
LXVF05S01	7/19/2006	VF	0	< 924	4.6E+03	144 J	< 461	< 545	< 345	--	--	--	--	--	--
LXSA22S01	10/30/2006	SV	5	< 4.7E+03	1.5E+06	4.4E+04	2.1E+04	< 536	< 346	--	--	--	--	--	--
LXSA22S02	10/30/2006	SV	10	< 4.5E+03	1.6E+06 J	1.1E+05 J	3.2E+04	607	< 330						
LXBS24S01	7/26/2006	S	1.5	--	--	--	--	--	--	6.7	90.79	2.7	0.46	10	2.13E-06
LXBS24S02	7/26/2006	S	5.5	< 0.47	38	1.6 J	< 0.4	< 0.43	< 0.88	14.8	82.49	2.67	0.49	19	2.22E-04
LXBS24S03	7/26/2006	S	10.5	--	--	--	--	--	--	16	88.85	2.74	0.48	20	2.31E-05

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux

VOC result units:
Soil = µg/kg
Vapor = µg/m^3

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: Physical property measurements did not go thorough formal validation procedures
pcf = pounds per cubic foot
cm/sec = centimeters per second
bgs = below ground surface

TABLE 16
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR AND MATRIX SAMPLES COLLECTED AT LOX LOCATIONS LXVF06, LXSA23 AND LXBS25
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
LXVF06S01	7/19/2006	VF	0	0.12 J	25	0.31	0.6	< 0.29	< 0.19	--	--	--	--	--	--
LXSA23S01	7/25/2006	SV	5	< 2.5E+05	7.0E+05 J	2.2E+04 J	< 6.3E+04	< 7.4E+04	< 4.7E+04	--	--	--	--	--	--
LXSA23S01	10/31/2006	SV	5	5.0E+03 J	2.4E+06	9.2E+04	3.5E+04	< 663	< 428	--	--	--	--	--	--
LXSA23D01	10/31/2006	SV	5	3.0E+03 J	2.4E+06	1.0E+05	3.2E+04	< 663	< 428	--	--	--	--	--	--
LXSA23S02	7/25/2006	SV	10	< 6.5E+04	6.5E+05	2.1E+04 J	< 3.3E+04	< 3.9E+04	< 2.4E+04	--	--	--	--	--	--
LXBS25D01	7/26/2006	S	5.5	< 0.48	< 0.33	< 0.81	< 0.4	< 0.44	< 0.89	--	--	--	--	--	--
LXBS25S01	7/26/2006	S	1.5	--	--	--	--	--	--	2.6	83.7	2.68	0.5	4	7.78E-06
LXBS25S02	7/26/2006	S	5.5	< 0.49	5.1	< 0.83	< 0.41	< 0.45	< 0.91	10.2	100.78	2.68	0.4	14	1.20E-04
LXBS25S03	7/26/2006	S	10.5	--	--	--	--	--	--	8.8	77.71	2.69	0.54	12	7.76E-07

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux

VOC result units:
Soil = µg/kg
Vapor = µg/m^3

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: Physical property measurements did not go thorough formal validation procedures
pcf = pounds per cubic foot
cm/sec = centimeters per second
bgs = below ground surface

TABLE 17
LABORATORY RESULTS OF VAPOR FLUX, SOIL VAPOR AND SOIL MATRIX XAMPLES COLLECTED FROM LOX LOCATIONS LXVF03, LXSA25 AND LXBS27
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
LXVF03S01	7/19/2006	VF	0	0.84 J	225 J	< 5.6	< 5.0	< 5.6	< 3.6	--	--	--	--	--	--
LXVF03D01	7/19/2006	VF	0	3.5 J	726	9.3 J	< 12	< 14	< 8.8	--	--	--	--	--	--
LXVF03S02	7/19/2006	VF	0	2.5 J	536 J	7.9 J	4.5 J	< 5.6	< 3.6	--	--	--	--	--	--
LXVF03S03	7/19/2006	VF	0	68 J	1.4E+03	40 J	< 326	< 385	< 244	--	--	--	--	--	--
LXVF03S04	7/19/2006	VF	0	1.9 J	412	7.0	3.4 J	< 5.6	< 3.6	--	--	--	--	--	--
LXSA25S01	7/26/2006	SV	5	1.4E+04 J	5.6E+06 J	2.8E+05 J	1.5E+05 J	< 6.8E+04	3.0E+04 J	--	--	--	--	--	--
LXSA25S02	7/26/2006	SV	10	2.0E+04 J	2.0E+07 J	3.4E+06 J	1.1E+06 J	< 1.1E+05	4.7E+05 J	--	--	--	--	--	--
LXSA25D01	7/26/2006	SV	10	1.5E+04 J	1.9E+07 J	3.1E+06 J	1.1E+06 J	< 8.5E+04	3.0E+05 J	--	--	--	--	--	--
LXSA25S02	10/31/2006	SV	10	5.1E+04 J	1.5E+07 J	2.2E+06 J	7.0E+05 J	1.3E+04 J	2.1E+05 J	--	--	--	--	--	--
LXSA25S03	7/26/2006	SV	15	< 5.3E+03	7.4E+04 J	3.0E+04 J	1.3E+04 J	< 3.1E+03	1.1E+03 J	--	--	--	--	--	--
LXBS27S01	7/26/2006	S	1.5	--	--	--	--	--	--	19.3	110.08	2.62	0.43	31	9.35E-06
LXBS27S02	7/26/2006	S	3	< 0.49	20	< 0.83	< 0.41	< 0.45	< 0.91	6.2	73.7	2.65	0.55	8	1.26E-04
LXBS27S03	7/26/2006	S	5.5	0.84 J	890	41	2.5	< 0.52	< 1.1	9.5	104.13	2.7	0.45	15	7.23E-06
LXBS27S04	7/26/2006	S	8	--	--	--	--	--	--	14	109.74	2.68	0.42	22	9.55E-05
LXBS27S05	7/26/2006	S	15.5	--	--	--	--	--	--	9.8	114.63	2.73	0.39	15	1.34E-05

Sample Matrix:
S = soil
SV = soil vapor
VF = vapor flux

VOC result units:
Soil = µg/kg
Vapor = µg/m^3

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: Physical property measurements did not go thorough formal validation procedures
cm/sec = centimeters per second
bgs = below ground surface

TABLE 18
LABORATORY RESULTS OF SOIL VAPOR AND SOIL MATRIX SAMPLES COLLECTED AT LOX LOCATIONS LXSA27 AND LXBS26
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Toal Porosity	Saturation (%)	Conductivity (cm/sec)
LXSA27S01	7/26/2006	SV	13	< 1.6E+04	1.7E+05 J	7.6E+03 J	< 8.1E+03	< 9.6E+03	< 6.1E+03	--	--	--	--	--	--
LXSA27S01	11/1/2006	SV	13	< 1.2E+03	1.9E+04 J	2.9E+03 J	656 J	< 741	< 478	--	--	--	--	--	--
LXBS26S01	7/26/2006	S	6.5	< 0.49	< 0.34	< 0.83	< 0.41	< 0.45	< 0.91	15.6	98.61	2.64	0.48	25	1.74E-04
LXBS26S02	7/26/2006	S	10.5	< 0.55	5.3	< 0.93	< 0.46	< 0.5	< 1.0	19.5	103.5	2.69	0.49	31	2.99E-04

Sample Matrix:
S = soil
SV = soil vapor

VOC result units:
Soil = µg/kg
Vapor = µg/m^3

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

Notes: Physical property measurements did not go thorough formal validation procedures
ug/kg = micrograms per kilogram

ug/m3 = micrograms per cubic meter
cm/sec = centimeters per second
bgs = below ground surface

TABLE 19
LABORATORY RESULTS OF SOIL VAPOR SAMPLES COLLECTED AT LOX LOCATIONS LXSA24, LXSV72 AND LXSV74
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride
LXSA24									
LXSA24S01	7/26/2006	SV	17	< 327	1.7E+04 J	3.9E+03 J	1.1E+03 J	< 191	93 J
LXSA24S01	10/31/2006	SV	17	2.6E+05 J	3.1E+05 J	3.0E+04 UJ	1.9E+04 UJ	4.7E+04 J	4.3E+03 UJ
LXSA72									
LXSV72S01	10/31/2006	SV	9	1.1E+03 J	2.4E+06 J	4.1E+05 J	3.9E+05 J	3.6E+03	4.3E+03
LXSA74									
LXSV74S01	10/31/2006	SV	5	1.3E+03 J	1.6E+05	2.3E+03 J	< 2.6E+03	< 606	< 391
LXSV74S02	10/31/2006	SV	10	< 1.1E+03	8.4E+03	369 J	143 J	< 651	< 420

Sample Matrix:
SV = soil vapor

bgs=below ground surface

VOC result units:
Vapor = $\mu g/m^3$

Result Data Qualifiers:
All non-detected result were preceded by "<"
J = estimated value

TABLE 20
Laboratory Results of Soil Matrix Samples Collected at LOX Locations LXSB28, LXSB29 and LXSB30
Santa Susana Field Laboratory
Ventura County, CA

Co-Located Sampling Locations	Date Collected	Sample Matrix	Depth (feet bgs)	Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,1-Dichloroethene	Vinyl Chloride	Moisture (%)	Bulk Density (pcf)	Specific Gravity	Total Porosity	Saturation (%)	Conductivity (cm/sec)
LXBS28															
LXBS28S01	7/25/2006	S	5.5	< 39	1.7E+03	< 43	< 45	< 43	< 58	12.5	102.74	2.67	0.45	19.9	1.06E-05
LXBS28S02	7/25/2006	S	10.5	--	--	--	--	--	--	14,5	98.72	2.11	0.34	27.5	7.61E-08
LXBS28S03	7/25/2006	S	15.5	--	--	--	--	--	--	25.6	92.9	2.62	0.49	25.2	2.76E-05
LXBS29															
LXBS29S01	7/25/2006	S	3.5	--	--	--	--	--	--	9.6	80.89	2.69	0.56	15.3	6.45E-05
LXBS30S01															
LXBS30S01	7/25/2006	S	3.5	--	--	--	--	--	--	9.7	89.14	2.66	0.51	15.5	6.45E-05

Sample Matrix:
S = soil

VOC result units:
Soil = µg/kg (micrograms per liter)

Result Data Qualifiers:
All non-detected result were preceded by "<"

Notes: Physical property measurements did not go thorough formal validation procedures
pcf = pounds per cubic foot
cm/sec = centimeters per second
bgs = below ground surface

TABLE 21
SUMMARY OF PHYSICAL PROPERTY MEASUREMENTS OF SOIL SAMPLES
Santa Susana Field Laboratory
Ventura County, CA

Location	No of Samples	Hydraulic Conductivity (cm/s)			Moisture Content (percent)			Saturation (percent)			Bulk Density (pcf)			Specific Gravity			Porosity (percent)		
		Min	Max	Geo Mean	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
VMMV Study Sites	12	2.12E-07	9.59E-05	4.16E-06	4.6%	22.9%	14.2%	7.0%	27.0%	18.2%	91.3	116.7	102.8	2.65	2.73	2.68	32%	45%	39%
LOX	20	7.61E-08	2.99E-04	1.96E-05	2.6%	25.6%	12.0%	4.0%	31.0%	17.6%	73.7	114.6	94.1	2.11	2.74	2.65	34%	56%	47%
Combined	32	7.61E-08	2.99E-04	1.09E-05	2.6%	25.6%	12.8%	4.0%	31.0%	17.8%	73.7	116.7	97.4	2.11	2.74	2.66	32%	56%	44%

cm/s: centimeters per second
pcf: pounds per cubic feet
VMMV: vapor migration model validation
LOX: Liquid oxygen

TABLE 22
REVISED SOIL PHYSICAL PROPERTY INPUTS
Santa Susana Field Laboratory
Ventura, CA

Soil

Porosity (percent)	40.3		
Water Content (percent of pore space occupied by water)	0.36	14.7	Vol water content, soil
Air Content (percent of pore space occupied by air)	0.64	25.6	Vol air content, soil

Weathered

Bedrock porosity (percent)	20.2		
Water Content (percent of pore space occupied by water)	0.56	11.4	Vol water content, weathered bedrock
Air Content (percent of pore space occupied by air)	0.44	8.8	Vol air content, weathered bedrock

Unweathered

Bedrock porosity (percent)	12.7		
Water Content (percent of pore space occupied by water)	0.7	8.89	Vol water content, unweathered bedrock
Air Content (percent of pore space occupied by air)	0.3	3.81	Vol air content, unweathered bedrock

Includes analysis of all data in Appendix F of SRAM, Revision 2 and additional data produced as presented in this report

TABLE 23
MODELING INPUTS
Santa Susana Field Laboratory
Ventura County, CA

Subsurface Soil and Bedrock Properties			
Parameter	**Units**	**Value**	**Source**
Soil bulk density (Qb)	kg/m^3	1620	Site-specific
Water recharge (R)	m/sec	1.00E-09	Median groundwater recharge rate of 1.2 inches per year. MWH (2003a)
Organic carbon content of soil (foc)	fraction	0.0020	Mean total organic carbon content, SRAM App. F
Volumetric soil water content (θw)	cm^3/cm^3	0.143	Calculated from mean soil water saturation, App. G
Volumetric soil air content (θa)	cm^3/cm^3	0.249	Calculated from mean soil water saturation, App. G
Soil porosity (ns)	cm^3/cm^3	0.392	Mean soil porosity, App. G
Volumetric unweathered bedrock water content (θw,ubr)	cm^3/cm^3	0.089	Calculated from unweathered bedrock water saturation, App. G
Volumetric unweathered bedrock air content (θa,ubr)	cm^3/cm^3	0.038	Calculated from unweathered bedrock water saturation, App. G
Unweathered bedrock porosity (nubr)	cm^3/cm^3	0.127	Mean unweathered bedrock porosity, App. G
Unweathered bedrock fractures (ϕubr)	cm^3/cm^3	0.00005	Montgomery Watson (2000)
Volumetric weathered bedrock water content (θw,wbr)	cm^3/cm^3	0.114	Calculated from mean weathered bedrock water saturation, App. G
Volumetric weathered bedrock air content (θa,wbr)	cm^3/cm^3	0.088	Calculated from mean weathered bedrock water saturation, App. G
Weathered bedrock porosity (nwbr)	cm^3/cm^3	0.202	Mean weathered bedrock porosity, App. G
Weathered bedrock fractures (ϕwbr)	cm^3/cm^3	1.00E-04	MWH (2003)
Soil Cover Thickness	ft	1.00E+01	Scenario-specific
Weathered Bedrock Thickness	ft	1.00E+01	Scenario-specific
Depth to top of contaminated zone (L)	ft	56.6	Scenario-specific
Source Concentration in Groundwater	ug/L	0.53	Scenario-specific
Chemical Properties			
Parameter	**Units**	**Value**	**Source**
Chemical		Trichloroethylene	
Organic carbon partition coefficient (Koc)	cm^3/g	1.66E+02	USEPA, 2003
Diffusivity in air (Da)	cm^2/s	7.90E-02	USEPA, 2003
Diffusivity in water (Dw)	cm^2/s	9.10E-06	USEPA, 2003
Enthalpy of vaporization at the normal boiling point	cal/mol	7,505	USEPA, 2003
Normal Boiling Point	^oK	360.36	USEPA, 2003
Critical Temperature	^oK	544.20	USEPA, 2003
Henry's law constant (H') at reference temperature	$atm\text{-}m^3/mol$	1.03E-02	USEPA, 2003
Henry's law constant reference temperature	^oC	25	USEPA, 2003
Average soil/groundwater temperature	^oC	18	USEPA, 2003
Enthalpy of vaporization at average groundwater temperature	cal/mol	8,458	USEPA, 2003
Henry's law constant (H') at average groundwater temperature	$atm\text{-}m^3/mol$	7.29E-03	USEPA, 2003
Henry's law constant (H') at average groundwater temperature	unitless	3.05E-01	USEPA, 2003

Notes:
$atm\text{-}m^3/mol$
cm^3/cm^3 = cubic centimeter per cubic centimeter
cal/mol
ft = feet
H =
kg/m3 = kilograms per cubic meter
^OC = degrees centigrade
^OK
m/sec = meters per second
ug/L = micrograms per meter

TABLE 24
CALCULATED FLUX RESULTS FROM GROUNDWATER
Santa Susana Field Laboratory
Ventura County, CA

Class	Site	Groundwater	Depth to Groundwater feet	Groundwater TCE Conc. (ug/L)	Soil Thickness feet	Calculated Flux (ug/m2/min)	Measured Flux Average (ug/m2/min)	Measured Flux Max Detect (ug/m2/min)	Ratio Calculated / Measured*		Calc > Measured?
									m	Average	
Source - NSGW	COMP A	NSGW	20.3	5700	0	1.4E-01	1.3E-02	1.8E-02	11	8	Yes
Source - NSGW	FSDF	NSGW	17.5	2100	15	1.7E+00	1.5E-02	2.4E-02	111	71	Yes
Source - CFGW	CTL-III (Source)	CFGW	66.21	3200	17	2.8E-03	4.6E+00	4.8E+00	0.0006	0.0006	No
Source - CFGW	DELTA	CFGW	47.54	6700	0	7.2E-03	5.4E-03	8.9E-03	1	1	Yes
Plume - NSGW	CTL-III (Distal)	NSGW	14.34	270	2	3.2E-02	1.9E-03	5.7E-03	17	6	Yes
Plume - NSGW	RD-9/B515	NSGW	14.65	210	20	4.3E-01	1.8E-03	1.4E-03	243	304	Yes
Plume - CFGW	B1	CFGW	89.9	210	1	3.1E-06	1.7E-03	1.4E-03	0.0018	0.0022	No
Plume - CFGW	LOX	CFGW	126.94	110	0	3.2E-08	6.0E-04	7.0E-04	0.0001	0.00005	No

Notes:
CFGW = Chatsworth formation groundwater
CTL = Components Test Lab
FSDF= Former Sodium Disposal Facility
NSGW = Near-surface groundwater
ug/L = micrograms per liter
ug/m2/min - micrograms per square meter per minute
*The average flux used here can be greater than the maximum measured value when one-half of non-detect result is used as an estimate to represent the non-detect value and the detection limit of the non-detect result is greater than twice the maximum detected value.

TABLE 25
CALCULATED FLUX RESULTS FROM SOIL VAPOR
Santa Susana Field Laboratory
Ventura County, CA

Type and Depth (feet bgs)	Site	Groundwater	MWH ID	Depth to Soil Vapor feet	Soil Vapor TCE Conc. (ug/m3)	Soil Thickness feet	Calculated Flux (ug/m2/min)	Measured Flux Average (ug/m2/min)	Measured Flux Max Detect (ug/m2/min)	Ratio Calculated / Measured* Average	Ratio Calculated / Measured* Maximum	Calc > Measured?	Average calculated flux (ug/m2/min)	Ratio of Avg Calculated to Avg Measured	Ratio of Avg Calculated to Max Measured
Source-4	FSDF	NSGW	FSSV03S01	4	2.1E+02	4	5.2E-03	1.5E-02	2.4E-02	0.34	0.21	No	8.5E-02	5.5	3.5
Source-7	FSDF	NSGW	FSSV03D01	7	1.2E+04	7	1.7E-01	1.5E-02	2.4E-02	11	7	Yes			
Source-7	FSDF	NSGW	FSSV03S02	7	1.2E+04	7	1.6E-01	1.5E-02	2.4E-02	11	7	Yes			
Source-5	CTL-III (Source)	CFGW	CLSV89S01	5	5.5E+02	5	1.1E-02	4.6E+00	4.8E+00	0.002	0.002	No	6.6E+00	1.4	1.4
Source-10	CTL-III (Source)	CFGW	CLSV89S02	10	1.5E+06	10	1.4E+01	4.6E+00	4.8E+00	3	3	Yes			
Source-15	CTL-III (Source)	CFGW	CLSV89S03	15	8.6E+05	15	5.6E+00	4.6E+00	4.8E+00	1	1	Yes			
Distal-5	RD-9/B515	NSGW	BTSV11S01	5	2.7E+05	5	5.3E+00	1.8E-03	1.4E-03	3056	3820	Yes	1.4E+00	793.4	991.8
Distal-10	RD-9/B515	NSGW	BTSV11S02	10	3.1E+02	10	3.0E-03	1.8E-03	ND	1.7	-	Yes			
Distal-15	RD-9/B515	NSGW	BTSV11S03	15	6.2E+01	15	4.0E-04	1.8E-03	1.4E-03	0.2	0.3	No			
Distal-20	RD-9/B515	NSGW	BTSV11S04	20	4.2E+04	20	2.0E-01	1.8E-03	1.4E-03	115	144	Yes			
LXSA21-5	LXSA21	NA	LXSA21S01	5	3.5E+02	5	6.9E-03	6.5E-03	6.5E-03	1.1	1.1	Yes	2.6E-02	4.0	4.0
LXSA21-10	LXSA21	NA	LXSA21S02	10	4.6E+03	10	4.5E-02	6.5E-03	6.5E-03	6.9	6.9	Yes			
LXSA22-5	LXSA22	NA	LXSA22S01	5	1.5E+06	5	2.9E+01	1.8E+02	1.8E+02	0.17	0.17	No	2.2E+01	0.1	0.1
LXSA22-10	LXSA22	NA	LXSA22S02	10	1.6E+06	10	1.6E+01	1.8E+02	1.8E+02	0.09	0.09	No			
LXSA23-5	LXSA23	NA	LXSA23D01	5	2.8E+06	5	5.6E+01	9.7E-01	9.7E-01	57.4	57.4	Yes	3.3E+01	33.6	33.6
LXSA23-5	LXSA23	NA	LXSA23S01	5	3.0E+06	5	5.9E+01	9.7E-01	9.7E-01	60.7	60.7	Yes			
LXSA23-10	LXSA23	NA	LXSA23S02	10	6.5E+05	10	6.3E+00	9.7E-01	9.7E-01	6.5	6.5	Yes			
LXSA23-5	LXSA23	NA	LXSA23S01	5	3.0E+06	5	5.9E+01	9.7E-01	9.7E-01	60.7	60.7	Yes			
LXSA25-10	LXSA25	NA	LXSA25D01	10	1.9E+07	10	1.9E+02	2.5E+01	5.3E+01	7.3	3.5	Yes	1.0E+02	4.0	1.9
LXSA25-5	LXSA25	NA	LXSA25S01	5	5.6E+06	5	1.1E+02	2.5E+01	5.3E+01	4.4	2.1	Yes			
LXSA25-10	LXSA25	NA	LXSA25S02	10	2.0E+07	10	2.0E+02	2.5E+01	5.3E+01	7.7	3.7	Yes			
LXSA25-15	LXSA25	NA	LXSA25S03	15	7.4E+04	15	4.8E-01	2.5E+01	5.3E+01	0.02	0.01	No			

Note: The average calculated flux uses only primary sample results and does not include duplicate samples or duplicate data.
Notes:
Avg- average
bgs - below ground surface
ug/m3 - micrograms per cubic meter
ug/m2/min - micrograms per square meter per minute
*The average flux used here can be greater than the maximum measured value when one-half of non-detect result is used as an estimate to represent the non-detect value and the detection limit of the non-detect result is greater than twice the maximum detected value.

TABLE 26
SUMMARY OF CO-LOCATED GROUNDWATER AND SOIL VAPOR CALCULATED AND MEASURED FLUX
Santa Susana Field Laboratory
Ventura County, CA

Class	Site	Groundwater	MWH ID	Depth to Soil Vapor (feet)	Soil Vapor TCE Concentration (ug/m3)	Soil Thickness (feet)	Soil Vapor-Calculated Flux (ug/m2/min)	Groundwater-Calculated Flux (ug/m2/min)	Measured Flux Average (ug/m2/min)	Measured Flux Max Detect (ug/m2/min)	Ratio Calculated / Avg Measured*		Calc > Measured?	Ratio: Groundwater Calculated Flux to Soil Vapor Calculated Flux
											Soil vapor to measured flux	Groundwaer to measured flux		
Distal-10	RD-9/B515	NSGW	BTSV11S02	10	3.1E+02	10	0.003	0.43	0.002	1.4E-03	1.7	243.4	Yes	142
Source-7	FSDF	NSGW	FSSV03D01	7	1.2E+04	7	0.17	1.72	0.015	2.4E-02	11	111	Yes	10

Notes:
ug/m3 - micrograms per cubic meter
ug/m2/min - micrograms per square meter per minute
Avg- average
NSGW - near-surface groundwater
FSDF - Former Sodium Disposal Facility
*The average flux used here can be greater than the maximum measured value when one-half of non-detect result is used as an estimate to represent the non-detect value and the detection limit of the non-detect result is greater than twice the maximum detected value.

TABLE 27
COMPARISON OF MEASURED CONCENTRATIONS IN FLUX AND AMBIENT AIR SAMPLES
Santa Susana Field Laboratory
Ventura County, CA

Sample Type	Location ID	MWH_ID	Result (ug/m3)	Data Qualifier	MDL (ug/m3)	Result in ppb	Result in ppt
LOX Ambient Air	LXAA01	LXAA01BS01	0.13	J	0.048	0.025	25
		LXAA01S01	0.027	J	0.013	0.0051	5.1
	LXAA02	LXAA02S01	0.028	J	0.02	0.0053	5.3
	LXAA03	LXAA03S01	0.03	J	0.018	0.0057	5.7
	LXAA04	LXAA04S01	0.066	J	0.017	0.013	13
	LXAA05	LXAA05S01	ND		0.018		
	LXAA06	LXAA06S01	ND		0.016		
	LXAA07	LXAA07S01	0.13	J	0.016	0.025	25
Flux	B1	B1VF01S01	0.037	J	0.013	0.0070	7.0
		B1VF01S02	ND		0.031		
		B1VF02S01	ND		0.013		
		B1VF02S02	ND		0.013		
	COMP A	CFVF01S01	0.46	J	0.013		
		CFVF01S02	0.17		0.013		
		CFVF02S01	0.33		0.013		
		CFVF02S02	0.41		0.012		
	Control (North)	NCVF01S01	0.026	J	0.015	0.0049	4.9
		NCVF01S02	ND		0.013		
	Control (South)	BZVF01S01	ND		0.012		
		BZVF01S02	ND		0.012		
	CTL-III (Distal)	CLVF01S01	ND		0.013		
		CLVF01S02	0.15	J	0.013	0.029	29
		CLVF02S01	ND		0.013		
		CLVF02S02	ND		0.012		
	CTL-III (Source)	CLVF03S01	123	J	1.1		
		CLVF03S02	116	J	0.96		
	DELTA	DAVF01D01	0.12	J	0.013		
		DAVF01S01	0.15	J	0.012		
		DAVF01S02	0.16	J	0.013		
		DAVF02S01	ND		0.013		
		DAVF02S02	0.23	J	0.012		
	FSDF	FSVF01S01	0.63	J	0.013		
		FSVF01S02	0.17		0.013		
	LOX (Vapor Model Study Locations)	LXVF01D01	ND		0.013		
		LXVF01S01	0.018	J	0.014	0.0034	3.4
		LXVF01S02	ND		0.013		
		LXVF02S01	ND		0.012		
		LXVF02S02	ND		0.013		
	LOX (Ambient Air and LOX Flux Study)	LXVF03S01	225	J			
		LXVF03S02	536	J			
		LXVF03S03	1.4E+03				
		LXVF03S04	412				
		LXVF04S01	0.17				
		LXVF05S01	4.6E+03				
		LXVF06S01	25				
	RD-9/B515	BTVF01S01	0.036	J	0.013	0.0068	6.8
		BTVF01S02	ND		0.013		
Range of ambient air values (TCE Hazard Summary, EPA Air Toxics Website)							
			0.01	NA	NA	0.0019	1.9
			3.9	NA	NA	0.74	741
Atmospheric measurements (TCE Toxicity: Exposure Pathways, ATSDR)			Arctic:			0.009	9
			Rural, remote areas:			0.03	30
			Urban, suburban areas:			0.26	260
Proposed Identification of TCE as a Toxic Air Contaminant (CARB, Aug 1990)			South Coast Air Basin			0.19	190

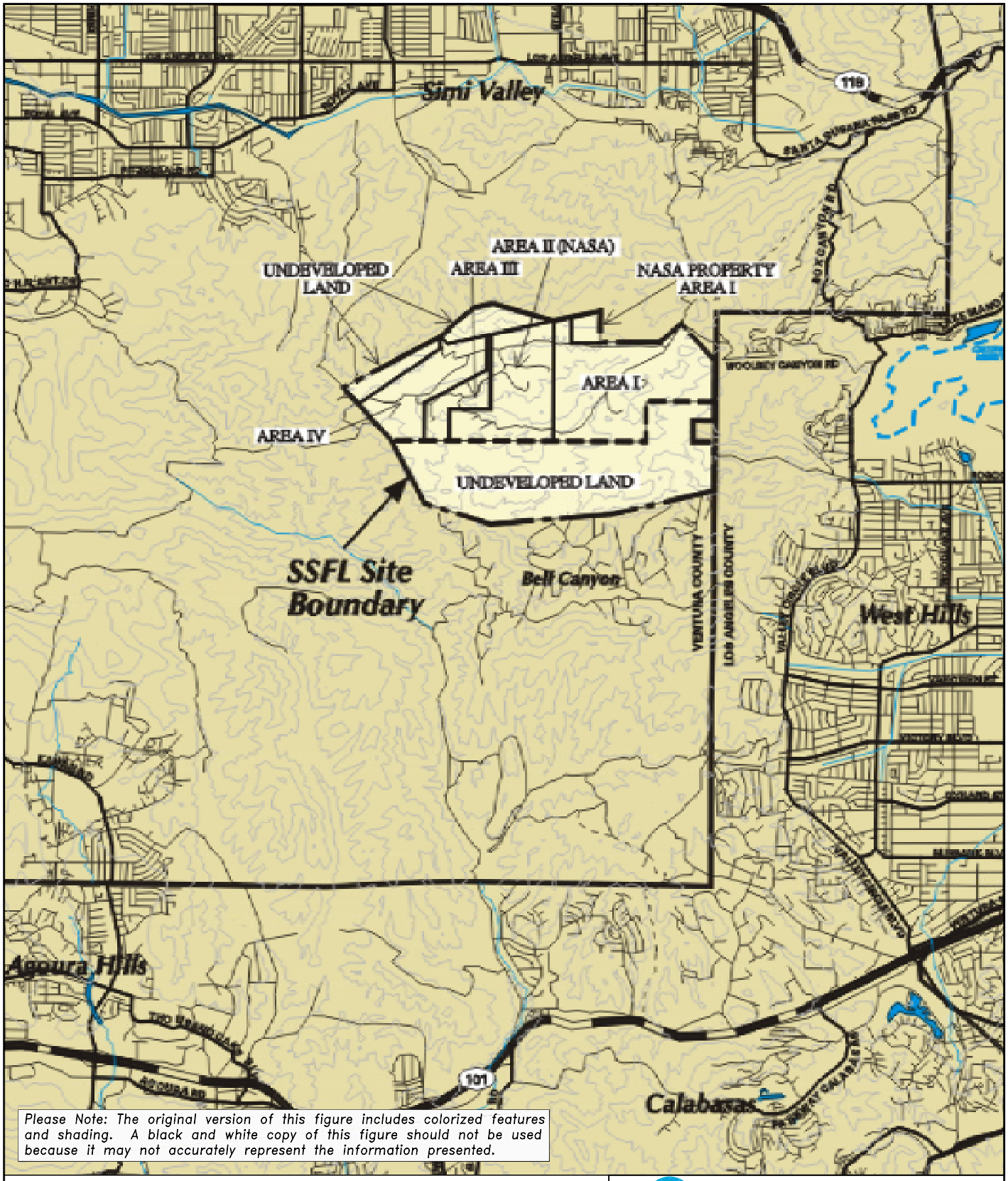
Notes:
CTL = Component Test Laboratory
FSDF = Former Sodium Disposal Facility
J = Estimated Value
LOX = liquid oxygen
NA = not applicable
MDL = method detection limit
ppb = parts per billion
ppt = part per trillion
TCE = trichloroethene
ug/m3 = micrograms per cubic meter

TABLE 28
RESULTS OF SENSITIVITY ANALYSIS
Santa Susana Field Laboratory
Ventura County, CA

	Class	**Control - CFGW**	**Control - CFGW**	**Distal - CFGW**	**Distal - CFGW**	**Source - CFGW**	**Source - CFGW**	**Distal - NSGW**	**Distal - NSGW**	**Source - NSGW**	**Source - NSGW**
	Site	**Control (North)**	**Control (South)**	**B1**	**LOX**	**CTL-III (Source)**	**DELTA**	**CTL-III (Distal)**	**RD-9/B515**	**COMP A**	**FSDF**
	Groundwater	CFGW	CFGW	CFGW	CFGW	CFGW	CFGW	NSGW	NSGW	NSGW	NSGW
	Depth to Groundwater (feet)	54.97	77.85	89.9	126.94	66.21	47.54	14.34	14.65	20.3	17.5
	Groundwater TCE Conc. (ug/L)	0.13	0.13	210	110	3200	6700	270	210	5700	2100
	Soil Thickness (fddt)	3.5	14	1	0	17	0	2	20	0	15
	Baseline Calculated Flux (ug/m2/min)	9.2E-08	2.5E-08	3.1E-06	3.2E-08	2.8E-03	7.2E-03	3.2E-02	4.3E-01	1.4E-01	1.7E+00
Sensitivity Analysis Input Variation Flux Results											
Soil Air Content	**+ 50% Calculated Flux (ug/m2/min)**	9.2E-08	2.5E-08	3.1E-06	3.2E-08	2.9E-03	7.2E-03	3.2E-02	1.7E+00	1.4E-01	2.5E+00
	- 50% Calculated Flux (ug/m2/min)	8.6E-08	1.9E-08	3.0E-06	3.2E-08	2.0E-03	7.2E-03	2.9E-02	3.7E-02	1.4E-01	3.1E-01
Weathered Bedrock Air Content	**+ 50% Calculated Flux (ug/m2/min)**	1.0E-07	2.8E-08	3.5E-06	3.6E-08	3.1E-03	8.1E-03	4.8E-02	4.3E-01	1.7E-01	3.0E+00
	- 50% Calculated Flux (ug/m2/min)	2.5E-08	6.9E-09	8.6E-07	8.8E-09	7.7E-04	2.0E-03	3.7E-03	4.3E-01	3.0E-02	2.6E-01
Unweathered Bedrock Air Content	**+ 50% Calculated Flux (ug/m2/min)**	2.8E-06	1.8E-06	1.3E-03	2.3E-04	7.3E-02	1.7E-01	6.2E-02	4.3E-01	6.0E-01	1.7E+00
	- 50% Calculated Flux (ug/m2/min)	1.5E-18	2.5E-22	9.4E-27	1.2E-38	1.7E-13	1.2E-12	3.2E-03	4.3E-01	2.1E-04	1.7E+00
Weathered Bedrock Thickness	**+ 50% Calculated Flux (ug/m2/min)**	1.4E-07	3.8E-08	4.7E-06	4.9E-08	4.3E-03	1.1E-02	7.1E-02	4.3E-01	2.8E-01	1.7E+00
	- 50% Calculated Flux (ug/m2/min)	5.9E-08	1.6E-08	2.0E-06	2.1E-08	1.8E-03	4.6E-03	1.2E-02	4.3E-01	8.0E-02	1.7E+00
Water recharge	**+ 50% Calculated Flux (ug/m2/min)**	1.5E-08	2.1E-09	7.2E-08	1.0E-10	4.9E-04	1.4E-03	2.9E-02	4.2E-01	9.7E-02	1.7E+00
	- 50% Calculated Flux (ug/m2/min)	4.7E-07	2.3E-07	1.0E-04	7.2E-06	1.3E-02	3.1E-02	3.6E-02	4.3E-01	2.0E-01	1.7E+00
Weathered bedrock fractures	**+ 50% Calculated Flux (ug/m2/min)**	9.2E-08	2.5E-08	3.1E-06	3.2E-08	2.8E-03	7.2E-03	3.2E-02	4.3E-01	1.4E-01	1.7E+00
	- 50% Calculated Flux (ug/m2/min)	9.2E-08	2.5E-08	3.1E-06	3.2E-08	2.8E-03	7.2E-03	3.2E-02	4.3E-01	1.4E-01	1.7E+00
Sensitivity Analysis Input Variation Ratios to Baseline Conditions											
Soil Air Content	**+ 50% Ratio to Baseline**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**3.9**	1.0	1.5
	- 50% Ratio to Baseline	0.9	0.8	1.0	1.0	0.7	1.0	0.9	**0.1**	1.0	**0.2**
Weathered Bedrock Air Content	**+ 50% Ratio to Baseline**	1.1	1.1	1.1	1.1	1.1	1.1	**1.5**	1.0	1.2	**1.8**
	- 50% Ratio to Baseline	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.1**	1.0	**0.2**	**0.2**
Unweathered Bedrock Air Content	**+ 50% Ratio to Baseline**	**30.9**	**71.5**	**428.7**	**7109.0**	**26.3**	**23.9**	**1.9**	1.0	**4.2**	1.0
	- 50% Ratio to Baseline	**2E-11**	**1E-14**	**3E-21**	**4E-31**	**6E-11**	**2E-10**	**0.10**	1.0	**0.0015**	1.0
Weathered Bedrock Thickness	**+ 50% Ratio to Baseline**	**1.6**	**1.5**	**1.5**	**1.5**	**1.6**	**1.6**	**2.2**	1.0	**2.0**	1.0
	- 50% Ratio to Baseline	0.6	0.6	0.6	0.6	0.6	0.6	**0.4**	1.0	0.6	1.0
Water recharge	**+ 50% Ratio to Baseline**	**0.16**	**0.1**	**0.023**	**0.003**	**0.2**	**0.2**	0.9	1.0	0.7	1.0
	- 50% Ratio to Baseline	**5.1**	**9.4**	**32.5**	**229**	**4.7**	**4.3**	1.1	1.0	1.4	1.0
Weathered bedrock fractures	**+ 50% Ratio to Baseline**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	- 50% Ratio to Baseline	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Bolded values are either less than 0.5 or greater than 1.5, indicating a greater than 1-to-1 change in flux result to change in the input parameter.
ug/m2/min = micrograms per square meter per minute
ug/L = micrograms per liter

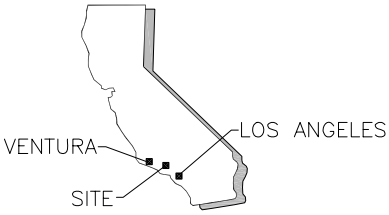
FIGURES



Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.

N

0 FEET 6,000
APPROXIMATE SCALE

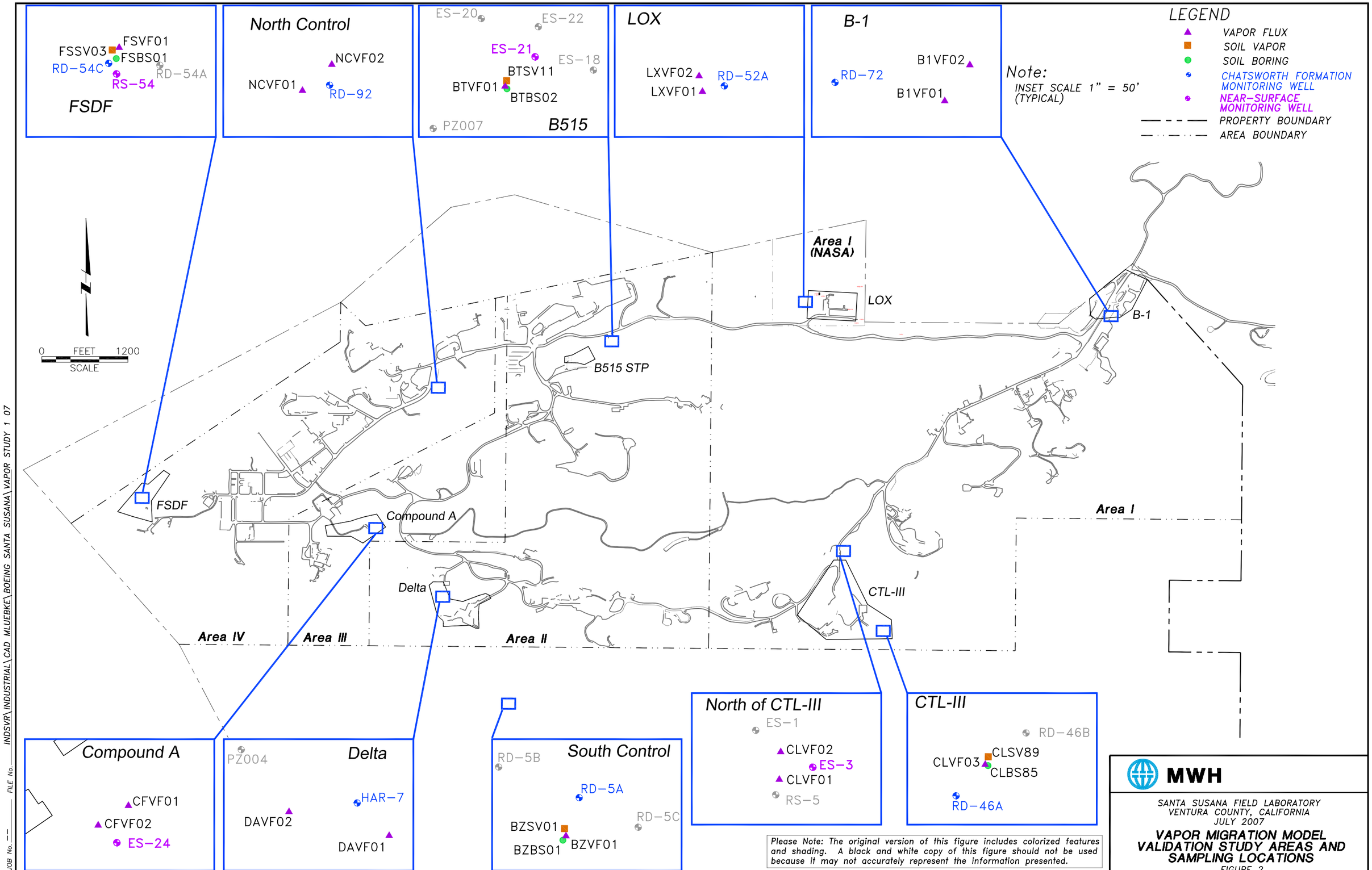


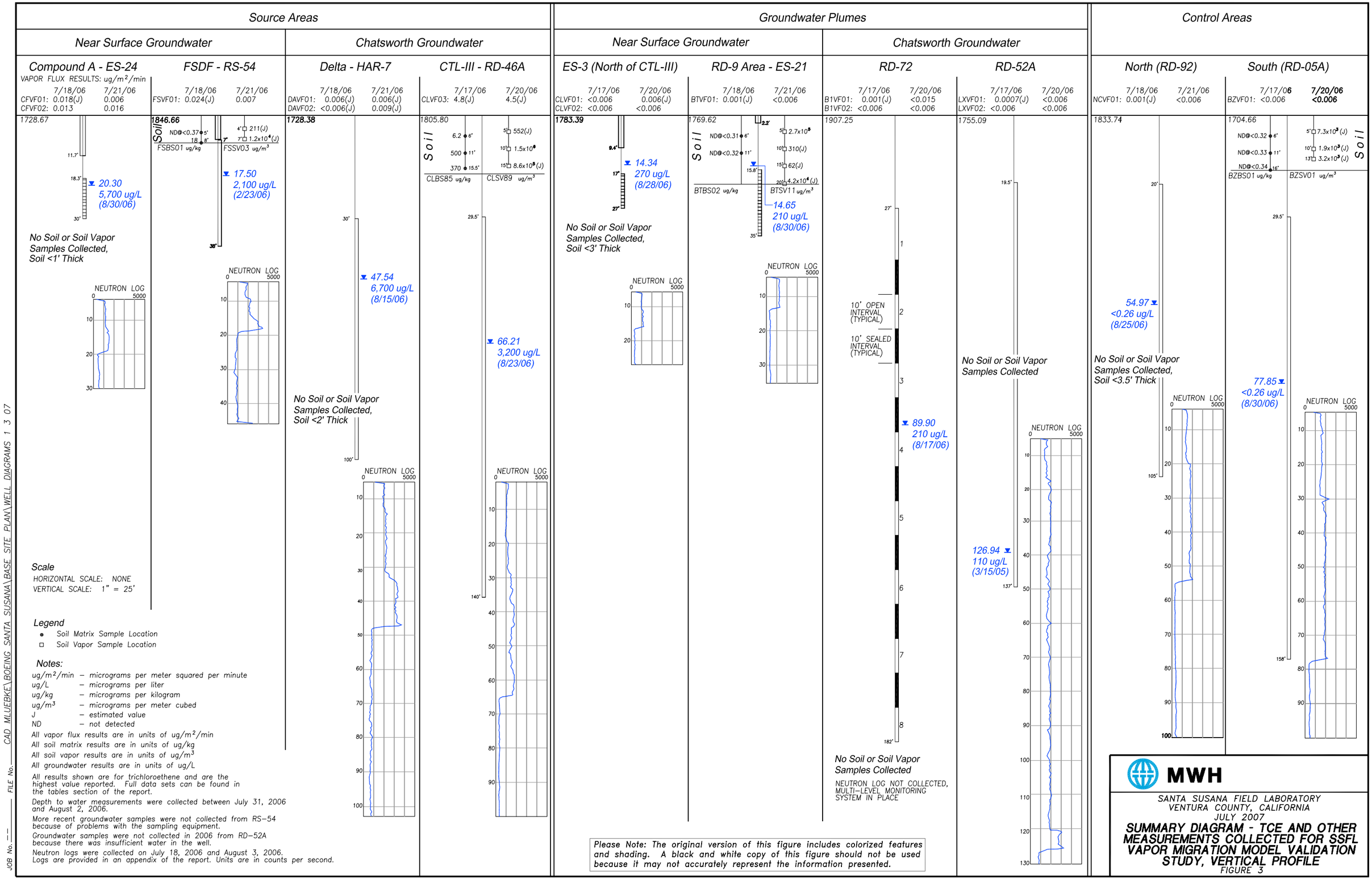
MWH
MONTGOMERY WATSON HARZA

ROCKETDYNE PROPULSION & POWER
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA

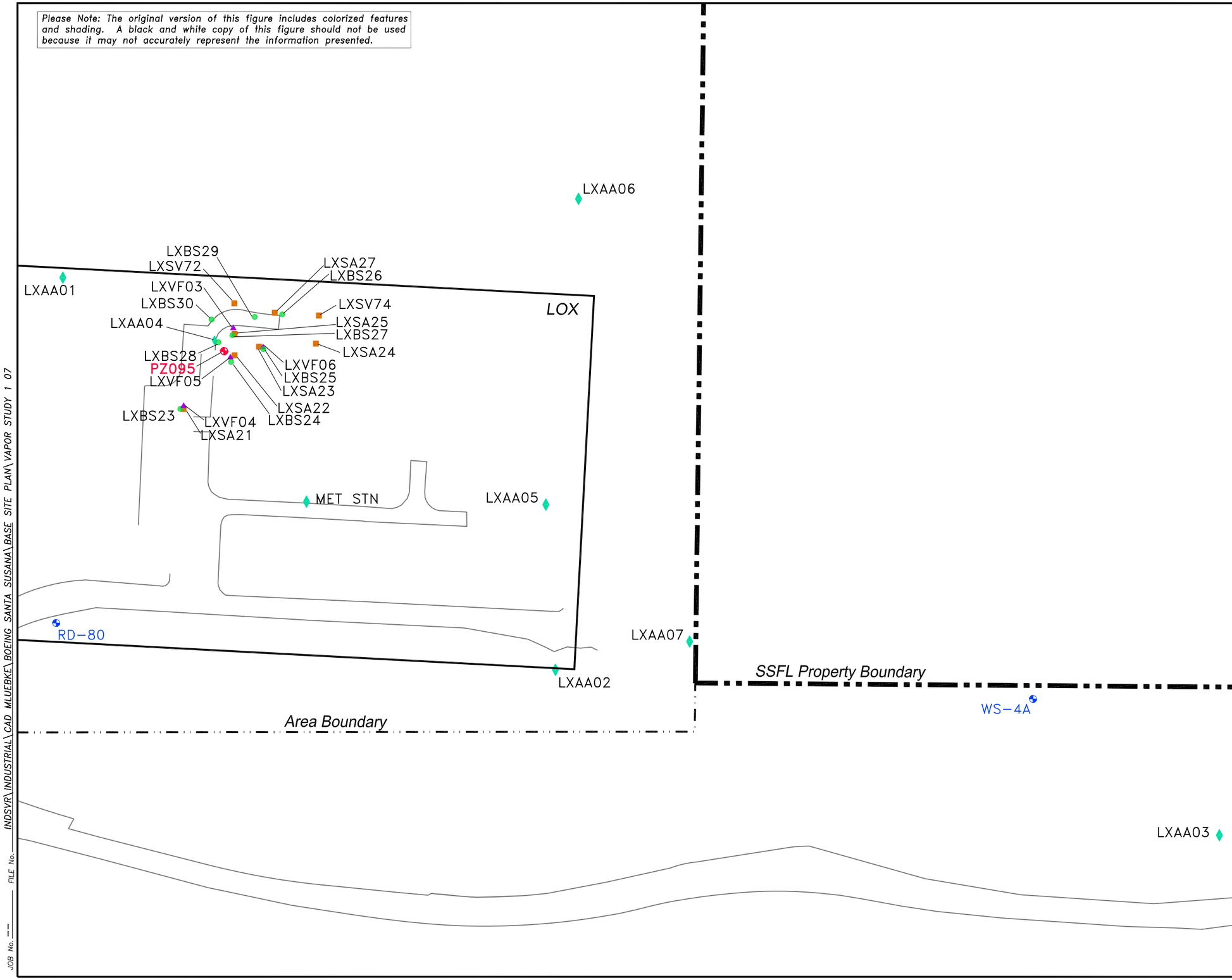
SITE LOCATION MAP

FIGURE 1


FSDF
FSSV03
FSVF01
FSBS01
RD-54C
RD-54A
RS-54
North Control
NCVF01
NCVF02
RD-92
B515
ES-20
ES-22
ES-21
ES-18
BTSV11
BTVF01
BTBS02
PZ007
LOX
LXVF02
LXVF01
RD-52A
B-1
RD-72
B1VF02
B1VF01
Note:
INSET SCALE 1" = 50'
(TYPICAL)
LEGEND
VAPOR FLUX
SOIL VAPOR
SOIL BORING
CHATSWORTH FORMATION MONITORING WELL
NEAR-SURFACE MONITORING WELL
PROPERTY BOUNDARY
AREA BOUNDARY
0 FEET 1200
SCALE
Area I (NASA)
LOX
B-1
B515 STP
FSDF
Compound A
Delta
CTL-III
Area IV
Area III
Area II
Area I
Compound A
CFVF01
CFVF02
ES-24
Delta
PZ004
HAR-7
DAVF02
DAVF01
South Control
RD-5B
RD-5A
RD-5C
BZSV01
BZVF01
BZBS01
North of CTL-III
ES-1
CLVF02
ES-3
CLVF01
RS-5
CTL-III
RD-46B
CLSV89
CLVF03
CLBS85
RD-46A
Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.
MWH
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA
JULY 2007
VAPOR MIGRATION MODEL VALIDATION STUDY AREAS AND SAMPLING LOCATIONS
FIGURE 2
JOB No. -- FILE No. INDSVR\INDUSTRIAL\CAD MLUEBKE\BOEING SANTA SUSANA\VAPOR STUDY 1 07

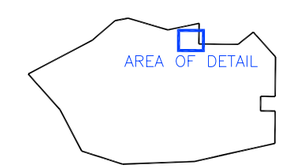

Source Areas
Near Surface Groundwater
Chatsworth Groundwater
Compound A - ES-24
VAPOR FLUX RESULTS: ug/m²/min
7/18/06 7/21/06
CFVF01: 0.018(J) 0.006
CFVF02: 0.013 0.016
1728.67
11.7'
18.3'
20.30
5,700 ug/L
(8/30/06)
30'
No Soil or Soil Vapor Samples Collected, Soil <1' Thick
NEUTRON LOG
0 5000
10
20
30
FSDF - RS-54
7/18/06 7/21/06
FSVF01: 0.024(J) 0.007
1846.66
Soil
ND@<0.37 5'
18 8'
7'
4' 211(J)
7' 1.2x10⁴(J)
FSBS01 ug/kg
FSSV03 ug/m³
17.50
2,100 ug/L
(2/23/06)
38'
NEUTRON LOG
0 5000
10
20
30
40
Delta - HAR-7
7/18/06 7/21/06
DAVF01: 0.006(J) 0.006(J)
DAVF02: <0.006(J) 0.009(J)
1728.38
30'
47.54
6,700 ug/L
(8/15/06)
No Soil or Soil Vapor Samples Collected, Soil <2' Thick
100'
NEUTRON LOG
0 5000
10
20
30
40
50
60
70
80
90
100
CTL-III - RD-46A
7/17/06 7/20/06
CLVF03: 4.8(J) 4.5(J)
1805.80
Soil
6.2 6'
500 11'
370 15.5'
5 552(J)
10 1.5x10⁶
15 8.6x10⁵(J)
CLBS85 ug/kg
CLSV89 ug/m³
29.5'
66.21
3,200 ug/L
(8/23/06)
140'
NEUTRON LOG
0 5000
10
20
30
40
50
60
70
80
90
Groundwater Plumes
Near Surface Groundwater
ES-3 (North of CTL-III)
7/17/06 7/20/06
CLVF01: <0.006 0.006(J)
CLVF02: <0.006 <0.006
1783.39
9.4'
14.34
270 ug/L
(8/28/06)
17'
27'
No Soil or Soil Vapor Samples Collected, Soil <3' Thick
NEUTRON LOG
0 5000
10
20
RD-9 Area - ES-21
7/18/06 7/21/06
BTVF01: 0.001(J) <0.006
1769.62
Soil
ND@<0.31 6'
ND@<0.32 11'
2.2'
15.8'
5 2.7x10⁵
10 310(J)
15 62(J)
20 4.2x10⁴(J)
BTBS02 ug/kg
BTSV11 ug/m³
14.65
210 ug/L
(8/30/06)
35'
NEUTRON LOG
0 5000
10
20
30
Chatsworth Groundwater
RD-72
7/17/06 7/20/06
B1VF01: 0.001(J) <0.015
B1VF02: <0.006 <0.006
1907.25
27'
1
2
10' OPEN INTERVAL (TYPICAL)
10' SEALED INTERVAL (TYPICAL)
3
89.90
210 ug/L
(8/17/06)
4
5
6
7
8
182'
No Soil or Soil Vapor Samples Collected
NEUTRON LOG NOT COLLECTED, MULTI-LEVEL MONITORING SYSTEM IN PLACE
RD-52A
7/17/06 7/20/06
LXVF01: 0.0007(J) <0.006
LXVF02: <0.006 <0.006
1755.09
19.5'
No Soil or Soil Vapor Samples Collected
126.94
110 ug/L
(3/15/05)
137'
NEUTRON LOG
0 5000
10
20
30
40
50
60
70
80
90
100
110
120
130
Control Areas
North (RD-92)
7/18/06 7/21/06
NCVF01: 0.001(J) <0.006
1833.74
20'
54.97
<0.26 ug/L
(8/25/06)
No Soil or Soil Vapor Samples Collected, Soil <3.5' Thick
105'
NEUTRON LOG
0 5000
10
20
30
40
50
60
70
80
90
100
South (RD-05A)
7/17/06 7/20/06
BZVF01: <0.006 <0.006
1704.66
Soil
ND@<0.32 6'
ND@<0.33 11'
ND@<0.34 16'
5' 7.3x10³(J)
10' 1.9x10³(J)
13' 3.2x10³(J)
BZBS01 ug/kg
BZSV01 ug/m³
29.5'
77.85
<0.26 ug/L
(8/30/06)
158'
NEUTRON LOG
0 5000
10
20
30
40
50
60
70
80
90
Scale
HORIZONTAL SCALE: NONE
VERTICAL SCALE: 1" = 25'
Legend
Soil Matrix Sample Location
Soil Vapor Sample Location
Notes:
ug/m²/min – micrograms per meter squared per minute
ug/L – micrograms per liter
ug/kg – micrograms per kilogram
ug/m³ – micrograms per meter cubed
J – estimated value
ND – not detected
All vapor flux results are in units of ug/m²/min
All soil matrix results are in units of ug/kg
All soil vapor results are in units of ug/m³
All groundwater results are in units of ug/L
All results shown are for trichloroethene and are the highest value reported. Full data sets can be found in the tables section of the report.
Depth to water measurements were collected between July 31, 2006 and August 2, 2006.
More recent groundwater samples were not collected from RS-54 because of problems with the sampling equipment.
Groundwater samples were not collected in 2006 from RD-52A because there was insufficient water in the well.
Neutron logs were collected on July 18, 2006 and August 3, 2006. Logs are provided in an appendix of the report. Units are in counts per second.
Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.
MWH
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA
JULY 2007
SUMMARY DIAGRAM - TCE AND OTHER MEASUREMENTS COLLECTED FOR SSFL VAPOR MIGRATION MODEL VALIDATION STUDY, VERTICAL PROFILE
FIGURE 3
JOB No. -- FILE No. CAD MLUEBKE\BOEING SANTA SUSANA\BASE SITE PLAN\WELL DIAGRAMS 1 3 07

Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.



LEGEND

- VAPOR FLUX
- SOIL VAPOR
- SOIL BORING
- AMBIENT AIR
- CHATSWORTH FORMATION MONITORING WELL
- NEAR-SURFACE MONITORING WELL
- NEAR-SURFACE PIEZOMETER



SANTA SUSANA FIELD LABORATORY

N

0 FEET 100
SCALE

MWH

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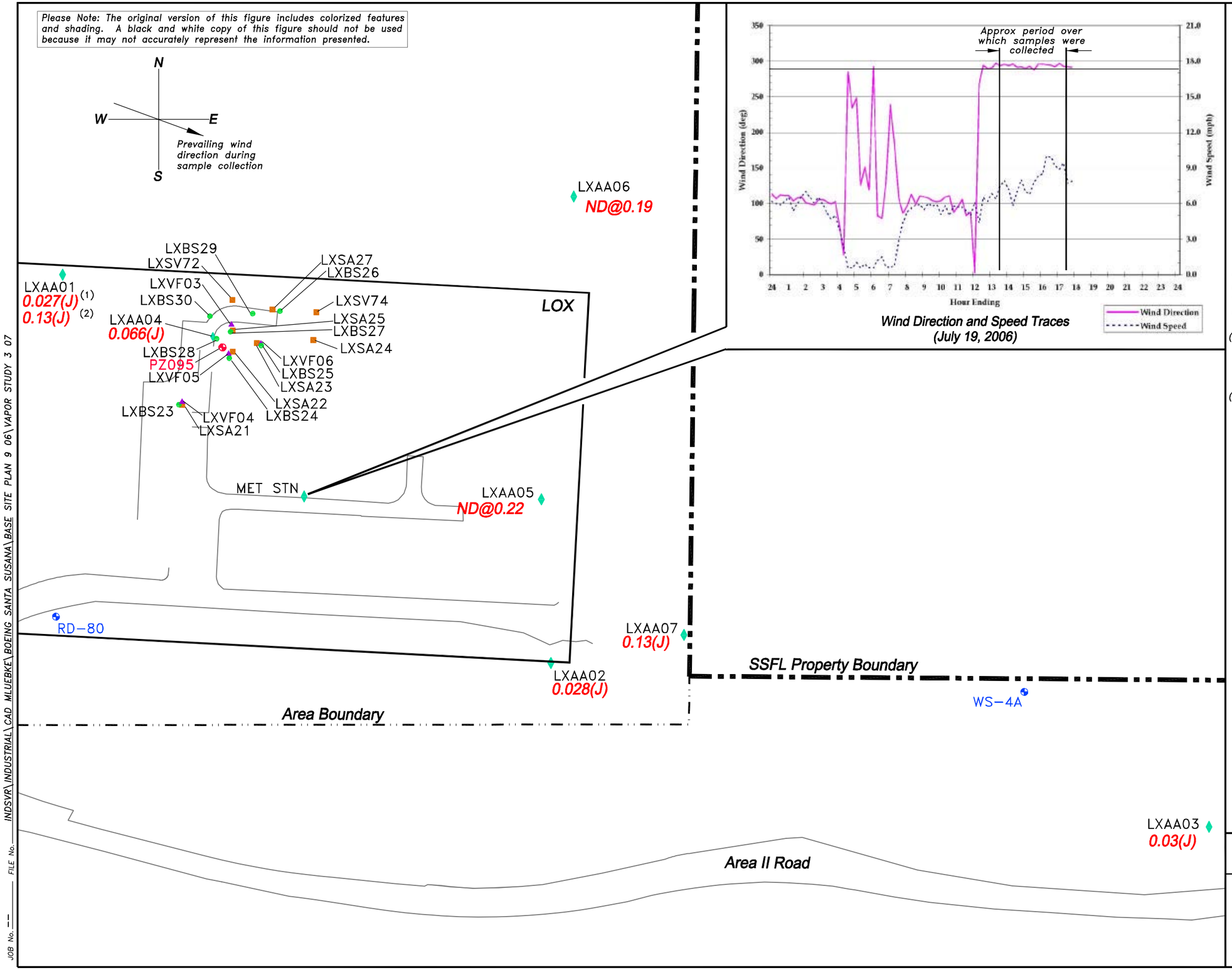
VENTURA COUNTY, CALIFORNIA
JULY 2007

LOX AREA VAPOR & AMBIENT AIR SAMPLING LOCATIONS

FIGURE 4

JOB No. --- FILE No. INDSVR\INDUSTRIAL\CAD MLUEBKE\BOEING SANTA SUSANA\BASE SITE PLAN\VAPOR STUDY 1 07

Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.



Wind Direction and Speed Traces
(July 19, 2006)

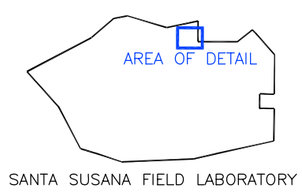
LEGEND

- VAPOR FLUX
- SOIL VAPOR
- SOIL BORING
- AMBIENT AIR
- CHATSWORTH FORMATION MONITORING WELL
- NEAR-SURFACE MONITORING WELL
- NEAR-SURFACE PIEZOMETER
- 0.03(J) TCE CONCENTRATIONS ug/m³
- J ESTIMATED VALUE

RESULTS CAN BE EVALUATED IN MICROGRAMS PER LITER (PARTS PER BILLION) BY DIVIDING THE POSTED VALUES THAT ARE IN MICROGRAMS PER CUBIC METER BY 1000

(1) RESULTS FOR SAMPLE LXAA01S01. THE SAMPLE CANNISTER APPEARED TO HAVE A FAULTY VALVE, HENCE A SECOND SAMPLE WAS COLLECTED.

(2) RESULTS FOR SAMPLE LXAA01BS01. THIS SAMPLE WAS COLLECTED IN A NEW SUMMA CANNISTER DUE TO THE POTENTIAL FOR AN UNREPRESENTATIVE SAMPLE AT LXAA01S01.



N

0 FEET 100
SCALE

MWH

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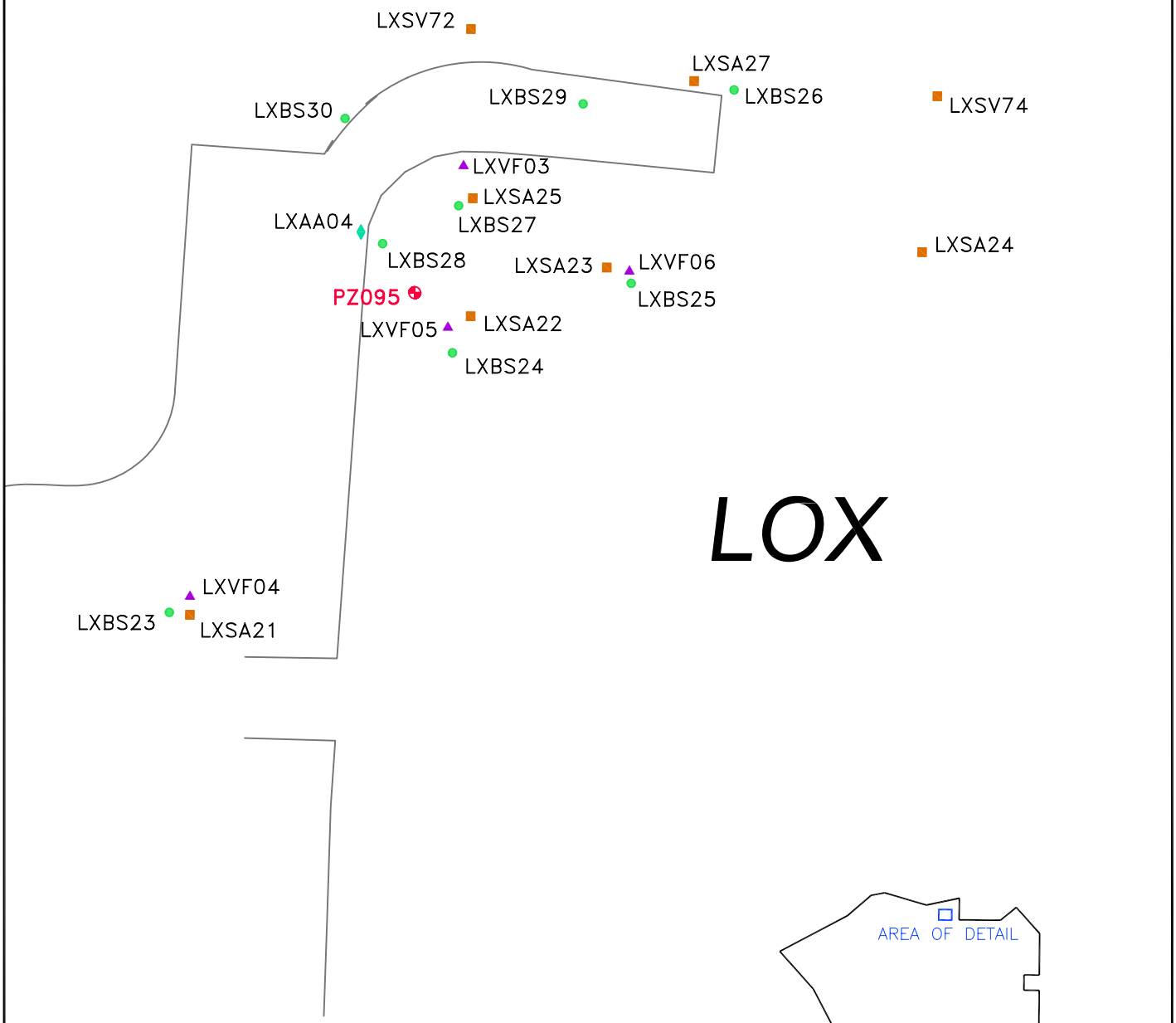
VENTURA COUNTY, CALIFORNIA
JULY 2007

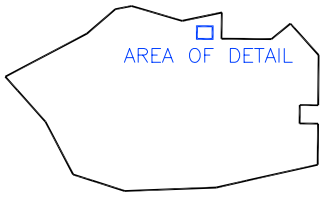
TCE ANALYTICAL RESULTS FROM AMBIENT AIR SAMPLES COLLECTED AT AND NEAR LOX

FIGURE 5

JOB No. -- FILE No. INDSVR\INDUSTRIAL\CAD\MLUEBKE\BOEING SANTA SUSANA\BASE SITE PLAN 9 06\VAPOR STUDY 3 07

Please Note: The original version of this figure includes colorized features and shading. A black and white copy of this figure should not be used because it may not accurately represent the information presented.





SANTA SUSANA FIELD LABORATORY

LEGEND

- VAPOR FLUX
- SOIL VAPOR
- SOIL BORING
- AMBIENT AIR
- NEAR-SURFACE PIEZOMETER

N

0 FEET 30
SCALE

MWH

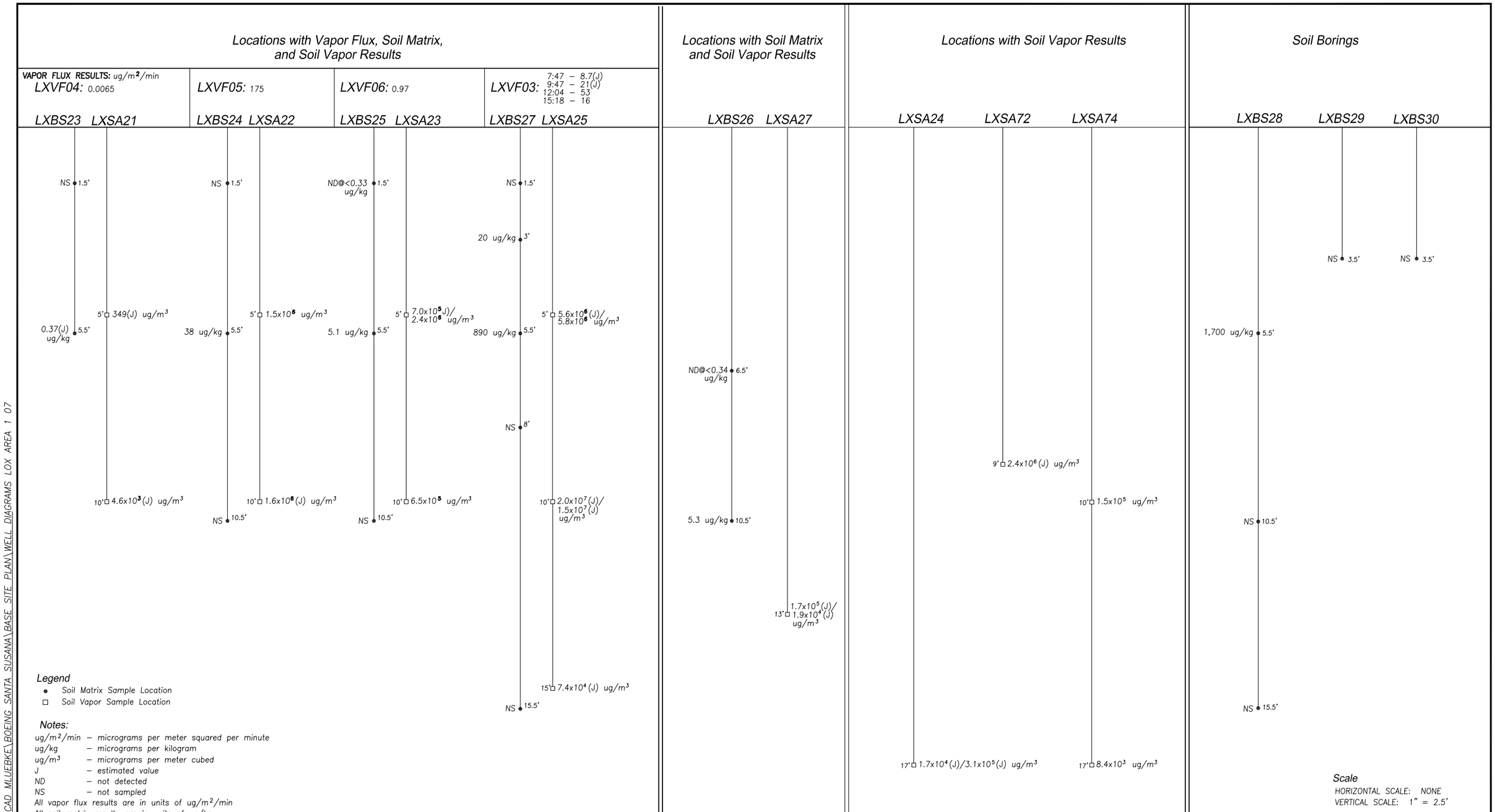
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA
JULY 2007

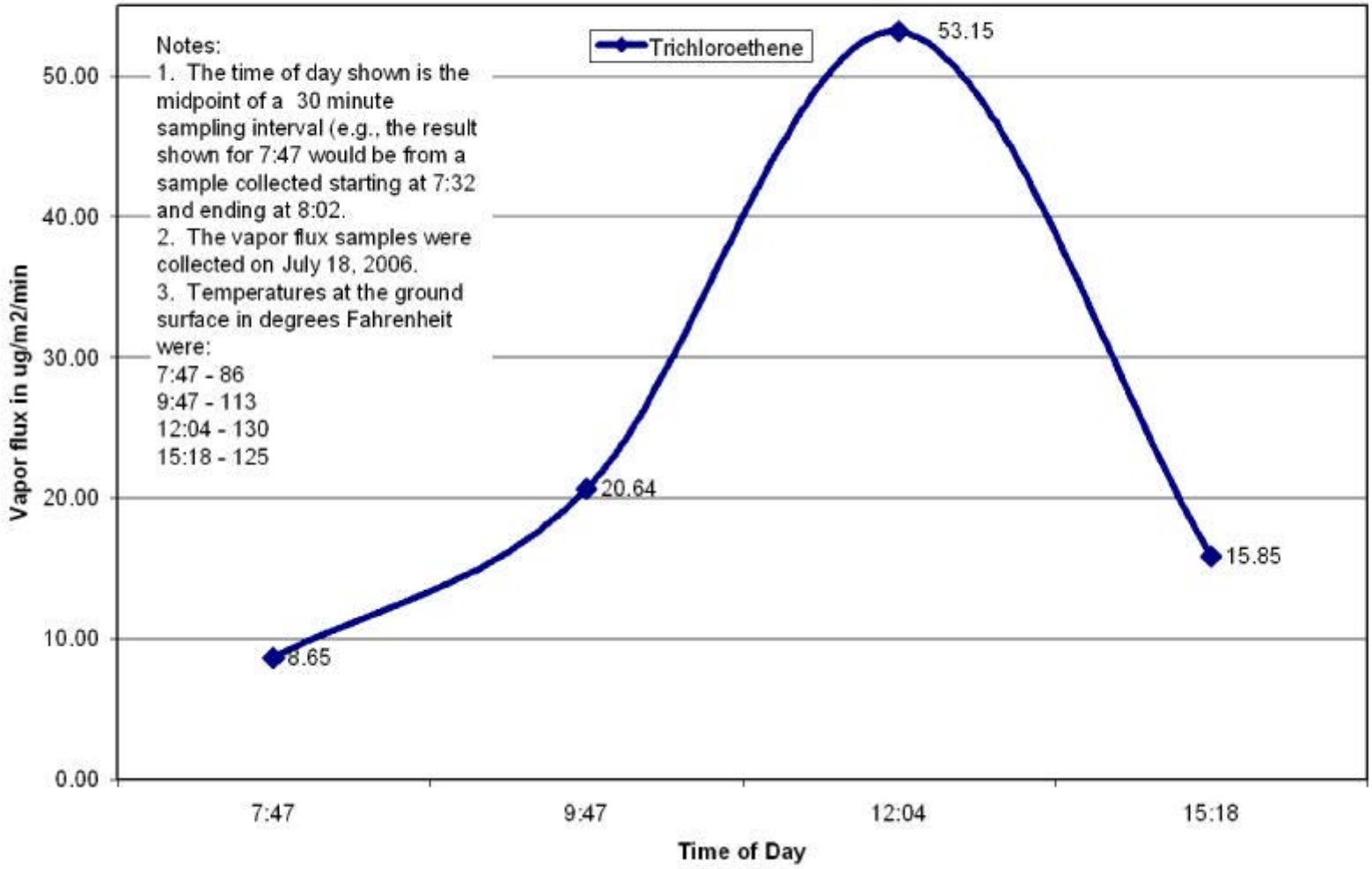
LOX AREA VAPOR FLUX, SOIL VAPOR, & SOIL BORING SAMPLE LOCATIONS

FIGURE 6

FILE: INDSVR\INDUSTRIAL\CAD MLUEBKE\BOEING SANTA SUSANA\VAPOR STUDY 1 07

JOB No.


Locations with Vapor Flux, Soil Matrix, and Soil Vapor Results
VAPOR FLUX RESULTS: ug/m2/min
LXVF04: 0.0065
LXVF05: 175
LXVF06: 0.97
LXVF03: 7:47 – 8.7(J) 9:47 – 21(J) 12:04 – 53 15:18 – 16
LXBS23 LXSA21
LXBS24 LXSA22
LXBS25 LXSA23
LXBS27 LXSA25
NS 1.5'
NS 1.5'
ND@<0.33 ug/kg 1.5'
NS 1.5'
20 ug/kg 3'
5' 349(J) ug/m3
5' 1.5x10^6 ug/m3
5' 7.0x10^5 J)/ 2.4x10^6 ug/m3
5' 5.6x10^6 (J)/ 5.8x10^6 ug/m3
0.37(J) ug/kg 5.5'
38 ug/kg 5.5'
5.1 ug/kg 5.5'
890 ug/kg 5.5'
NS 8'
10' 4.6x10^3 (J) ug/m3
10' 1.6x10^6 (J) ug/m3
10' 6.5x10^5 ug/m3
10' 2.0x10^7 (J)/ 1.5x10^7 (J) ug/m3
NS 10.5'
NS 10.5'
15' 7.4x10^4 (J) ug/m3
NS 15.5'
Locations with Soil Matrix and Soil Vapor Results
LXBS26 LXSA27
ND@<0.34 ug/kg 6.5'
5.3 ug/kg 10.5'
13' 1.7x10^5 (J)/ 1.9x10^4 (J) ug/m3
Locations with Soil Vapor Results
LXSA24 LXSA72 LXSA74
9' 2.4x10^6 (J) ug/m3
10' 1.5x10^5 ug/m3
17' 1.7x10^4 (J)/3.1x10^5 (J) ug/m3
17' 8.4x10^3 ug/m3
Soil Borings
LXBS28 LXBS29 LXBS30
NS 3.5'
NS 3.5'
1,700 ug/kg 5.5'
NS 10.5'
NS 15.5'
Legend
Soil Matrix Sample Location
Soil Vapor Sample Location
Notes:
ug/m2/min – micrograms per meter squared per minute
ug/kg – micrograms per kilogram
ug/m3 – micrograms per meter cubed
J – estimated value
ND – not detected
NS – not sampled
All vapor flux results are in units of ug/m2/min
All soil matrix results are in units of ug/kg
All soil vapor results are in units of ug/m3
All results shown are for trichloroethene and are the highest value reported. Full data sets can be found in the tables section of the report.
Soil vapor sample locations with two results reflect two different sampling timeframes. The first results are from samples collected in July 2006. The second results are from samples collected in late October/early November 2006 and were collected because leaks were indicated in the sampling system at these locations during the July sampling event.
The times shown on the vapor flux results for LXVF03 are the mid-points of a 30 minute sampling interval.
Scale
HORIZONTAL SCALE: NONE
VERTICAL SCALE: 1" = 2.5'
MWH
SANTA SUSANA FIELD LABORATORY
VENTURA COUNTY, CALIFORNIA
JULY 2007
SUMMARY DIAGRAM - TCE SAMPLE RESULTS FROM LOX AREA STUDY, VERTICAL PROFILE
FIGURE 7
JOB No. -- FILE No. CAD MLUEBKE\BOEING SANTA SUSANA\BASE SITE PLAN\WELL DIAGRAMS LOX AREA 1 07



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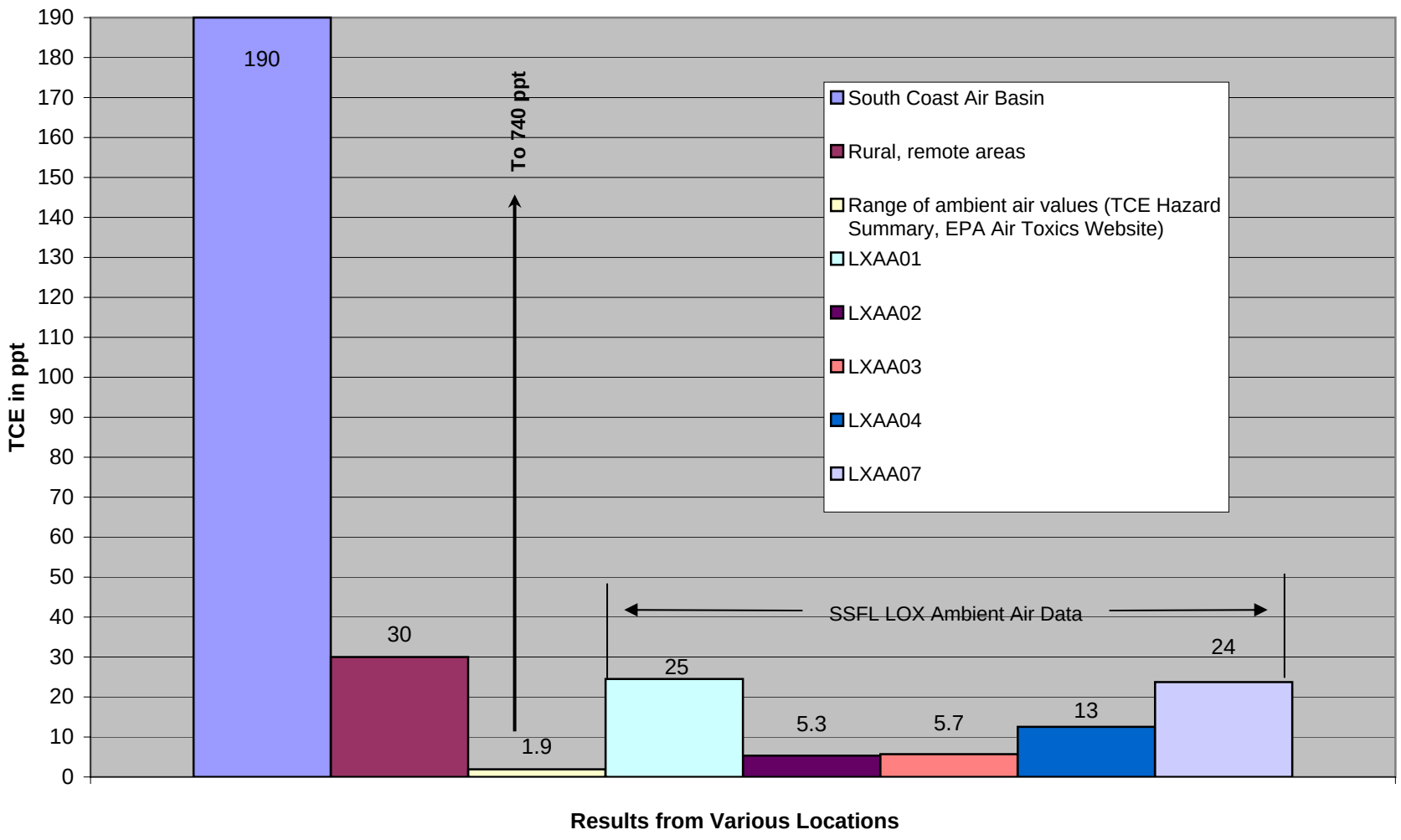
VENTURA COUNTY, CALIFORNIA
JULY 2007

TCE VAPOR FLUX OVER TIME AT LXVF03

FIGURE 8

JOB No. _____ FILE: CADMLUEBKE\BOEING SANTA SUSANA\BASE SITE 9 06\TCE VAPOR GRAPH 1 07



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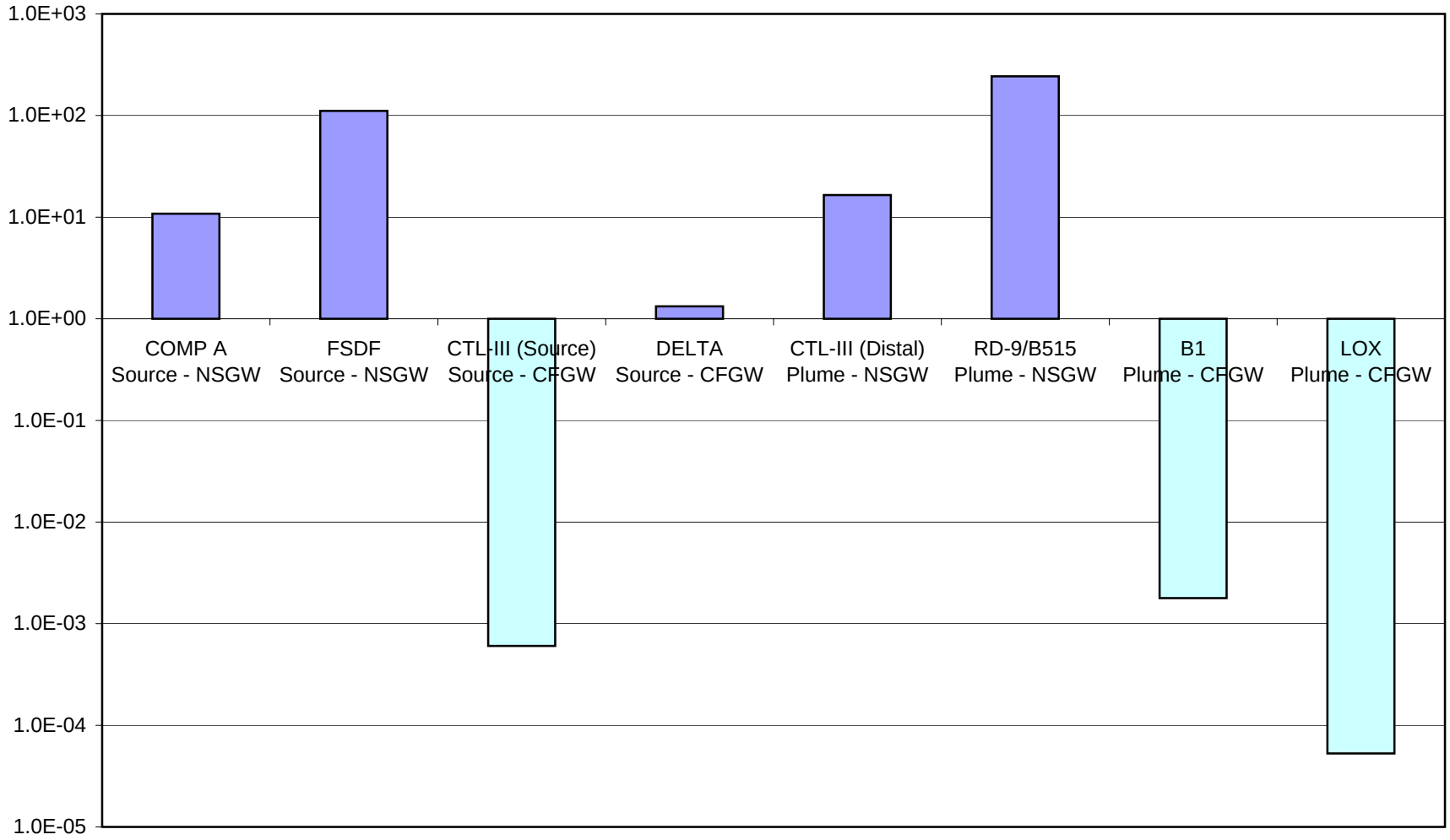
TCE IN AMBIENT AIR

FIGURE 9



Note: The locations shown above where the model under-predicts the flux relative to the measured values are not representative of the actual conditions encountered. See sections 5.0 and 6.0 of this report for descriptions of the basis for this conclusion.

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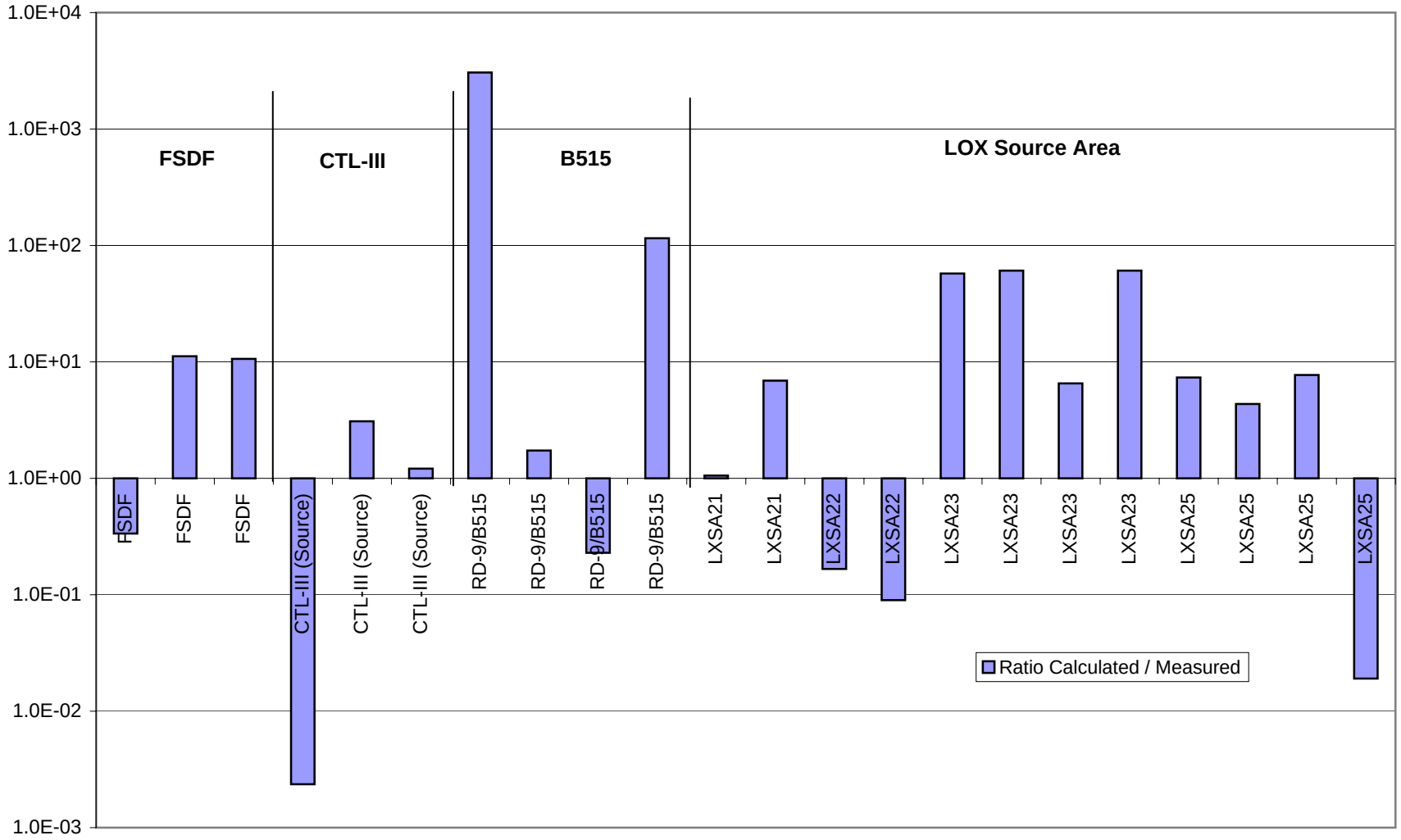
RATIO OF MODEL-CALCULATED FLUX FROM GROUNDWATER SAMPLES TO FIELD-MEASURED FLUX

FIGURE 10



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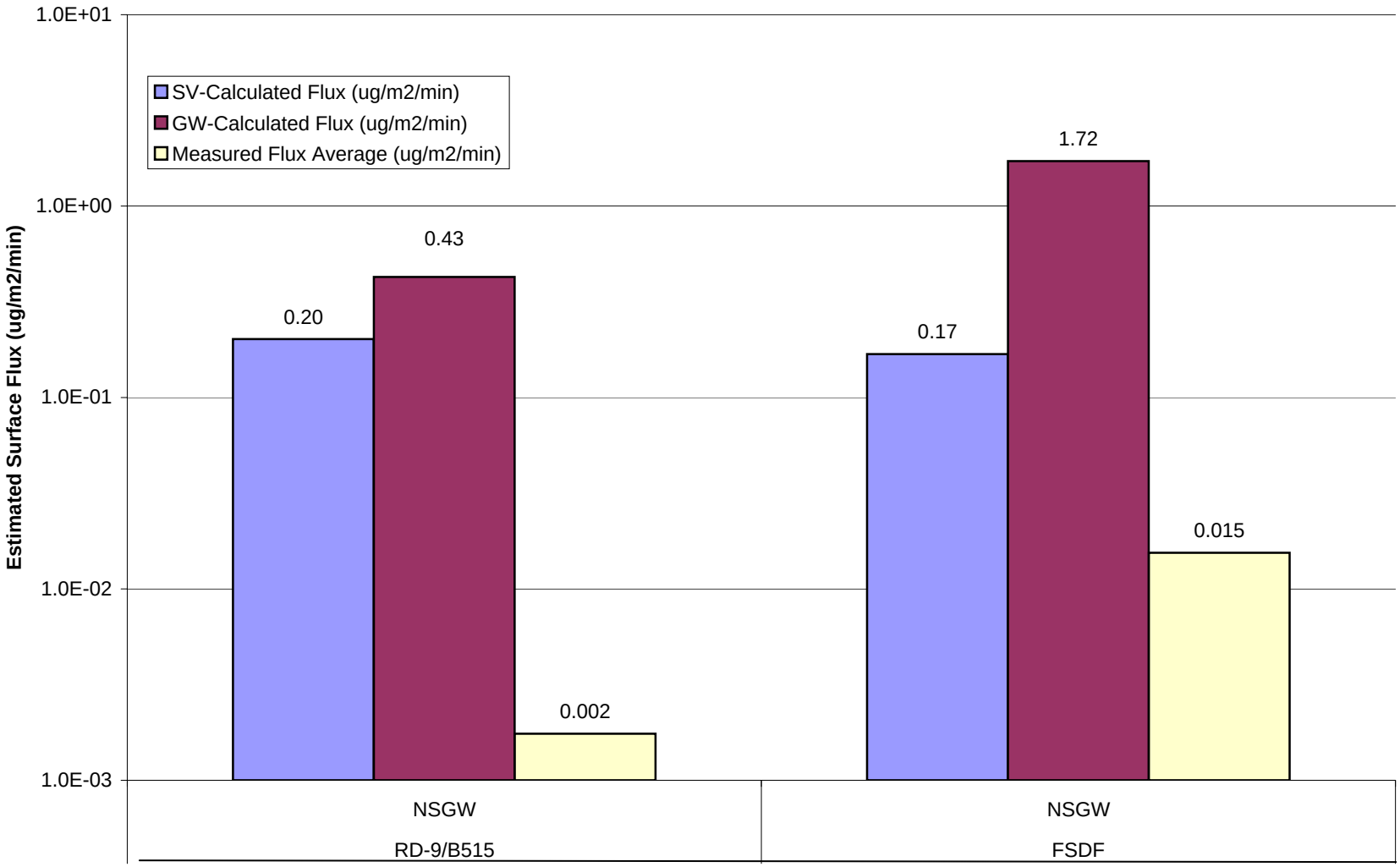
RATIO OF MODEL-CALCULATED FLUX FROM SOIL VAPOR SAMPLES TO FIELD-MEASURED FLUX

FIGURE 11



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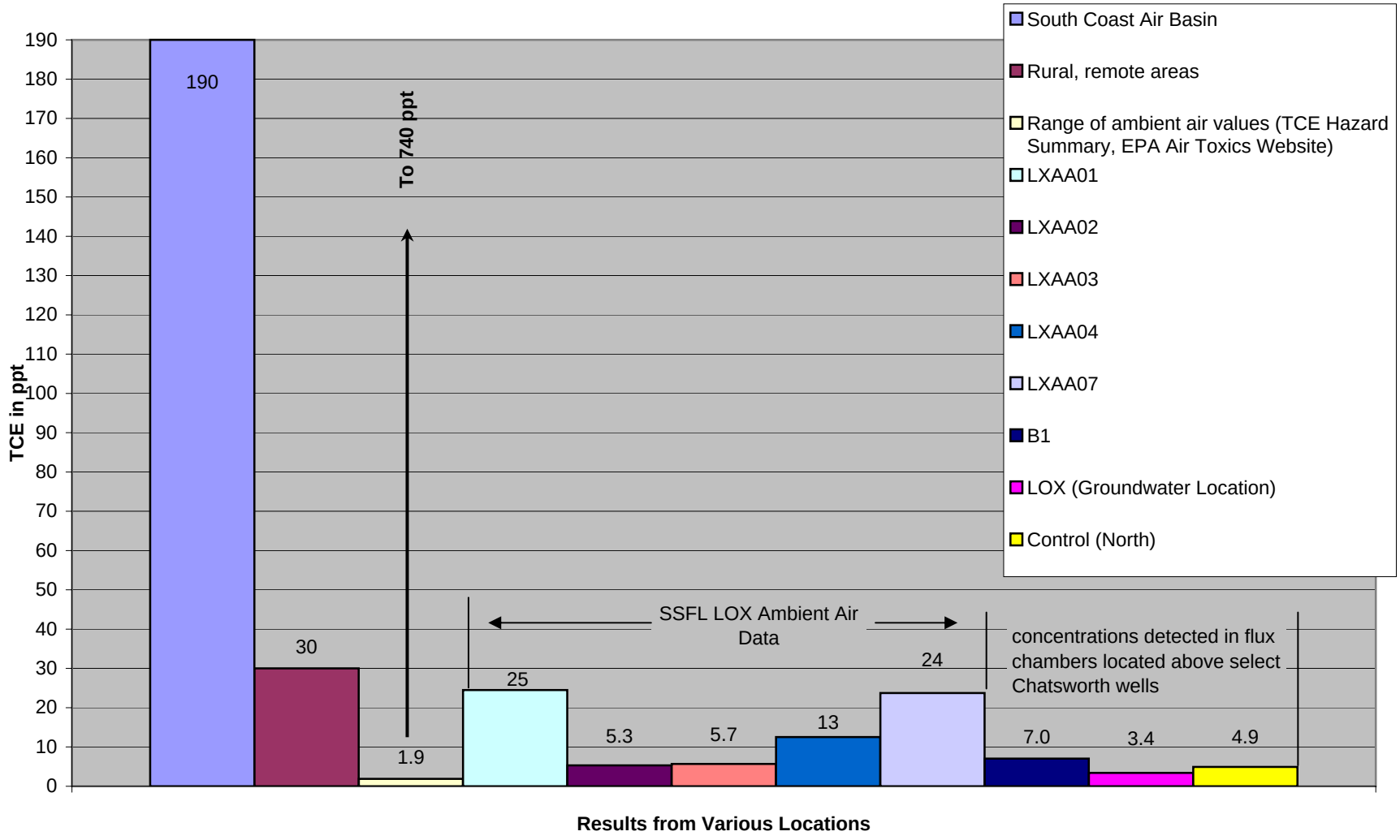
COMPARISON OF MODEL-CALCULATED SURFACE FLUX FROM SOIL VAPOR AND GROUNDWATER SAMPLES

FIGURE 12



Note: Results from vapor fluxes shown above are for locations where TCE was infrequently detected and at concentrations below the method reporting limit

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TCE IN AMBRIENT AIR AND IN SELECT VAPOR FLUX SAMPLES

FIGURE 13

APPENDICES

Appendix A

Surface Vapor Flux Data Sheets

(Electronic)

Appendix B

B-1: Memorandum: Soil Vapor Sampling Leak Test Evaluation, Vapor Migration Modeling Validation Study, Santa Susana Field Laboratory

MEMORANDUM

DATE: **October 9, 2006**

TO: **Gerard Abrams, DTSC**
Laura Rainey, DTSC

FROM: **Richard Andrachek, MWH**
Robert Ettinger, GeoSyntec
Elizabeth Wessling, MECx
Michael Sullivan, McDaniel Lambert

SUBJECT: **Soil Vapor Sampling Leak Test Evaluation**
Vapor Migration Modeling Validation Study
Santa Susana Field Laboratory

This memorandum summarizes the soil vapor sampling leak tests results obtained during the soil gas sample collection activities of the Santa Susana Field Laboratory (SSFL) Vapor Migration Modeling Validation Study (VMMVS). The leak test results, evaluation process and proposed future actions are discussed.

Purpose and Scope of Validation Study

The RCRA Facility Investigation (RFI) for SSFL is characterizing the presence of contaminants, including volatile organic compounds (VOCs), in various environmental matrices, predicting their migration both within and between these matrices and evaluating the potential associated health risks to both human and ecological receptors from exposure to these chemicals. One environmental matrix that cannot be sampled directly, because the buildings do not exist, is indoor air. Additionally, sufficient measurement of outdoor air concentrations is difficult due the transient nature of chemical dispersion in the atmosphere and potential influences of background sources. Therefore, the concentrations of volatile chemicals in outdoor and potential future indoor air are predicted using fate and transport (F&T) models.

F&T models for vapor migration in soil and/or fractured bedrock from a subsurface source have been proposed for the SSFL RFI[1]. These models predict vapor flux at the soil surface and use various input parameters including soil matrix concentration, soil vapor concentration, groundwater concentration, chemical properties and soil and rock properties. The SSFL vapor migration validation study collected and analyzed environmental samples for the purpose of field-validating the proposed model consistent with the approved work plan. Since the results of a human health risk assessment tend to over-predict exposures and risks (i.e., be conservative), it is expected that the proposed

[1] MWH, 2005. Standardized Risk Assessment Methodology (SRAM) Work Plan. Santa Susana Field Laboratory, Ventura County, California. June.

F&T model for vapor migration will be acceptable if it over-predicts potential future indoor air concentrations above a contaminated source.

Summary of Fieldwork Performed

The SSFL VMMVS collected co-located soil, soil gas, and surface flux samples at various locations that represent a broad range in site conditions across the SSFL. Differential conditions evaluated in the study included soil cover vs. no soil cover, source area (soil and groundwater contamination) vs. distal area (groundwater contamination only), contaminated vs. uncontaminated (control) areas, and both spatial and temporal variation in vapor flux. Soil matrix, soil vapor and soil vapor flux samples were collected at each sample location described in the work plan and analyzed for VOCs. A total of 10 sites were selected for the sampling and soil gas samples were collected at four of these locations. Multi-depth soil gas probes were installed at these locations, where appropriate, to collect data to characterize the vertical concentration profile of VOCs in sub-surface soils. A total of 12 samples and 1 field duplicate were collected for this portion of the study. The locations of the soil gas samples for the VMMVS are shown on Figure 1.

Additional sampling was performed at the former LOX facility for the purpose of studying air dispersion of VOCs migrating from the soil into the air. At the LOX facility, soil gas samples were collected at eight locations as shown on Figure 2 and a total of 14 samples and 1 field duplicate were collected.

Soil Vapor Sampling Leak Test Analysis

Leak Test Methods

Leak tests were conducted during soil vapor sampling using isopropyl alcohol (IPA) as the leak detection tracer. To conduct the leak test, a rag soaked with a 70% IPA solution was placed around the soil gas probe and sampling equipment prior to and during purging and sample collection. The analytical laboratory analyzed the soil gas samples for IPA to assess whether atmospheric air affected the sample.

Criteria

Low-level detection of the leak detection tracer in the soil gas sample does not necessarily indicate the sample is unusable due to the introduction of atmospheric air. In some cases, it is possible that the detection of the tracer compound is a result of subsurface impacts and does not suggest a problem with the sample collection. Various criteria have been proposed to determine when a reported sample may be inappropriately

biased[2]. Criteria for determining data usability may be based either on a concentration threshold for the tracer gas in the soil gas sample or a soil gas to source concentration ratio for the tracer.

A tracer concentration of 10 ug/L has become a common threshold for sample acceptability in California. This threshold value has been taken from the LARWQCB/DTSC Soil Gas Sampling Advisory[3]. Other threshold values have been proposed (e.g., San Mateo County has proposed a detection limit of 0.1 ug/L), but the 10 ug/L value is a much more practical value that allows for laboratory sample dilution due to elevated concentrations of other VOCs in the samples and limitations of field analytical methods.

A threshold based on a fraction of the source concentration in the sample has also been proposed to assess sample usability. The rationale for this approach is that the contribution of ambient air to the soil gas sample may be estimated by the relative concentration ratio of the tracer in the soil gas to that in the tracer source area. For example, if the tracer concentration in a soil vapor sample is 5% of the source concentration, then 95% of the sample would be representative of soil gas.

Variability is inherent in analytical chemistry measurements of environmental matrices. Acceptable limits of this variability have been established as confidence limits to ensure the usability of the data. For comparison, some of the method variability control criteria are presented below:

Audit Accuracy of the Method; 30%,
Replicate Precision of the Method; 25%,
Internal Standard Response; ±40% response of daily calibration,
Daily Calibration; 30% difference from initial calibration,
Initial Calibration; 30% relative standard deviation,
Laboratory Control Sample; 70-130% recovery.

The variability of the analytical methods which produces acceptable results is quite broad. By comparison, a 5% influence of ambient air appears to minimally affect the result reported by the laboratory.

Based upon the review of the different options to set a threshold value for a leak determination, an IPA concentration of 10 ug/L in the soil gas samples is used to evaluate whether the VOC analytical results are acceptable for use in the VMMVS.

---

[2] Gallagher, D. 2006 "Status and Application of DTSC's Vapor Intrusion Guidance Document," Air and Waste Management Association Symposium Vapor Intrusion: The Next Great Environmental Challenge – An Update, Los Angeles, CA. September

[3] CalEPA, 2003. Los Angeles Regional Water Quality Control Board/ Department of Toxic Substances Control, Advisory – Active Soil Gas Investigations. January.

Leak Test Results

The leak test results for the 28 soil vapor samples collected in the VMMVS are summarized in Table 1.

- The leak test tracer was not detected in 14 samples. These samples indicate that unacceptable leaks of ambient air into the soil gas sample did not occur.

- In 5 samples, the leak test tracer was detected in the soil gas sample below the threshold value. These samples do not indicate unacceptable leaks of ambient air into the soil gas sample. Note, however, that the detected IPA concentration in LXSA27S01 was 9.5 ug/L, which is just below the threshold value of 10 ug/L.

- The leak test tracer was detected in two soil gas samples, LXSA23S01 and LXSA24S01, at a concentration exceeding the threshold value.

- The leak test was not conducted in 7 samples at the LOX site.

Recommendations

Because the leak test was not conducted for some of the soil gas samples collected and the leak test tracer was detected some of the soil gas samples, recommendations for qualifying the analytical results and collecting additional data have been made. Additionally, refinements to the leak test protocol are suggested to improve the sampling program.

Follow-up Soil Gas Sample Collection

Soil gas samples are proposed to be collected as a result of the review of the leak test analytical results. Soil gas probes to be re-sampled are summarized in Table 1. Samples will be collected at:

- Each of the locations where the leak test was not previously conducted;
- Each of the locations where the IPA concentration in the soil gas sample exceeded the threshold value of 10 ug/L; and
- LXSA27S01, where the IPA concentration in the soil gas sample was just below the threshold value of 10 ug/L.

During the follow-up sampling, the following procedures will be conducted to test for leaks:

- <u>Vacuum response test</u>. At locations where soil gas probes screened at multiple depths are located, a vacuum response test will be conducted to determine the effectiveness of the vertical seal between probes. In this test, a vacuum will be applied to a soil vapor probe and a vacuum response in the adjacent probe(s) will

be measured. If the vacuum response in the neighboring probes is less than 5% of the induced vacuum, the seal between probes will be determined to be adequate for the investigation.

- Vacuum dissipation test. After the purging and sampling equipment is connected to the soil gas probe, a vacuum dissipation test will be conducted to test for leaks in the sampling train. To conduct this test, the valve to the probe will be closed, a vacuum of at least 20 in-H_2O will be created in the sampling train using a vacuum pump, the valve to the vacuum pump will be closed, and the vacuum within the sampling train monitored. If the vacuum within the sampling train does not reduce by more than 5% over a minute, then the leakage within the sampling train will be determined to be adequate for this investigation.

- Helium leak test. Helium, instead of IPA, will be used as the tracer gas for the leak test during the follow-up investigation. To conduct this test, a plastic shroud will be placed around the soil gas probe and helium will be introduced into the shroud. The helium concentration within the shroud will be monitored with a field helium detector and maintained between 70 – 80%. The soil gas removed from the probe during the purging will be collected in a Tedlar bag and tested for helium. Provided that the helium concentration in the purge gas sample is less than 5% of the shroud concentration (3.5 – 4.0%), a sample will be collected from the probe using a Summa canister equipped with a flow controller. Following collection of the sample in the Summa canister, an additional soil gas sample will be collected in a Tedlar bag and monitored for helium. The threshold concentration for the helium in the Tedlar bag samples will be 5% of the concentration within the shroud. If both the pre- and post-sampling Tedlar bag samples are below the 5%, then the sample will have passed the leak test. If not, additional corrective measures will be taken in the field (e.g., tightening fittings) and the test will be repeated. If the 5% criteria cannot be met at a given probe, that location and depth will be eliminated from the validation program.

Data Usability

All data will be validated and qualified using the guidance for volatile analyses in the National Functional Guidelines for Organic Data Review and the SSFL Quality Assurance Program Plan. Data collected where no leak detection was performed, will be rejected as being of unknown quality. Data from the second round of sampling with successful leak detection (helium less than 5%) will replace the data from the first sampling event where no leak detection was performed or where IPA was previously detected at or near the threshold value of 10 ug/L.

Conclusions

Boeing is requesting that DTSC review this memo and approve the recommendations so that the additional field work can be completed prior to the beginning of the rainy season.

It is timely to complete the VMMVS because the validated model will be used in the RFI reports currently being written for various areas of the SSFL. The authors of this memorandum are available to discuss these issues with DTSC to assist in expediting their review and the completion of VMMVS field activities.

Attachments

Table 1 Soil Gas Sampling Leak Test Results

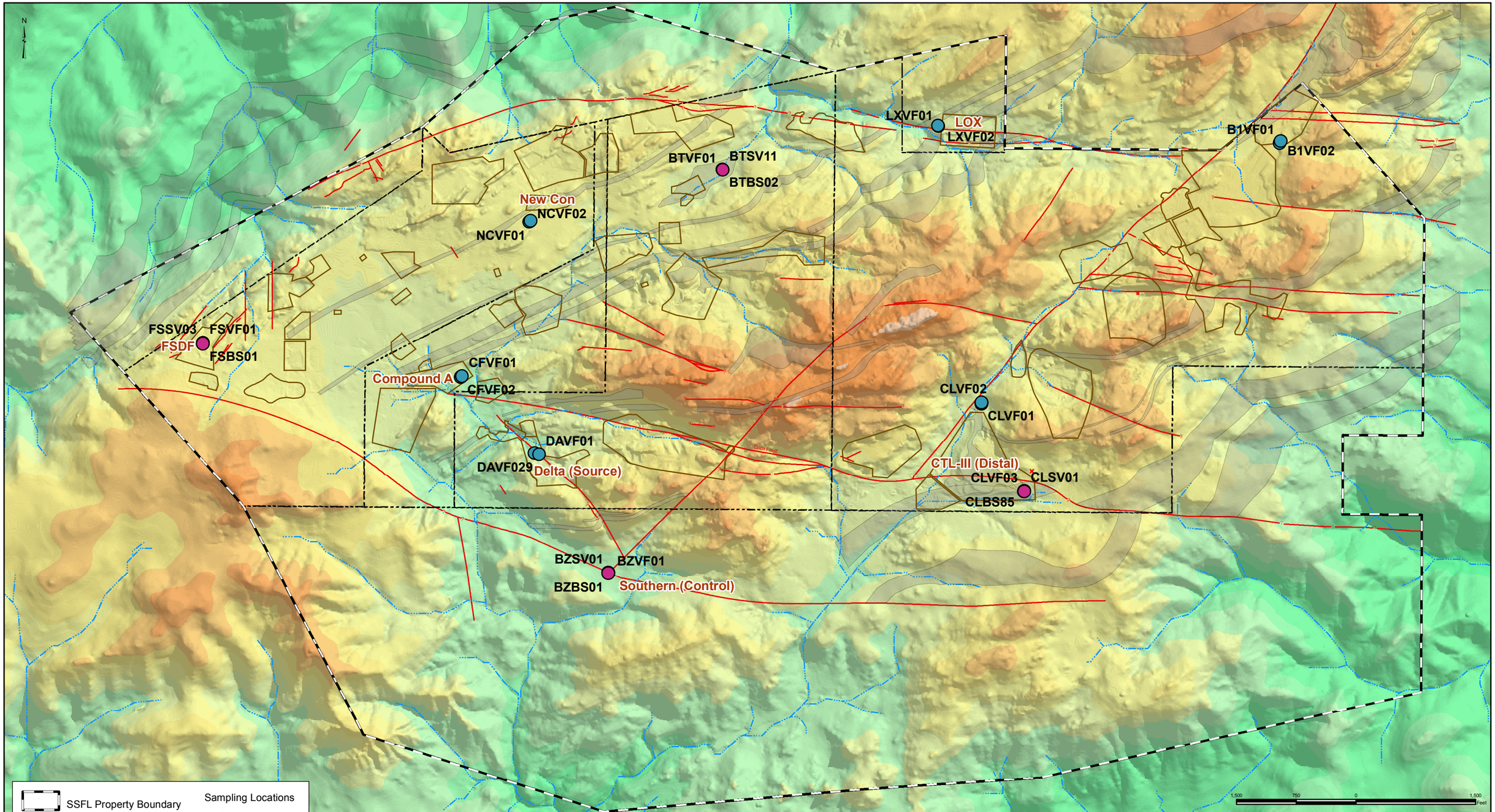
Figure 1 Sampling Locations for Vapor Migration Modeling Validation Study

Figure 2 Sampling Locations for Vapor Migration Modeling Validation Study – LOX Site

Table 1
Soil Gas Sampling Leak Test Results
Isopropyl Alcohol Concentrations (ug/L)
SSFL Vapor Migration Modeling Validation Study

Investigational Unit / Location	Sample_ID	Depth	Date Collected	Result (ug/L)	Locations Passing Leak Test	Locations To Be Resampled
BTSV11	BTSV11S01	5	7/26/2006	< 39	1	
	BTSV11S02	10	7/26/2006	< 0.004	1	
	BTSV11S02	15	7/26/2006	**0.47**	2	
	BTSV11S04	20	7/26/2006	< 1.5	1	
FSDF FSSV03	FSSV03S01	4	7/27/2006	**0.43**	2	
	FSSV03S02	7	7/27/2006	< 0.25	1	
	FSSV03D01	7	7/27/2006	< 0.26	1	
Control (south) RD-05A BZSV01	BZSV01S01	5	7/27/2006	< 0.099	1	
	BZSV01S02	10	7/27/2006	**2.3**	2	
	BZSV01S03	13	7/27/2006	**0.31**	2	
CLT-III (Source) CLSV89	CLSV89S01	5	7/27/2006	< 0.005	1	
	CLSV89S02	10	7/27/2006	< 37	1	
	CLSV89S03	15	7/27/2006	< 19	1	
LOX - LXSA23	LXSA23S01	5	7/25/2006	**4,100**		3
	LXSA23S02	10	7/25/2006	< 21	1	
LOX - LXSA24	LXSA24S01	17	7/26/2006	**21**		3
LOX - LXSA25	LXSA25S01	5	7/26/2006	< 97	1	
	LXSA25S02	10	7/26/2006	< 150	1	
	LXSA25D01	10	7/26/2006	< 120	1	
	LXSA25S03	15	7/26/2006	< 4.4	1	
LOX - LXSA27	LXSA27S01	13	7/26/2006	**9.5**		4
LOX - LXSA21	LXSA21S01	NR	7/25/2006	NA		5
	LXSA21S02	NR	7/25/2006	NA		5
LOX - LXSA22	LXSA22S01	NR	7/25/2006	NA		5
	LXSA22S02	NR	7/25/2006	NA		5
LOX - LXSV72	LXSV72S01	NR	7/28/2006	NA		5
LOX - LXSV74	LXSV74S01	NR	7/28/2006	NA		5
	LXSV74S02	NR	7/28/2006	NA		5

NR Not Reported
NA Not Analyzed
1 Leak test tracer not detected in soil gas sample
2 Leak test tracer detected below threshold concentration in soil gas sample
3 Leak test tracer detected above threshold concentration in soil gas sample
4 Leak test tracer detected slightly below threshold concentration in soil gas sample
5 Leak test not conducted during initial sample collection



SSFL Property Boundary

Administrative Boundary

RFI Sites

Shale Units

Drainages

Sampling Locations

Soil Boring

Soil Vapor

Vapor Flux

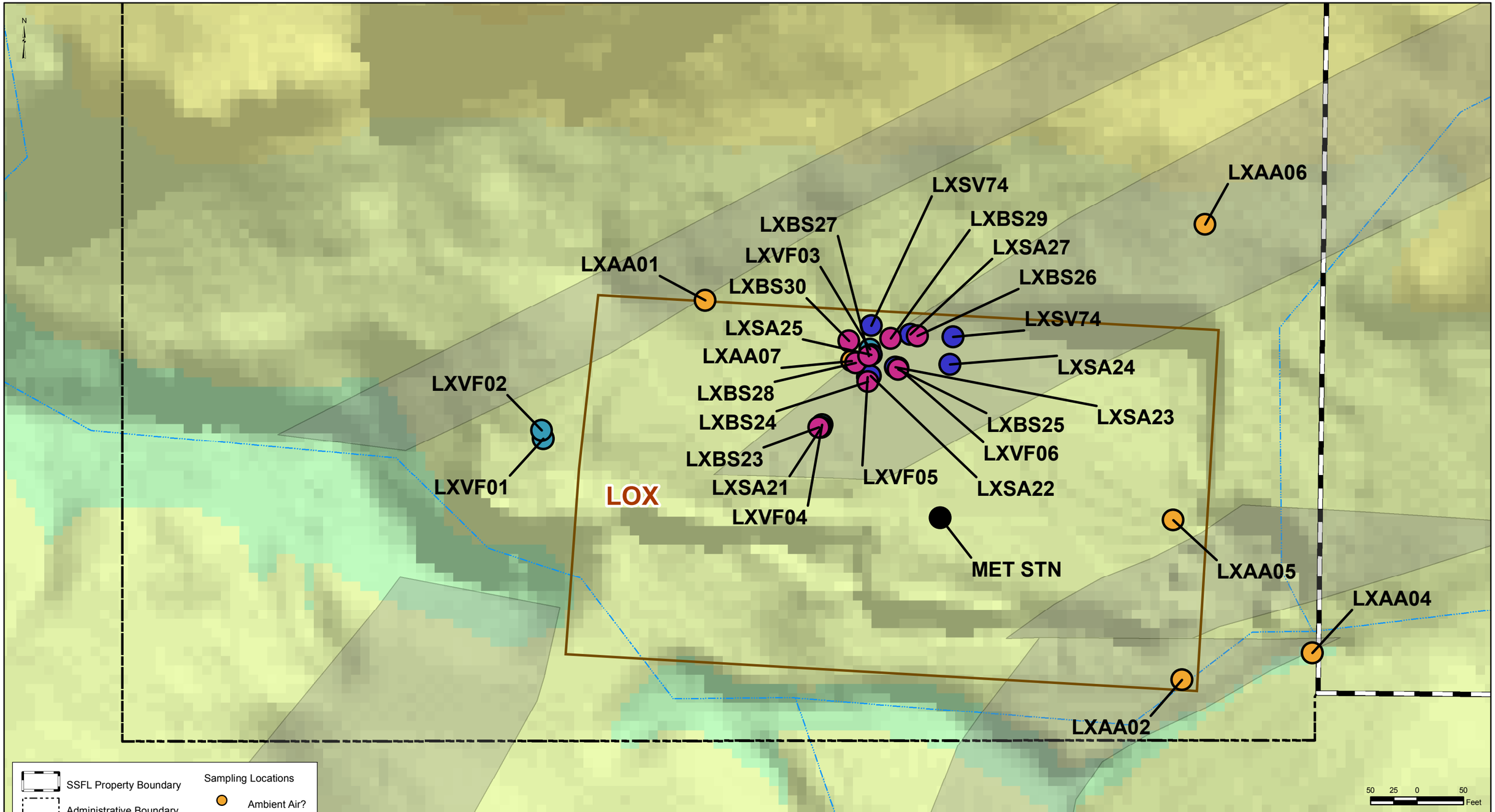
Santa Susana Field Laboratory
Ventura County, California

FIGURE 1_

SAMPLING LOCATIONS FOR VAPOR VALIDATION STUDY

MWH

Prepared by:	Date	
MKJ	09/05/06	FILE: GIS/SSFL/TCE_VMMS.MXD



SSFL Property Boundary
Administrative Boundary
RFI Sites
Shale Units
Drainages

Sampling Locations
Ambient Air?
Met Station
Soil Boring
Soil Vapor
Vapor Flux

Santa Susana Field Laboratory
Ventura County, California

FIGURE 2_

SAMPLING LOCATIONS FOR VAPOR VALIDATION STUDY

MWH

Prepared by: MKJ
Date 10/04/06
FILE: GIS/SSFL/TCE_VMMS.MXD

Appendix B

B-2: Technical Memorandum: Leak Test Results During Soil Vapor Probe Resampling in October/November 2006

APPENDIX B-2
VAPOR MIGRATION MODEL VALIDATION STUDY
FIELD ACTIVITIES CONDUCTED DURING THE RE-SAMPLING OF SELECT SOIL VAPOR PROBES
SANTA SUSANA FIELD LABORATORY

1.0 INTRODUCTION

Additional soil vapor sampling was performed as part of the Vapor Migration Model Validation Study (VMMVS) at the Santa Susana Field Laboratory (SSFL) from October 30 through November 1, 2006. These sampling activities were performed as a result of the soil vapor sampling leak test evaluation (MWH 2006) that was performed on samples collected during the VMMVS activities in July 2006. Re-sampling at chosen locations was performed based on the following criteria:

- Locations where soil vapor leak testing was not performed during the July 2006 sampling event.
- Locations where concentrations of the tracer, isopropyl alcohol (IPA) exceeded the threshold value 10 micrograms per liter (µg/L), and
- LXSA27S01, where the concentration of IPA in the soil gas sample was slightly below the threshold value 10 µg/L.

In addition, samples were recollected at the Control South (RD-05) location at the request of The Boeing Company.

1.1 Sampling Locations

The following table presents the locations that were re-sampled, the sample identification names, depths and dates sampled:

Investigational Area/ Location	Sample ID	Depth in feet	Date Sampled	Remarks
LOX/ LXSA21	LXSA21S01	5	30-Oct-06	
LOX/ LXSA21	LXSA21S02	10	30-Oct-06	
LOX/ LXSA22	LXSA22S01	5	30-Oct-06	
LOX/ LXSA22	LXSA22S02	10	30-Oct-06	

Investigational Area/ Location	Sample ID	Depth in feet	Date Sampled	Remarks
LOX/ LXSA23	LXSA23S01	5	31-Oct-06	
LOX/ LXSA23	LXSA23D01	5	31-Oct-06	Duplicate Sample
LOX/ LXSA24	LXSA24S01	17	31-Oct-06	
LOX/ LXSA25	LXSA25S02	10	31-Oct-06	
LOX/ LXSA27	LXSA27S02	13	01-Nov-06	
LOX/ LXSA27	LXSA27F01	0	01-Nov-06	Field Blank [a]
LOX/ LXSV72	LXSV72S01	9	31-Oct-06	
LOX/ LXSV74	LXSV72S02	5	31-Oct-06	
LOX/ LXSV74	LXSV74S02	10	31-Oct-06	
Control South/ BZSV01	BZSV01S01	5	01-Nov-06	
Control South/ BZSV01	BZSV01S02	10	01-Nov-06	
Control South/ BZSV01	BZSV01S03	13	01-Nov-06	

a – The field blank was collected approximately 500 feet east of LXSA27 at the SSFL boundary that abuts Sage Ranch Park.

2.0 SOIL VAPOR SAMPLING LEAK TESTS

During the re-sampling activities three different leak tests were performed prior to and post sampling. The methods used are discussed below:

2.1 Vacuum Response Test

A vacuum response test was performed at locations where soil vapor points were nested at multiple depths. Vacuum response tests were conducted to determine the effectiveness of the vertical seal between the probes. A vacuum was sequentially applied to each soil vapor probe and a vacuum response was monitored in the adjacent probe located either above and/or below the probe where the vacuum was being applied. If the vacuum response in the neighboring probes was less than 5% of the induced vacuum, the seal between the probes was deemed adequate.

2.2 Vacuum Dissipation Test

After the purging and sampling equipment were connected to the soil vapor probe, a vacuum dissipation test was conducted to test for leaks in the sampling train. The valve to the probe was closed, a vacuum was created in the sampling train using a vacuum pump, the valve to the vacuum pump was then closed, and the vacuum within the sampling train monitored. If the vacuum within the sampling train did not reduce by more than 5 % over a minute, the leakage within the sampling train was determined adequate for sampling.

2.3 Helium Leak Test

A leak test using helium was conducted by placing a plastic shroud around the tubing of the soil vapor probes positioned at the ground surface. Helium was introduced into the shroud during the purging process of each vapor probe. The helium concentration within the shroud was monitored with a helium detector and maintained between 70% and 90%. Upon completing the purging of the vapor probe, a vapor sample was collected in a Tedlar bag and tested for helium using the helium detector. If the helium concentration in the purge gas sample was less than 5% of the shroud concentration, a sample was then collected from the probe using a Summa canister and was submitted for analysis of volatile organics. An additional soil gas sample was collected in a Tedlar bag and monitored again for helium following collection of the sample in the Summa canister.

3.0 LEAK TESTING RESULTS

The following table's present results for the three leak tests performed at each sampling location.

Vacuum Response Test Results

Probe Tested	Probe Monitored	Induced Vacuum (in. Hg)	Response on Probe Monitored (in. H20)	Percent of Induced Vacuum
LXSA21 (5 ft)	LXSA21 (10 ft)	8	0	0
LXSA21 (10 ft)	LXSA21 (5 ft)	17	0	0
LXSA22 (5 ft)	LXSA22 (10 ft)	NR	0	0
LXSA22 (10 ft)	LXSA22 (5 ft)	NR	0	0
LXSA25 (5 ft)	LXSA25 (10 ft)	12	5.8	3.5
LXSA25 (5 ft)	LXSA25 (14 ft)	12	0.02	0.001
LXSA25 (10 ft)	LXSA25 (14 ft)	18	0	0
LXSA25 (10 ft)	LXSA25 (5 ft)	18	1.8	0.07
LXSA25 (14 ft)	LXSA25 (5 ft)	6.5	0.02	0.01
LXSA25 (14 ft)	LXSA25 (10 ft)	6.5	0	0
LXSV72 [a]	NA	NA	NA	NA
LXSA23 (5 ft)	LXSA23 (10 ft)	7.5	0	0
LXSA23 (10 ft)	LXSA23 (5 ft)	17.5	0	0
LXSA24 (5 ft)	LXSA24 (10 ft)	7	0	0
LXSA24 (5 ft)	LXSA24 (17 ft)	7	0	0
LXSA24 (10 ft)	LXSA24 (5 ft)	18.5	0.05	0.02
LXSA24 (10 ft)	LXSA24 (17 ft)	18.5	0	0
LXSA24 (17 ft)	LXSA24 (5 ft)	18.5	0	0
LXSA24 (17 ft)	LXSA24 (10 ft)	18.5	0	0
LXSV74 (5 ft)	LXSA74 (10 ft)	7	0	0
LXSV74 (5 ft)	LXSA74 (17 ft)	7	0	0
LXSV74 (10 ft)	LXS74 (5 ft)	18	0	0
LXSV74 (10 ft)	LXSA74 (17 ft)	18	0	0
LXSV74 (17 ft)	LXSA74 (5 ft)	18.5	0	0
LXSV74 (17 ft)	LXSA74 (10 ft)	18.5	0	0
BZSV01 (5 ft)	BZSV01 (10 ft)	7	0.5	0.5
BZSV01 (5 ft)	BZSV01 (13 ft)	7	0.05	0.05
BZSV01 (10 ft)	BZSV01 (5 ft)	7	0.35	0.36
BZSV01 (10 ft)	BZSV01 (13 ft)	7	0.5	0.5
BZSV01 (13 ft)	BZSV01 (5 ft)	7	0.05	0.05
BZSV01 (13 ft)	BZSV01 (10 ft)	7	0.35	0.36

[a] - Denotes location where a single vapor probe resides; no vacuum response test was performed.

Vacuum Dissipation Test Results

Sample Location	Probe Depth (ft)	Initial Vacuum (in. H2O)	Duration (minutes)	Vacuum Dissipation (in. H20)
LXSA21	5	39	2	1
LXSA21	10	210	2	NR
LXSA22	5	NR	5	0.5
LXSA22	10	NR	5	0.5
LXSA25	10	18 (in. Hg)	3	0
LXSV72	9	16 (in. Hg)	2	0
LXSA23	5	16 (in. Hg)	3	0
LXSA23	5 (dup)	16 (in. Hg)	3	0
LXSA24	17	12 (in. Hg)	2	0
LXSV74	5	11 (in. Hg)	2	0
LXSV74	10	12 (in. Hg)	2	0
LXSA27	5	12 (in. Hg)	2	0
LXSA27	10	12 (in. Hg)	2	0

Helium Tracer Test Results

Sample Location	Probe Depth (ft)	Helium Conc. During Probe Purge (%)	Purge Duration (minutes)	Helium Conc. Post Purge (Tedlar Bag)	Helium Conc. Post Canister Sampling (Tedlar Bag)
LXSA21	5	70-90	6	<1%	<1%
LXSA21	10	80	12	<1%	<1%
LXSA22	5	70-90	5	<1%	<1%
LXSA22	10	70-90	8	<1%	<1%
LXSA25	10	75 – 85	5	<1%	<1%
LXSV72	9	75 - 85	7	<1%	<1%
LXSA23	5	75 - 85	3	<1%	NR
LXSA24	17	75 - 85	6	<1%	<1%
LXSV74	5	70 – 90	6	<1%	<1%
LXSV74	10	70 – 90	6	<1%	<1%
LXSA27	5	70 – 90	5	<1%	<1%
LXSA27	10	70 – 90	8	<1%	<1%
LXSA27	13	70 – 90	5	<1%	<1%

NR: not recorded

Between sampling of each probe, the sampling trains used to collect each soil vapor sample were purged with ultra-high purity air supplied by the laboratory. This procedure was performed to purge residual vapor from the sampling train. Soil vapor samples collected each day were secured on-site at the SSFL. When the soil vapor sampling activities were completed, all Summa canisters were shipped to the contracted laboratory (EAS Laboratory in San Luis Obispo, California) as one sample data group.

Appendix C

Boring Logs

(Electronic)

Appendix D

(Electronic)

D-1: Data Validation Report, July Sampling Activities

Appendix D

(Electronic)

D-2: Data Validation Report, October/November Sampling Activities

Appendix E

(Electronic)

Neutron Logs

Appendix F

(Electronic)

Meteorologic Data

Appendix G

SSFL Physical Parameters Tables

Appendix G
Soil Physical Parameter Results

Location	Start Depth (ft)	End Depth (ft)	Average Depth (ft)	Soil Type	Porosity (% Volume)	Reported Moisture Content (% Volume)	Calculated Air Content (% Volume)[a]	Saturation	Revised Water Filled Porosity (Water Content; (% Volume)	Revised Calculated Air Content (% Volume)c	Wet bulk density (g/cc)	Dry bulk density (g/cc)	Particle Density (g/cc)	Organic Carbon (% weight)	Reference Document
AABS02S03	10	10	10	silty sand	41.3	7.2	34.1	0.3	11.3	30.0	1.64	1.56	2.66	0.17	SRAM MWH, 2005
AABS03S02	5	5	5	silty sand	44.1	12.17	31.93	0.4	18.6	25.5	1.65	1.53	2.73	0.18	SRAM MWH, 2005
AABS06S01	5	5	5	silty sand	41.4	11.82	29.58	0.5	18.6	22.8	1.69	1.58	2.69	1.4	SRAM MWH, 2005
AABS06S02	12	12	12	silty sand	40.4	11.03	29.37	0.4	17.5	22.9	1.7	1.59	2.66	0.41	SRAM MWH, 2005
ABSP-198-1	1	1	1	sand		10.2						1.6		0.13	McLaren/Hart, 1994c
ABSP-198-3-DUP3	3	3	3											0.0025	McLaren/Hart, 1994c
ABSP-198-3	3	3	3	sand		10.7						1.47		0.85	McLaren/Hart, 1994c
BD9	3	3	3	sand		9.9						1.62		0.86	McLaren/Hart, 1994c
AFBS09S03	10	10	10	silty sand	44.9	11.08	33.82	0.4	16.3	28.6	1.58	1.47	2.66	0.37	SRAM MWH, 2005
APTF-1-30-1-1	1	1	1			16						1.76		0.0097	McLaren/Hart, 1994a
APTF-1-30-3-3	3	3	3			16						1.83		0.0099	McLaren/Hart, 1994a
BD6	3	3	3			23						1.63		0.0092	McLaren/Hart, 1994a
APTF-1-30-5-5	5	5	5			17						1.78		0.0091	McLaren/Hart, 1994a
3'	3	3	3											0.53	McLaren/Hart, 1994a
APTF-2-35-1-1	1	1	1			13						1.59		0.0028	McLaren/Hart, 1994b
1-BD7	1	1	1			11						1.3		0.0023	McLaren/Hart, 1994b
APTF-2-35-3-3	3	3	3			11						1.47		0.0027	McLaren/Hart, 1994b
APTF-2-35-D-1'	1	1	1											0.072	McLaren/Hart, 1994b
BCBS03S01	1	1	1	silty sand										1.73	SRAM MWH, 2005
BPBS14S01	1	1	1			6									SRAM MWH, 2005
BSBT01S01	0.33	0.33	0.33			1								0.15	MWH, 2003b
BSBT01S01	0.33	0.33	0.33			1								0.51	MWH, 2003b
BSBT01S01	0.33	0.33	0.33			1								0.078	MWH, 2003b
BSBT02S01	0.04	0.04	0.04			1					1.8762	1.6738		0.054	MWH, 2003b
BSBT02S01	0.04	0.04	0.04			1					1.5888	1.4392		0.036	MWH, 2003b
BSBT02S01	0.04	0.04	0.04			1					1.6122	1.5471		0.35	MWH, 2003b
BSBT04S01	0.33	0.33	0.33			5					1.7016	1.6218		0.53	MWH, 2003b
BSBT04S01	0.33	0.33	0.33			5								0.53	MWH, 2003b
BSBT04S01	0.33	0.33	0.33			5								0.53	MWH, 2003b
BVBS02S04	6	6	6	silty sand	36.6	19.62	16.98	0.9	32.9	3.7	1.87	1.68	2.64	0.68	SRAM MWH, 2005
CLBS06S04	10	10	10	silty sand	46.5	14.88	31.62	0.5	21.4	25.1	1.59	1.44	2.69	0.17	SRAM MWH, 2005
CLBS31S01	8	8	8	silty sand	42.7	6.22	36.48	0.2	9.6	33.1	1.61	1.55	2.7	0.15	SRAM MWH, 2005

Appendix G
Soil Physical Parameter Results

Location	Start Depth (ft)	End Depth (ft)	Average Depth (ft)	Soil Type	Porosity (% Volume)	Reported Moisture Content (% Volume)	Calculated Air Content (% Volume)[a]	Saturation	Revised Water Filled Porosity (Water Content; (% Volume)	Revised Calculated Air Content (% Volume)c	Wet bulk density (g/cc)	Dry bulk density (g/cc)	Particle Density (g/cc)	Organic Carbon (% weight)	Reference Document
CLBS38S02	10	10	10	silty sand	38.8	8.16	30.64	0.3	13.2	25.6	1.7	1.62	2.65	0.56	SRAM MWH, 2005
CLBS39S02	10	10	10	silty sand	37.3	9.1	28.2	0.4	15.4	21.9	1.78	1.69	2.69	0.22	SRAM MWH, 2005
CLBS39S03	17	17	17	silty sand	27.6	3.14	24.46	0.2	6.0	21.6	1.94	1.9	2.63	0.13	SRAM MWH, 2005
CLBS40S03	17	17	17	silty sand	39.8	9.13	30.67	0.4	14.6	25.2	1.69	1.6	2.66	0.23	SRAM MWH, 2005
Dup	1	1	1											0.1	McLaren/Hart, 1994d
ECL-78-1-1	1	1	1	16								1.31		0.009	McLaren/Hart, 1994d
BD8	1	1	1	12										0.02	McLaren/Hart, 1994d
ECL-78-3-3	3	3	3	18								1.81		0.004	McLaren/Hart, 1994d
ECL-78-5-5	5	5	5	18								1.79		0.004	McLaren/Hart, 1994d
HVBS37S02	5	5	5	silty sand	37.6	10.51	27.09	0.5	17.4	20.2	1.76	1.66	2.66	0.43	SRAM MWH, 2005
ILBS01S03	9.5	9.5	9.5	silty sand	45.9	13.51	32.39	0.4	19.3	26.6	1.56	1.43	2.64	0.16	SRAM MWH, 2005
ILBS01S05	20	20	20	silty sand	40.9	7.14	33.76	0.3	11.2	29.7	1.64	1.57	2.65	0.12	SRAM MWH, 2005
ILBS01S06	29.5	29.5	29.5	silty sand	37.7	13.2	24.5	0.6	21.6	16.1	1.77	1.64	2.63	0.16	SRAM MWH, 2005
ILBS01S07	40	40	40	silty sand	35.9	21.87	14.03	1.0	36.6	-0.7	1.89	1.67	2.61	0.16	SRAM MWH, 2005
ILBS02S07	25	25	25	silty sand	36.1	13.36	22.74	0.6	22.8	13.3	1.84	1.71	2.67	0.14	SRAM MWH, 2005
ILBS05S03	30	30	30	silty sand	43.9	11.14	32.76	0.4	16.7	27.2	1.58	1.46	2.61	0.11	SRAM MWH, 2005
ILBS08S01	10	10	10	silty sand	37.6	12.49	25.11	0.5	20.7	16.9	1.78	1.65	2.65	0.29	SRAM MWH, 2005
ILBS09S02	14.5	14.5	14.5	silty sand	39.5	9.29	30.21	0.4	14.8	24.7	1.69	1.6	2.64	0.2	SRAM MWH, 2005
ILBS12S04	20	20	20	silty sand	33.2	14.21	18.99	0.8	24.9	8.3	1.89	1.75	2.62	0.95	SRAM MWH, 2005
ILBS15S01	26	26	26	silty sand	40.5	12.54	27.96	0.5	19.8	20.7	1.71	1.58	2.66	0.23	SRAM MWH, 2005
ILBS30S02	9.5	9.5	9.5	silty sand	34.5	10.16	24.34	0.5	17.4	17.1	1.82	1.72	2.62	0.29	SRAM MWH, 2005
ILBS31S02	10	10	10	silty sand	39	7.27	31.73	0.3	11.6	27.4	1.66	1.59	2.61	0.35	SRAM MWH, 2005
ILBS32S02	19.5	19.5	19.5	silty sand	37.9	11.97	25.93	0.5	19.6	18.3	1.76	1.64	2.64	0.28	SRAM MWH, 2005
ILBS35S02	5	5	5	silty sand	29.1	11.91	17.19	0.8	22.2	6.9	1.98	1.86	2.63	0.3	SRAM MWH, 2005
ILBS35S03	9.5	9.5	9.5	silty sand	37.3	10.33	26.97	0.5	17.1	20.2	1.76	1.65	2.64	0.2	SRAM MWH, 2005
ILBS36S02	5.5	5.5	5.5	silty sand	34	8.96	25.04	0.5	15.7	18.3	1.85	1.76	2.66	0.35	SRAM MWH, 2005
ILBS37S01	15	15	15	silty sand	39.8	8.09	31.71	0.3	12.9	26.9	1.67	1.59	2.64	0.27	SRAM MWH, 2005
ILBS45S02	7	7	7	sandy silt											SRAM MWH, 2005
ILBS46S03	15	15	15	sandy silt											SRAM MWH, 2005
PZ002GT01	24.5	25	24.75	silty sand	30.9	10	20.9	0.6	18.4	12.5	1.94	1.84	2.66		MWH, 2003a
PZ002GT02	79.3	79.8	79.55	sand	23.6	8.8	14.8	0.8	17.9	5.6	2.12	2.03	2.66		MWH, 2003a
PZ003GT01	8.5	9	8.75	silty sand	41.7	7.1	34.6	0.3	10.9	30.8	1.61	1.54	2.64		MWH, 2003a
PZ005GT01	17.5	17.5	17.5	silty sand	35.6	19.8	15.8	1.0	34.6	1.0	1.94	1.75	2.71		MWH, 2003a
SB4.15-2-8					27.3	10.8	16.5	0.8	20.7	6.6	2.03	1.92	2.64	0.033	ICF, 1993

Appendix G
Soil Physical Parameter Results

Location	Start Depth (ft)	End Depth (ft)	Average Depth (ft)	Soil Type	Porosity (% Volume)	Reported Moisture Content (% Volume)	Calculated Air Content (% Volume)[a]	Saturation	Revised Water Filled Porosity (Water Content; (% Volume)	Revised Calculated Air Content (% Volume)c	Wet bulk density (g/cc)	Dry bulk density (g/cc)	Particle Density (g/cc)	Organic Carbon (% weight)	Reference Document
SB5.9-4-16					33.3	16.6	16.7	0.9	29.9	3.4	1.97	1.8	2.7	0.056	ICF, 1993
SB6.1-2-3.5					35.7	13.4	22.3	0.7	23.4	12.3	1.88	1.75	2.72	0.343	ICF, 1993
SB7.10-3-3.5					35.7	10.3	25.4	0.5	17.8	17.9	1.83	1.73	2.69	0.205	ICF, 1993
SBHV-3-15					34.1	13.5	20.6	0.7	23.7	10.4	1.89	1.75	2.66	0.046	ICF, 1993
SPA-1-6-1	1	1	1			11						1.6		0.024	McLaren/Hart, 1994e
SPA-1-6-3	3	3	3			9.3						1.68		0.022	McLaren/Hart, 1994e
SPA-1-6-5	5	5	5			25						1.51		0.0031	McLaren/Hart, 1994e
SPA-1-6-6	6	6	6											0.01	McLaren/Hart, 1994e
SPA-2-23-1	1	1	1			6.8						1.2		0.0019	McLaren/Hart, 1994f
SPA-2-23-5	5	5	5			0.8						1.92		0.0021	McLaren/Hart, 1994f
SPA-2-47-1	1	1	1									1.76		0.01	McLaren/Hart, 1994f
BD3	1	1	1									1.76			McLaren/Hart, 1994f
SPA-2-58-3	3	3	3									2.08			McLaren/Hart, 1994f
SPA-2-58-5	5	5	5									1.92			McLaren/Hart, 1994f
STL-IV-1-16-1	1	1	1			21						1.6		0.0025	McLaren/Hart, 1994g
BD4	1	1	1			22						1.6		0.0026	McLaren/Hart, 1994g
STL-IV-2-15-1	1	1	1			21			43.7		2.29	2.08		0.0079	McLaren/Hart, 1994h
STL-IV-2-15-3	3	3	3			20			41.6		2.28	2.08		0.0068	McLaren/Hart, 1994h
STL-IV-2-15-5	5	5	5			14			33.6		2.54	2.4		0.01	McLaren/Hart, 1994h
LXBS23S01	1.5				53			0.10	5.3	47.7					This Document
LXBS23S02	5.5				41			0.12	4.9	36.1					This Document
LXBS24S01	1.5				46			0.10	4.6	41.4					This Document
LXBS24S02	5.5				49			0.19	9.3	39.7					This Document
LXBS24S03	10.5				48			0.20	9.6	38.4					This Document
LXBS25S01	1.5				50			0.04	2.0	48.0					This Document
LXBS25S02	5.5				40			0.14	5.6	34.4					This Document
LXBS25S03	10.5				54			0.12	6.5	47.5					This Document
LXBS26S01	6.5				48			0.25	12.0	36.0					This Document
LXBS26S02	10.5				49			0.31	15.2	33.8					This Document
LXBS27S01	1.5				43			0.31	13.3	29.7					This Document
LXBS27S02	3				55			0.08	4.4	50.6					This Document
LXBS27S03	5.5				45			0.15	6.8	38.3					This Document
LXBS27S04	8				42			0.22	9.2	32.8					This Document
LXBS27S05	15.5				39			0.15	5.9	33.2					This Document

Appendix G
Soil Physical Parameter Results

Location	Start Depth (ft)	End Depth (ft)	Average Depth (ft)	Soil Type	Porosity (% Volume)	Reported Moisture Content (% Volume)	Calculated Air Content (% Volume)[a]	Saturation	Revised Water Filled Porosity (Water Content; (% Volume)	Revised Calculated Air Content (% Volume)c	Wet bulk density (g/cc)	Dry bulk density (g/cc)	Particle Density (g/cc)	Organic Carbon (% weight)	Reference Document
LXBS28S01	5.5				45			0.20	9.0	36.0					This Document
LXBS28S02	10.5				34			0.28	9.4	24.7					This Document
LXBS28S03	15.5				49			0.25	12.3	36.7					This Document
LXBS29S01	3.5				56			0.15	8.6	47.4					This Document
LXBS30S01	3.5				51			0.16	7.9	43.1					This Document
BTBS02S01	6				38			0.15	5.7	32.3					This Document
BTBS02S02	11				34			0.19	6.5	27.5					This Document
BTBS02S03	16				42			0.21	8.8	33.2					This Document
BTBS02S04	20				41			0.24	9.8	31.2					This Document
BZBS01S01	6				42			0.13	5.5	36.5					This Document
BZBS01S02	11				32			0.07	2.2	29.8					This Document
BZBS01S03	16				43			0.20	8.6	34.4					This Document
CLBS85S01	6				41			0.19	7.8	33.2					This Document
CLBS85S02	11				32			0.16	5.1	26.9					This Document
CLBS85S03	15.5				38			0.15	5.7	32.3					This Document
FSBS01S01	5				45			0.27	12.2	32.9					This Document
FSBS01S02	8				40			0.22	8.8	31.2					This Document

Minimum Value	23.6	0.8	14.03	0.0	2.0	-0.708828761	1.56	1.20	2.61	0.0019	
Maximum Value	56	25	36.48	1.0	43.7	50.6	2.54	2.4	2.73	1.73	
Average Value	40.3	11.0	26.1	0.365	14.9	26.5	1.8	1.7	2.7	0.2	
Standard Deviation	6.6	5.7	6.3	0.2	9.1	11.9	0.2	0.2	0.0	0.3	
Total Number of Samples with Results	71	69	39	71	74	71	46	70	39	75	

a - Air content (% Volume) = Porosity (% Volume) - Moisture Content (% Volume)

Notes:
1. Where soil type is not identified, no information is available.

Units:
ft = feet
g/cc = grams per cubic centimeter

Appendix H

Analysis of Vapor Transport from Groundwater in Bedrock

April 29, 2004

DBM

Rich:

The following analysis pertains to Scenario 3. In this scenario, contaminated groundwater underlies a bedrock vadose zone. There may also be a soil vadose zone overlying the bedrock vadose zone. Section I contains the analysis for the case where the bedrock vadose zone extends all the way to the ground surface. Section II presents the modification necessary to account for a soil cover. Section III discusses the way the effective diffusion coefficient can be handled. Finally, Section IV outlines the calculations and results.

Section I Contaminant Flux to Ground Surface from Contaminated Groundwater

The system is conceptualized as a vadose zone in homogeneous bedrock (fractured) extending from a water table to ground surface. The volumetric water content in the vadose zone is assumed to be uniform and equal to the value required to transmit downward the steady recharge rate, R. Dissolved VOC in the groundwater partitions into the soil/bedrock gas at the base of the vadose zone, and diffuses upward in response to the concentration gradient thus established. It is assumed that the VOC concentrations in the aqueous and gaseous phases are everywhere related by equilibrium partitioning. Because recharge is assumed to be steady state, advective mass flux of VOC occurs only in the aqueous

phase and that flux is downward. In contrast the diffusive mass flux of VOC is directed upward, so advection and diffusion occur in opposite directions under this scenario. In accordance with previous work on the vadose zone, the fractures are assumed to be air filled, while the matrix contains both air and water.

I (a) Diffusion in Gaseous Phase

There is no advection in the gaseous phase, so mass transport of VOC is entirely diffusive according to

$$F_g = -D_{eg} \frac{dC_g}{dz} \qquad 1$$

where

F_g = mass flux of VOC in the gaseous phase $(M/L^2 \cdot T)$

D_{eg} = effective diffusion coefficient in the gaseous phase (L^2/T)

C_g = mass concentration of VOC in the gas phase (M/L^3)

z = vertical coordinate measured positive upward (L)

Because we invoke equilibrium partitioning

$$C_g = K_{HD} C$$

and eqn. 1 becomes

$$F_g = -K_{HD} D_{eg} \frac{dC}{dz} \qquad (2)$$

where F_g = mass flux of VOC in the gaseous phase ($M/L^2 \cdot T$)

D_{eg} = effective diffusion coefficient in gaseous phase (L^2/T)

C = mass concentration of VOC in the <u>aqueous</u> phase (M/L^3)

K_{HD} = dimensionless Henry's constant

z = vertical coordinate measured positive upward (L)

I (b) Diffusion and Advection in Aqueous Phase

The combined diffusive and advective flux in the aqueous phase is given by the familiar expression

$$F_a = -D_{ea} \frac{dC}{dz} + qC \qquad (3)$$

where F_a = mass flux of VOC in the aqueous phase ($M/L^2 \cdot T$)

D_{ea} = effective diffusion coefficient in the aqueous phase (L^2/T)

q = Darcy flux of aqueous phase (L/T)

C = mass concentration of VOC in the aqueous phase (M/L^3).

Under the assumptions detailed above, the Darcy flux is negative because flow is from large z toward small z. Thus, we write

$$q = -R$$

where R is the average steady recharge rate (L/T). Eqn. 3 becomes

$$F_a = -D_{ea}\frac{dC}{dz} - RC \qquad (4)$$

wherein the recharge rate is a positive number.

I (c) Steady Mass Flux of VOC

The total mass flux due to aqueous diffusion and adjection and gaseous diffusion is obtained by adding eqns. 2 and 4.

$$F = -(D_{ea} + K_{HD} D_{eg})\frac{dC}{dz} - CR \qquad (5)$$

where F = total mass flux of VOC (M/L²·T) and other parameters are as previously defined. For convenience in writing, let

$$D \equiv D_{ea} + K_{HD} D_{eg}$$

so eqn. 5 becomes

$$F = -D\frac{dC}{dz} - CR. \qquad (6)$$

The way in which D can be calculated, including the effect of fractures, is discussed in detail in a subsequent section.

Steady downward flow in a homogeneous medium results in a constant and uniform water content, except for a small interval near the water table. Under conditions of uniform water content, the bulk diffusion coefficient, D, is also constant and uniform over the vadose zone. The mass concentration of VOC is taken to be zero at ground surface and C_o at the water table. The thickness of the vadose zone (i.e. the depth to water table) is given the symbol T.

Under the above conditions, eqn. 6 is integrated and manipulated to yield

$$F = \frac{C_o R}{\exp\left(\frac{RT}{D}\right) - 1} \qquad (7)$$

where

F = steady mass flux of VOC to ground surface ($M/L^2 \cdot T$)

R = steady recharge rate (L/T)

C_o = mass concentration of VOC in ground water (M/L^3).

D = bulk diffusion coefficient (L^2/T)

T = thickness of vadose zone (L)

The bulk diffusion coefficient, D, is highly dependent upon the recharge rate, R. This relationship is discussed in detail in a later section. For now

it is emphasized that R and D are not independent and should not be treated as such in any sensitivity analysis that may be performed.

I (d) Concentration Profile (Distribution)

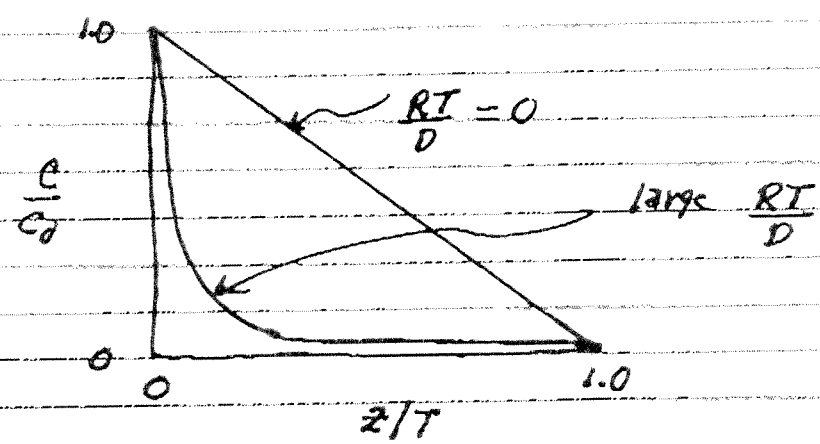
Integration of eqn. 6 subject to $C = C_0$ at $z = 0$ and C at z gives

$$\frac{C}{C_0} = \left(\frac{F}{C_0 R} + 1\right) \exp\left(-\frac{zR}{D}\right) - \frac{F}{C_0 R} \qquad (8)$$

Putting eqn. 7 in eqn. 8 gives

$$\frac{C}{C_0} = \frac{\exp\left[-\frac{RT}{D}(z/T)\right] - \exp\left(-\frac{RT}{D}\right)}{1 - \exp\left(-\frac{RT}{D}\right)} \qquad (9)$$

A useful graph of eqn. 9 would be C/C_0 vs z/T with the dimensionless group RT/D as a curve parameter. This graph would look something like this:



It is clear from both eqns. 7 and 9 that the critical parameter is the dimensionless grouping RT/D. When this ratio is large, the mass flux is very small and so is the VOC concentration in the near-surface part of the vadose zone. Large RT/D occurs when the thickness of the vadose zone is large and/or when recharge is large. The quantity R/D increases extremely rapidly as R increases because D becomes small very fast as R increases.

Section II Effect of Soil Cover on Contaminant Flux to Surface from Ground Water.

Conceptually, placing a soil cover over the bedrock vadose zone changes only the way eqn. 6 must be integrated. The bulk diffusion coefficient, D, now has one value in the bedrock vadose zone and another in the soil vadose zone.

Integration of eqn. 6 is

$$\int_0^{T_{BR}} \frac{dz}{D_{BR}} + \int_{T_{BR}}^{T} \frac{dz}{D_s} = \frac{1}{R} \ln\left(1 + \frac{C_0 R}{F}\right) \qquad (10)$$

or

$$\frac{T_{BR}}{D_{BR}} + \frac{T - T_{BR}}{D_s} = \frac{1}{R} \ln\left(1 + \frac{C_0 R}{F}\right) \qquad (11)$$

where T_{BR} = thickness of bedrock vadose zone (L)

T = total thickness of vadose zone (L)

D_{BR} = bulk diffusion coefficient in bedrock (L^2/T)

D_s = bulk diffusion coefficient in soil (L^2/T)

Now eqns. 7 and 9 apply unchanged with an average bulk diffusion coefficient defined as

$$D \equiv \frac{D_{BR} D_s T}{D_s T_{BR} + D_{BR}(T - T_{BR})} \qquad (12)$$

Owing to the fact that the water content in the soil is expected to be much less than in the bedrock, it is expected that the mean bulk diffusion coefficient is approximated by $D_{BR} T / T_{BR}$. In other words, the overall diffusion process is controlled by the smaller of the two diffusion coefficients.

section III Calculation of Bulk Diffusion Coefficient

The calculations indicated in this section are pretty much standard fare in soil physics and vadose zone contaminant hydrology.

III (a) Aqueous Diffusion Coefficient

The bulk or effective diffusion coefficient in the aqueous phase is given by

$$D_{ea} = \theta \tau_w D_w \qquad (13)$$

where

D_{ea} = aqueous phase diffusion coefficient

θ = volumetric water content of the matrix

τ_w = tortuosity in the aqueous phase

D_w = molecular diffusion coefficient in water (L^2/T)

The Millington-Quirk formula allows this to be written as

$$D_{ea} = \phi_m S_w^{10/3} \tau_o D_w \qquad (14)$$

where ϕ_m = matrix porosity

S_w = water saturation

τ_o = medium tortuosity

D_w = molecular Diffusion coefficient (L^2/T)

If not known from other measurements, the medium tortuosity, τ_o, can be estimated from

$$\tau_o \sim \phi_m^{1/3}. \qquad (15)$$

Note that fractures make no contribution because they are assumed to be air-filled.

III (b) Gaseous Diffusion Coefficient

Similar to eqn. 13, we write for the gas phase

$$D_{eg} = \phi_f D_g + (\phi_m - \theta)\tau_g D_g \qquad (16)$$

where ϕ_f = fracture porosity

ϕ_m = matrix porosity

θ = volumetric water content

τ_g = tortuosity in gas phase

D_g = molecular diffusion coefficient in air (L^2/T)

This can be written as

$$D_{eg} = \left\{\phi_f + \phi_m S_g^{10/3} \tau_o\right\} D_g \qquad (17)$$

where S_g = gas (air) saturation.

The fractures are regarded as smooth channels and, consequently, the fracture tortuosity is unity.

III (c) The Bulk Diffusion Coefficient

With eqns. 14 and 17, the bulk diffusion coefficient is

$$D = \phi_m S_w^{10/3} \tau_o D_w + K_{HD}\left\{\phi_f + \phi_m S_g^{10/3} \tau_o\right\} D_g \qquad (18)$$

where

D = bulk diffusion coefficient (L^2/T)
D_w = molecular diffusion coefficient in water (L^2/T)
D_g = molecular diffusion coefficient in air (L^2/T)
S_w = water saturation
S_g = gas saturation
τ_ϕ = medium tortuosity
ϕ_m = matrix porosity
ϕ_f = fracture porosity
K_{HD} = dimensionless Henry's constant

III (d) Relationship Between Water Content and Recharge

The theory of flow in porous media predicts that steady downward flow of water will result in a uniform water content in a homogeneous medium. Under uniform water content there is no pressure gradient and flow is driven entirely by gravity. Darcy's law shows that

$$q = -K_e \tag{19}$$

under this circumstance. Here q is the volumetric flux of water and K_e is the hydraulic (effective) conductivity of the medium at the prevailing water content. The effective hydraulic conductivity can be written as the product of hydraulic conductivity and relative permeability. Also, $q = -R$ in our case.

$$R = K k_r . \tag{20}$$

There are many formulae in the literature that relate R_r to water saturation. The simplest is

$$R_r = S_w^3 . \tag{21}$$

Combining eqn. 20 and 21 gives

$$\frac{R}{K} = S_w^3 \tag{22}$$

Section IV Calculation Procedure

Step 1 - Estimate water saturation.

This may be accomplished using eqn. 22 and knowledge of R and K. Alternatively, S_w can be estimated from geophysical data or even measured. It is recommended that eqn. 22 be used in any sensitivity analysis.
Note:

$$S_w + S_g = 1 \tag{23}$$

Step 2 - Bulk diffusion coefficient

Use eqn. 18 to compute the bulk diffusion coefficient. The medium tortuosity can be estimated from eqn. 15 if no other data for τ_0 are available.

Step 3 - Mass flux to ground surface

Use eqn. 7 to make this estimate. The concentration C_o is the aqueous concentration in the underlying groundwater. In the limit as $R \to 0$, equation 7 becomes

$$F = \frac{D C_o}{T} \qquad (24)$$

which is just the linear form of Fick's law. The assumption of a uniform water saturation doesn't hold with $R = 0$, however.

Step 4 - Calculate Concentration Distribution.

This is accomplished with eqn. 9. This result gives an indication of the level of contamination throughout the vadose zone under this scenario.