

Final Project Report for the Development of an Active Soil Gas Sampling Method

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's natural resources. Under the mandate of national environmental laws, the EPA strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and scientific support that can be used to solve environmental problems, build the scientific knowledge base needed to manage ecological resources wisely, understand how pollutants affect public health, and prevent or reduce environmental risks.

The National Exposure Research Laboratory (NERL) is the Agency's center for investigation of technical and management approaches for identifying and quantifying risks to human health and the environment. Goals of the laboratory's research program are to (1) develop and evaluate methods and technologies for characterizing and monitoring air, soil, and water; (2) support regulatory and policy decisions; and (3) provide the scientific support needed to ensure effective implementation of environmental regulations and strategies.

Tetra Tech EM Inc. prepared this Project Report for NERL to document the results of an investigation into the effects of purge rate, purge volume, and sample volume on soil gas sample results. Field work for this investigation was conducted during October 2006 at Vandenberg Air Force Base (AFB) Installation Restoration Program (IRP) Site 15. Vandenberg AFB is home to the U.S. Air Force Western Missile Test Range and is headquarters for the 30th Space Wing, which manages Department of Defense space and missile testing, and placing satellites into polar orbit from the West Coast. The Vandenberg AFB IRP, overseen by Mr. Michael McElligott, supported this project by providing access to IRP Site 15 to conduct the testing, facilitating and expediting dig permit reviews, and providing logistical support during the field sampling activities.

Executive Summary

Tetra Tech EM, Inc. was contracted by the U.S. Environmental Protection Agency (EPA) to quantitatively assess the effect of sampling procedures on soil gas sample results. Specifically, this investigation was designed to assess the effect of purge rate, purge volume, and sample volume (the principal parameters) on soil gas results and to develop technically defensible values or ranges of values for these parameters that can be incorporated into active soil gas sampling guidance.

A number of research groups and local, state, and federal agencies have developed guidance concerning sampling and analytical protocols for active soil gas measurements with the overall objective of facilitating a technically correct approach for site investigations. However, the various guidance documents often omit prescribed ranges for the principal parameters, or if prescribed, lack a quantitative basis for the recommended parameter settings. This investigation was designed to evaluate the principal parameters over the range of values commonly cited in guidance documents and provide defensible recommendations for parameter settings.

The experiments were conducted at Installation Restoration Program (IRP) Site 15 on Vandenberg Air Force Base (AFB). To provide data for this investigation, an array of 15 soil vapor sampling probes was deployed at IRP Site 15 above the larger of two plumes of trichloroethylene (TCE) in the groundwater.

Three experiments were conducted for this investigation. The first consisted of collecting soil gas samples using purge rates ranging from 100 to 2,000 milliliters per minute (ml/min) while holding the purge volume and sample volume constant at 3 system volumes and 60 ml, respectively. The second consisted of collecting soil gas samples after purging 1 to 100 system volumes from the probes, while holding the purge rate and sample volume constant at 200 ml/min and 60 ml. The third experiment consisted of collecting samples with volumes ranging from 25 to 6,000 ml, while holding the purge rate constant at 200 ml/min.

The results of the purge rate experiment show a pronounced increase in the measured TCE concentration at purge rates of 100 ml/min to 200 ml/min followed by a modest trend of increasing measured concentrations with increasing purge rate. However, the observed variability in measured volatile organic compound (VOC) concentrations would not generally be considered significant from a site characterization or vapor intrusion perspective. Based on the data from this investigation, it appears that purge rates of 200 to 500 ml/min should be recommended.

The results from the purge volume experiment indicate there was a statistically significant positive correlation between the measured TCE concentrations and purge volume, with concentrations typically more than doubling over the range of purge volumes tested. The effect of purge volume on the measured VOC concentrations was more pronounced than the effect of purge rate; however, this variability may not be significant in terms of site characterization. The data indicate that varying purge volume from 1 to 5 system volumes has relatively little effect on the sample results; however, increasing purge volume above 5 system volumes appears to result in somewhat higher measured TCE concentrations. These experimental data suggest that purge volumes of 2 to 5 system volumes are most appropriate.

Measured TCE concentrations were observed to increase with increasing sample volume from 25 to 1,000 ml, but then drop off in the 6,000 ml samples. This observation is significant as the 6,000 ml sample size is commonly used to achieve very low detection levels with EPA method TO-15; however, the drop in measured TCE concentrations at a 6,000 ml sample volume suggests that the low detection levels achievable with large sample size may need to be balanced against the risk of over-purging. Based on the

data obtained from this investigation, it appears that a sample volume of 1,000 ml should be recommended, as this volume resulted in the highest measured TCE concentrations.

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List of Acronyms and Abbreviations

ABRES	Advanced Ballistics Re-Entry System
ABS	Acrylonitrile butadiene styrene
AFB	Air Force Base
ANCOVA	Analysis of covariance
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
bgs	Below ground surface
Cal/EPA	California Environmental Protection Agency
DCE	Dichloroethene
DTSC	Department of Toxic Substances Control
Earth Tech	Earth Tech, Inc.
ECD	Electron capture detector
EPA	U.S. Environmental Protection Agency
GC	Gas chromatograph
HPMG	H&P Mobile Geochemistry
InterPhase	InterPhase Environmental, Inc.
IPA	Isopropyl alcohol
IRP	Installation Restoration Program
ITRC	Interstate Technology and Regulatory Council
LARWQCB	California Regional Water Quality Control Board, Los Angeles Region
LOX	Liquid oxygen
$\mu\text{g}/\text{m}^3$	Micrograms per cubic meter
$\mu\text{g}/\text{L}$	Micrograms per liter
ml	Milliliter
ml/min	Milliliters per minute
MO-DNR	Missouri Department of Natural Resources
MS	Mass spectrometry
msl	Mean sea level
NERL	National Exposure Research Laboratory
NJ-DEP	New Jersey Department of Environmental Protection
NRML	National Risk Management Research Laboratory
NY-DOH	New York State Department of Health
ORD	Office of Research and Development
PID	Photoionization detector
QA	Quality Assurance
QAPP	Quality assurance project plan
QC	Quality Control
RI	Remedial investigation
RP-1	Rocket Propellant No. 1
RPD	Relative percent difference
RPM	Remedial project manager
SAIC	Science Applications International Corporation
Shaw	Shaw Environmental, Inc.
Tetra Tech EMI	Tetra Tech, EM Incorporated
TCE	Trichloroethene
VOC	Volatile organic compound

1.0 Introduction

Soil gas data are widely used in site investigation and remediation projects to delineate volatile organic compound (VOC) vapor plumes, as a screening tool to refine soil and groundwater sampling efforts, to track the progress of soil remediation, and to identify potential risks from the inhalation of indoor air potentially contaminated by soil gas. The overall goal of any monitoring or sampling program is to enable the collection of representative samples; that is, samples that are representative of the environmental, chemical, and physical conditions present during the time of sample collection. Over a period of time, collection of a sequence of representative samples can enable a better understanding of trends in the data set regarding the fate and transport of the chemicals being monitored. However, due to numerous environmental as well as sampling and analytical variables, the representativeness of a sample can often be compromised, the degree to which is often not well understood or quantified.

Tetra Tech EM, Inc. (Tetra Tech) was contracted by the U.S. Environmental Protection Agency (EPA) to quantitatively assess the effect of sampling procedures on soil gas sample results. Specifically, this investigation was designed to assess the effect of purge rate, purge volume, and sample volume on soil gas results and to develop technically defensible values, or ranges of values for these parameters that can be incorporated into active soil gas sampling guidance. These three parameters (purge rate, purge volume, and sample volume) are referred to throughout this report as the “principal parameters.”

A number of research groups and local, state, and federal agencies have developed guidance concerning sampling and analytical protocols for active soil gas measurements with the overall objective of facilitating a technically correct approach for site investigations. The first step in developing the experimental approach for this investigation was to review the existing soil gas sampling guidance available from the regulatory community and other agencies. Guidance was reviewed from a variety of sources including the American Petroleum Institute (API); American Society for Testing and Materials (ASTM); California Environmental Protection Agency (Cal/EPA), Department of Toxic Substances Control (DTSC) and California Regional Water Quality Control Board, Los Angeles Region (LARWQCB); Interstate Technology and Regulatory Council (ITRC); Missouri Department of Natural Resources (MO-DNR); New Jersey Department of Environmental Protection (NJ-DEP); New York State Department of Health (NY-DOH); and the U.S. EPA. The Literature Review report is provided in Appendix A, and the findings of the literature are summarized briefly below.

The general consensus of guidance documents reviewed for this investigation is that purge rates should be minimized to limit potential short-circuiting of the sampling system (introduction of atmospheric air) and to reduce the potential for desorption. Specific recommendations range from 100 to 200 milliliters per minute (ml/min) (e.g., DTSC/LARWQCB 2003, MO-DNR 2005, NJ-DEP 2005, NY-DOH 2005, ITRC 2007) to 1,000 ml/min (e.g., API 2005, EPA 2006).

The guidance documents generally recommend that purge volume be minimized to increase the likelihood that the collected sample is representative of conditions immediately surrounding the sampling probe and to reduce the potential of short-circuiting the sampling system. However, few of the documents provide specific recommendations for purge volumes. DTSC/LARWQCB (2003) guidance stipulates that a step purge test be conducted by collecting samples after one, three, and seven dead-volumes have been purged. MO-DNR (2005) and NJ-DEP (2005) recommend three volumes be purged prior to sampling. Health Canada (2004), recommends two to three volumes and NY-DOH (2005) recommends one to three dead volumes.

The guidance documents reviewed for this investigation provide few recommendations regarding sample volume beyond concerns related to detection levels. There appears to be some consensus that within the constraints imposed by analytical requirements, sample volume should be minimized for the same reasons

that purge volume should be minimized. Common sample volumes cited range from 10 to 50 milliliters (ml) collected in glass bulbs or gas-tight syringes and from 1 to 6 liters in Summa canisters for TO-14/TO-15 analyses.

2.0 Background, Scope, and Methods

2.1 Experimental Design

The concentrations of VOCs measured in soil gas samples are a function of a number of variables, including soil properties, proximity of and magnitude of the VOC source area(s), type of sampling point, sample collection procedures, and analytical method. The objective of this project was to assess the nature and magnitude of the effect on soil gas sample results of varying three principal parameters (purge rate, purge volume, and sample volume) during sample collection. In order to achieve the project objective, it was necessary to eliminate and/or reduce, to the extent possible, all other variables. Therefore, the overall approach of the project consisted of the following primary elements:

- Identify a site with a known VOC contaminant plume at moderate to shallow depths and with “homogeneous” soil conditions;
- Install an array of similarly constructed soil gas probes from which multiple samples could be collected;
- Collect a series of soil gas samples from the probe array while varying one of the principal parameter settings, and holding all other variables constant;
- Collect a series of soil gas samples without varying any principal parameters from a single soil gas control probe; and
- Analyze all of the samples under identical analytical conditions.

These conditions allow the effects of varying the principal parameters to be largely isolated from other variables and provide a data set with which to assess the effects of the principal parameters on sample results.

2.2 IRP Site 15 Setting and Background

The site selected for this research project was Vandenberg AFB, IRP Site 15. Vandenberg is located on the Central Coast of California, approximately 120 miles west-northwest of Los Angeles and 225 miles southeast of San Francisco. IRP Site 15 is located approximately 1.5 miles from the Pacific Ocean and 1,300 feet north of San Antonio Creek on north Vandenberg AFB (Figure 2-1). The site is on the southwest side of Umbra Road and comprises three former Atlas missile launch pads and two launch-support buildings (Figure 2-2). The support buildings are the launch control center and a water pumping station. The site was known as the Advanced Ballistic Re-Entry System (ABRES)-B Launch Complex. Tetra Tech has been investigating Site 15 under the Vandenberg AFB IRP since 1993. Currently, Tetra Tech is conducting quarterly groundwater monitoring of 19 on-site monitoring wells.

2.2.1 IRP Site 15 History

The ABRES-B complex was constructed in 1959 to launch Atlas missiles. The complex comprises three nearly identical launch pads, each of which consists of a concrete gantry foundation, flame bucket, deluge water channel, and miscellaneous appurtenances. The launch pads are identified as Pad 1, Pad 2, and Pad 3, and the corresponding deluge water channels are identified as Channel A, Channel B, and Channel C, respectively (Figure 2-2). The area selected for this project is adjacent to Pad 1/Channel A. A total of 63 Atlas missiles were launched from the complex between 1960 and 1967, 14 of these were launched from

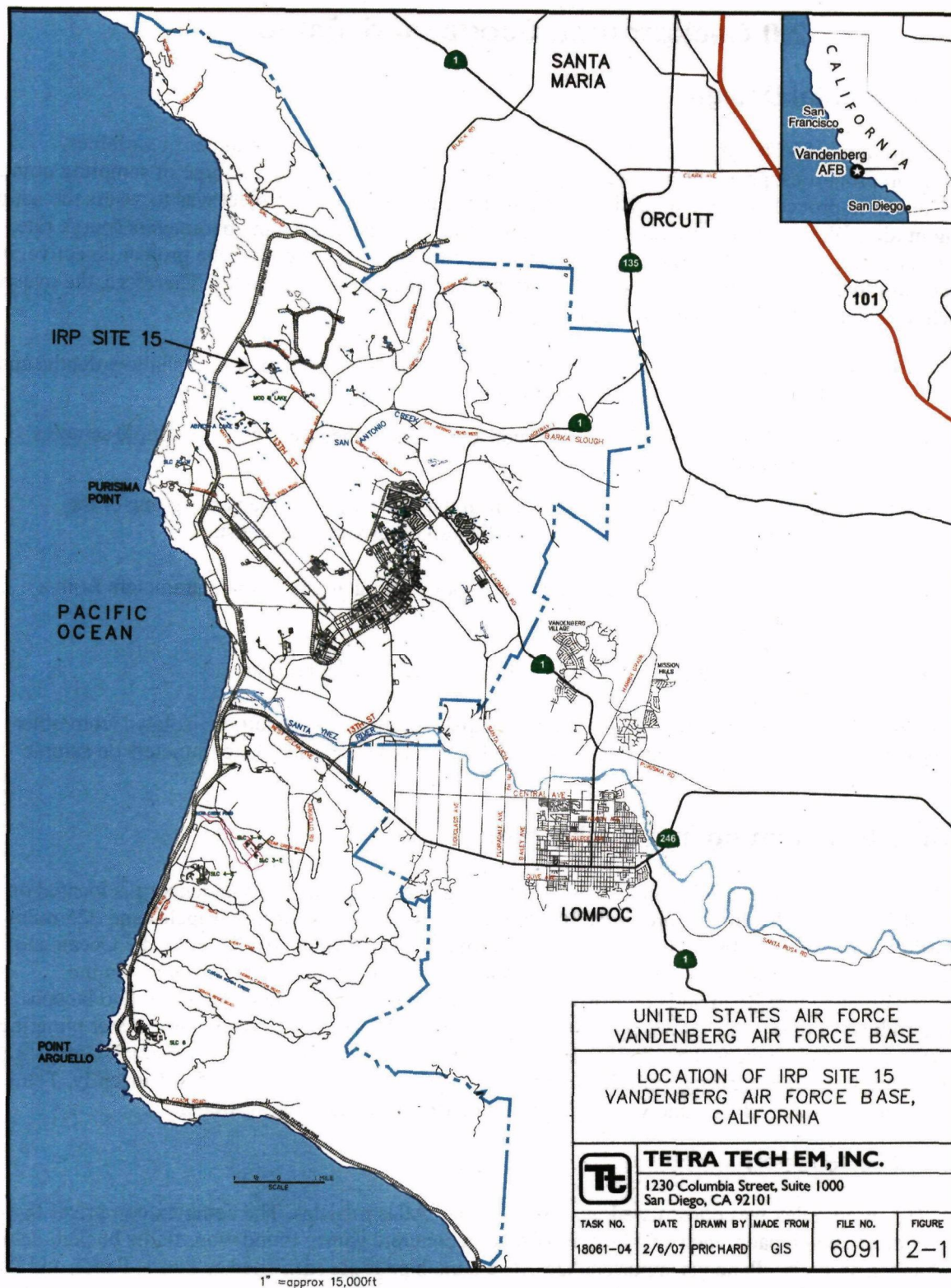
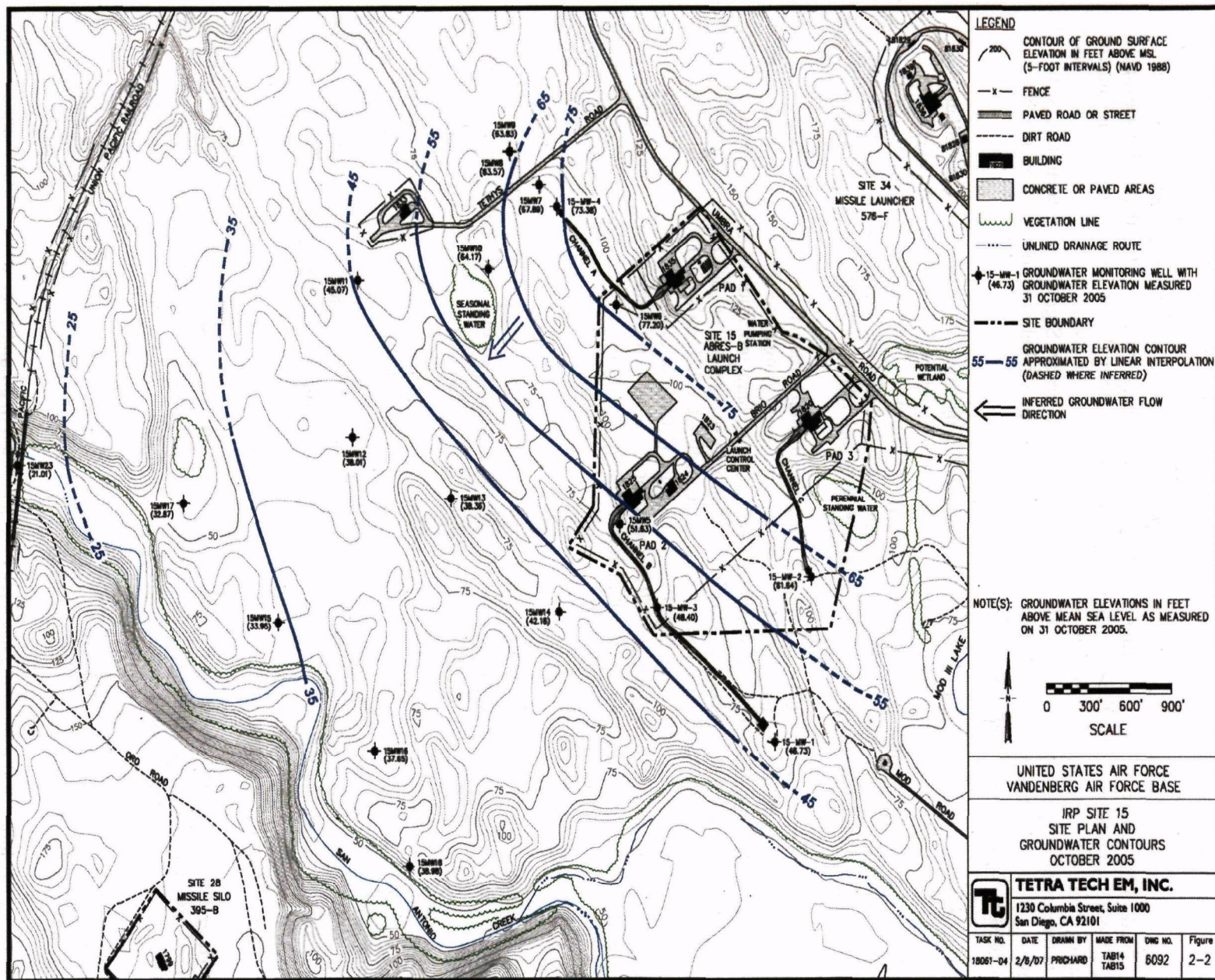


Figure 2-1. Location of IRP Site 15, Vandenberg Air Force Base, California

Figure 2-2. IRP Site 15, Site Plan and Groundwater Contours, October 2005



Pad 1. The Atlas missile used a combination of Rocket Propellant No. 1 (RP-1), a kerosene-based fuel, and liquid oxygen (LOX) as an oxidizer. Prior to fuel loading, the missiles were flushed with 150 to 180 gallons of trichloroethylene (TCE) for degreasing purposes. Much of the TCE used for engine flushing is believed to have been vaporized during the subsequent launches; however, TCE that did not evaporate may have been washed to grade with deluge water used for sound and heat suppression during launches. During launches, deluge water that did not flash to steam flowed down the deluge water channels to concrete lined retention basins, from which it was released to grade. Significant concentrations of TCE have been detected in groundwater at IRP Site 15, and the source is believed to be the pre-launch engine degreasing followed by transport with deluge water to grade.

Initial subsurface investigations of Site 15 were conducted in the late 1970's by Leroy Crandall and Associates and continued at various portions of the site with Battelle Corporation (1986), Science Applications International Corporation (SAIC) (1990), the Bureau of Reclamation (1994a, b), Jacobs Engineering Group (1993, 1998) and Shaw Environmental, Inc. (Shaw). The investigation findings are presented in the *Final Remedial Investigation Report, IRP Site 15* (Shaw 2004).

In 2005, Earth Tech, Inc. (Earth Tech) completed a supplemental remedial investigation (RI) of groundwater beneath the Channel A and Channel B source areas using a membrane interface probe and confirmation sampling. The supplemental RI included further characterization of the leading edges of the chlorinated solvent plumes with the installation of four pairs of shallow and deep monitoring wells to supplement the existing well array. The information regarding Earth Tech's supplemental RI was presented during quarterly IRP Remedial Project Manager (RPM) meetings at Vandenberg AFB, which Tetra Tech attends as a Vandenberg AFB IRP contractor. To date, Earth Tech's supplemental RI report has not been made public and no formal citation is available.

2.2.2 Geology and Hydrogeology

Sediments at IRP Site 15 consist of highly uniform dune sand overlying Sisquoc Formation clayey diatomite and siliceous shale (Dibblee 1989). The sands have low moisture content and very low organic carbon.

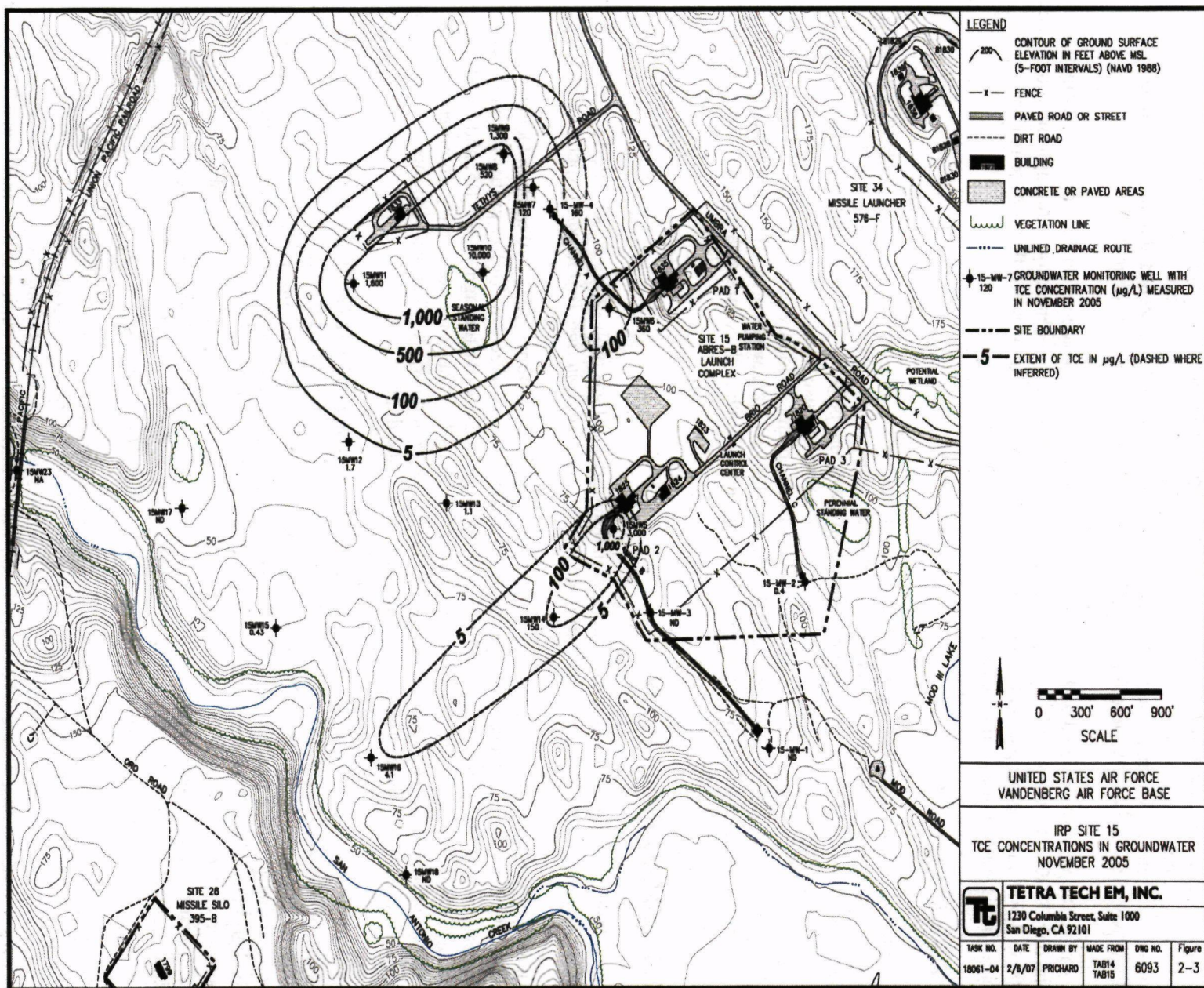
Site 15 is located on the western portion of the San Antonio Creek Groundwater Basin. Groundwater at the site exists within the unconsolidated dune sands. Groundwater levels measured in October 2005 indicate the groundwater elevation ranged from approximately 21 to 77 feet above mean sea level (msl) or 6 to 38 feet below ground surface (bgs). During October 2005, the interpreted direction of groundwater flow was to the southwest toward San Antonio Creek with an average hydraulic gradient of 0.01 feet per foot (Figure 2-2). The interpreted direction of groundwater flow beneath the site appears to correlate with the slope of bedrock topography.

Surface water at Site 15 consists of seasonal and perennial areas of standing water and storm water runoff. In the past, deluge water releases were also part of the surface water at this site. A seasonal area of standing water is located approximately 1,400 feet west of Pad 1. A perennial area of standing water is located approximately 200 feet southeast of Pad 3. Storm water runoff rapidly infiltrates site soils or collects in channels that direct flow toward the San Antonio Creek floodplain.

2.2.3 Chlorinated Solvent Plume Conditions

Two distinct chlorinated solvent plumes have been identified in groundwater at Site 15. A relatively small plume is associated with Pad 2/Channel B and is located to the south of the study area (Figure 2-3). A larger plume is associated with Pad 1/Channel A (Figure 2-3), where this study was conducted. The larger

Figure 2-3. IRP Site 15, TCE Concentrations in Groundwater, November 2005



plume is located to the northwest of Pad 1 and consists primarily of TCE and *cis*-1,2-dichloroethene (DCE), with minor concentrations of *trans*-1,2-DCE. The source of this plume is likely the discharge point of Channel A. The maximum TCE and *cis*-1,2-DCE concentrations detected in this groundwater plume were 10,000 and 29 micrograms per liter ($\mu\text{g/L}$), respectively, in October 2005.

A soil vapor plume associated with the larger groundwater plume was identified during this investigation. The only VOC detected in soil vapor during this study was TCE, at concentrations ranging from roughly 100 to 3,500 micrograms per cubic meter ($\mu\text{g/m}^3$); however, it should be noted that no attempt was made through this study to assess the extent of the TCE vapor plume.

2.2.4 Selection of Site 15

The purpose of this investigation was to assess the impact of the principal parameters (purge rate, purge volume, and sample volume) on soil gas sample results. In order to effectively accomplish this task, it was important to isolate the principal parameters to the extent possible, and hold all other potential variables stable. Site 15 was selected as a suitable location because it provides a study area with a previously characterized chlorinated solvent groundwater plume in highly permeable, relatively homogenous subsurface sediments and underlying a relatively flat surface area. Thus, the sampling was not expected to be impacted by significant variations in the depth to the contaminant plume, or variations in subsurface stratigraphy.

2.3 Soil Gas Probe Array

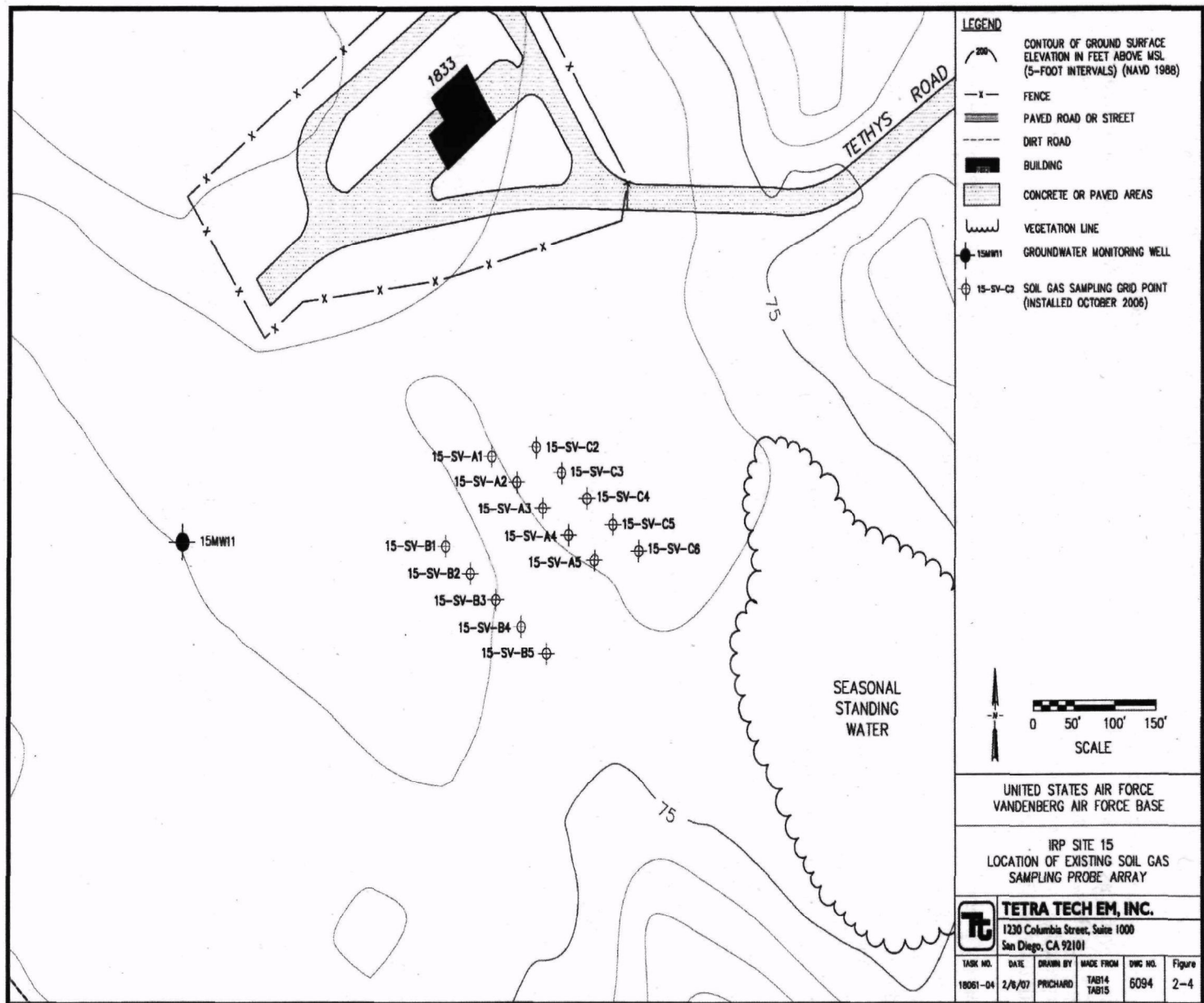
The following paragraphs summarize the installation of the soil gas probe array at IRP Site 15. Details of the drilling and probe installation activities are presented in the *Sampling Trip Report* (Appendix B).

An array of soil gas sampling probes was installed at IRP Site 15 from October 10 through October 12, 2006. The probes were installed in a geometric grid consisting of three rows of five probes (Figure 2-4). The probes were designated 15-SV-A1 through 15-SV-A5, 15-SV-B1 through 15-SV-B5, and 15-SV-C2 through 15-SV-C6. Each probe was set approximately 2 to 4 feet above the water table. In order to minimize variations in the depth of the probes relative to ground surface, the rows of probes were oriented northwest-southeast, parallel with the orientation of the sand dunes.

The sampling probes were installed in pilot holes drilled using a 6610DT GeoProbe direct push rig equipped with 2.5-inch outside-diameter drill rods and operated by InterPhase Environmental, Inc. (InterPhase). The 6610DT is mounted on tracks and was chosen for this project due its maneuverability on sand dunes, where traditional two- or four-wheel-drive trucks are not practical. After identifying the final grid location, five probes for row A were installed on October 11 and 12 with a spacing of 40 feet between each probe along a bearing of N50°W. Rows B and C were completed on October 12 along the same bearing and with the same spacing as row A. Row B is located 100 feet south-southwest of row A. Row C is located 40 feet north-northeast of row A and is offset by 40 feet to the southeast. Figure 2-4 presents the location and orientation of the soil gas probe array.

Most pilot holes were advanced to the planned depth of between 14 and 19 feet bgs so that the sampling probes could be positioned at the target distance of 2 to 4 feet above the groundwater table. One probe location within each row (15-SV-A1, 15-SV-B3, and 15-SV-C5) was continuously cored using acetate sleeves in order to observe the lithology and confirm its uniformity in relation to the other probe locations. Pilot holes for probes 15-S-A1, 15-SV-B3, and 15-SV-C5 were drilled to depths of 24, 24, and 22 feet bgs, respectively, and then backfilled with #2/12 sand to the planned probe depth of between 14 and 19 feet bgs. Soils encountered in these three borings were predominantly fine grained, poorly graded,

Figure 2-4. IRP Site 15, Location of Existing Soil Gas Sampling Probe Array



subangular, slightly moist dune sands. In boring 15-SV-C5, clayey sand was encountered at 17.5 feet bgs and Sisquoc Formation shale bedrock was encountered at 20 feet bgs. It is very common in this part of Vandenberg AFB to encounter clayey soils immediately above the shale bedrock, and these clay horizons are interpreted as a weathering surface on the bedrock. In boring 15-SV-B3, clayey sand was encountered at 23.5 feet bgs. This boring was terminated before bedrock was encountered, but the clayey sand is interpreted as weathered bedrock. Groundwater was encountered at 21 feet bgs in boring 15-SV-B3. Groundwater was not encountered in either of the other two borings.

Sampling probes were constructed as follows. Approximately 4 inches of #2/12 sand was poured into the bottom of the pilot holes. A 1-inch long gas-permeable membrane sampling probe, attached to 1/4-inch Nylaflow tubing, was then lowered through the drill rod to the top of the #2/12 sand. Additional #2/12 sand was then poured around the sampling probe until it extended approximately 2 inches above the membrane to form a sandpack around the sample point. Approximately 12 inches of dry bentonite was then placed on top of the sandpack, followed by hydrated bentonite to the surface. During the probe construction, the drill rod was removed slowly from the pilot hole to avoid sloughing of the sandy soils.

The sampling probes were completed at the surface with approximately 18 inches of Nylaflow tubing extending out of the ground and a Swagelok valve was inserted into the end of the tubing. The surface completions were protected with 3-inch diameter acrylonitrile butadiene styrene (ABS) plastic pipes driven a few feet into the ground and then fitted with slip-cap covers. Pilot holes that were drilled deeper than the intended probe installation depth were backfilled with #2/12 sand to the target probe depth. In these borings, the height of the sandpack was recorded from the bottom of the boring to a depth approximately 2 inches above the soil gas probe. Details of the probe installations are summarized in Table 2-1 and a schematic diagram of the probe construction is provided in Figure 2-5.

2.4 Sample Collection

Based on the results of the literature review (Appendix A), baseline sampling procedures were established for the investigation. The baseline sampling procedures are considered typical, or industry standard procedures. The baseline principal parameter settings were as follows:

- Purge Rate: 200 ml/min
- Purge Volume: 3 system volumes
- Sample Volume: 60 ml (equivalent to disposable syringe volume; see Section 2.7.3)

A system volume was considered the volume of the 1/4-inch Nylaflow tubing plus the volume of the probe. The tubing volume was estimated as 4 ml per foot of tubing. Calculated system volumes for each probe are shown in Table 2-1.

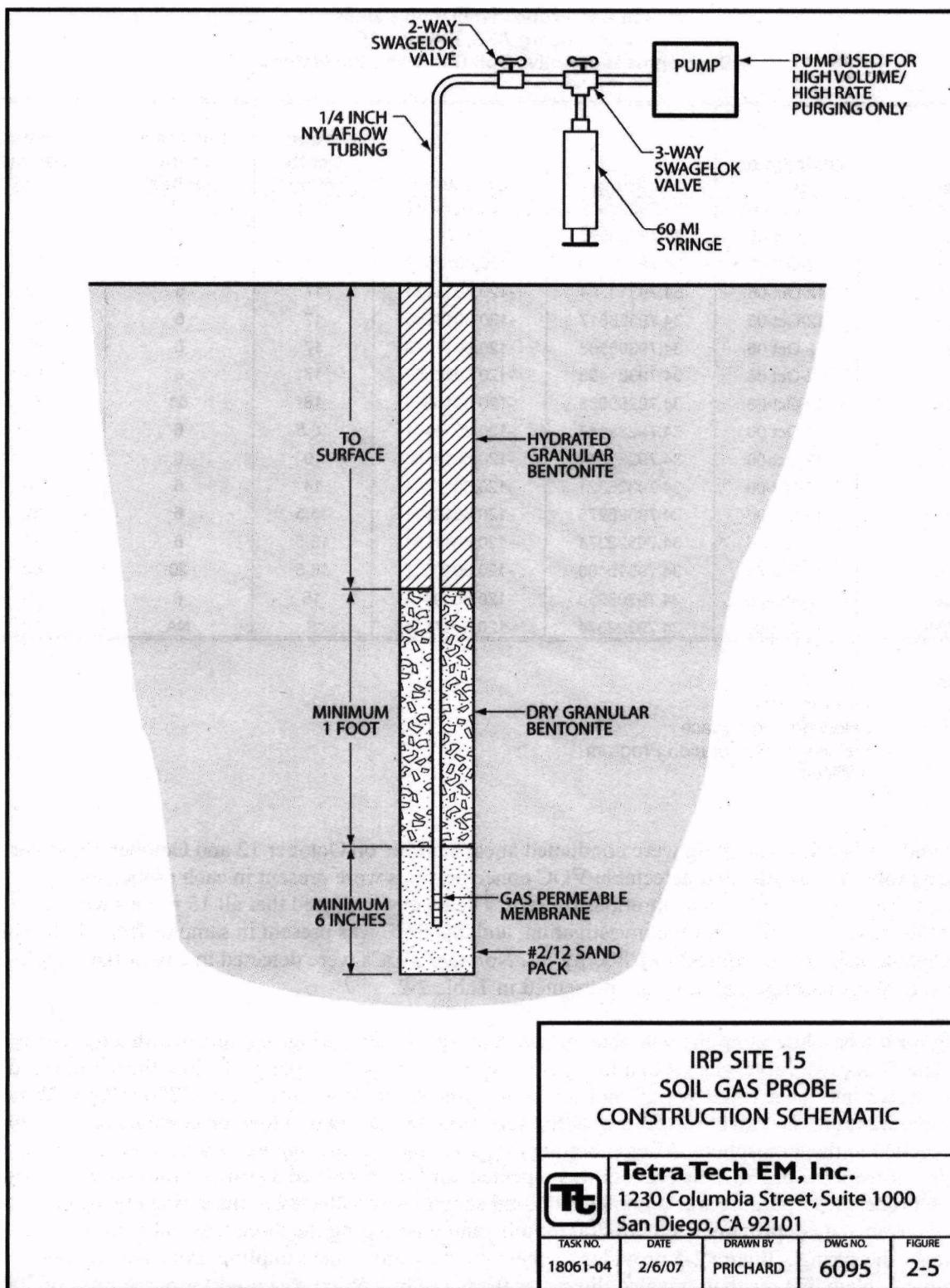


Figure 2-5. IRP Site 15, Soil Gas Probe Construction Schematic

Table 2-1
Soil Gas Probe Installation Details
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Location	Installation Date	Latitude	Longitude	Probe Depth (feet bgs)	Sandpack Length (inches)	System Volume (ml)
15-SV-A1	11-Oct-06	34.79330957	-120.6015641	17.5	84	70
15-SV-A2	11-Oct-06	34.79325593	-120.6014622	16.5	12	66
15-SV-A3	12-Oct-06	34.79318619	-120.6013549	17	6	68
15-SV-A4	12-Oct-06	34.79313254	-120.6012423	17	6	68
15-SV-A5	12-Oct-06	34.79306817	-120.6011296	17	6	68
15-SV-B1	12-Oct-06	34.79308963	-120.6017573	17	6	68
15-SV-B2	12-Oct-06	34.79301453	-120.6016553	17	6	68
15-SV-B3	12-Oct-06	34.79296088	-120.6015534	18	58	72
15-SV-B4	12-Oct-06	34.79289115	-120.6014461	18.5	6	74
15-SV-B5	12-Oct-06	34.79283214	-120.6013388	19	6	76
15-SV-C2	12-Oct-06	34.79336321	-120.6013764	14	6	56
15-SV-C3	12-Oct-06	34.79328275	-120.6012691	15.5	6	62
15-SV-C4	12-Oct-06	34.79322374	-120.6011564	15.5	6	62
15-SV-C5	12-Oct-06	34.79315400	-120.6010652	15.5	20	62
15-SV-C6	12-Oct-06	34.79308963	-120.6009472	15	6	60
15-SV-C4HP	17-Oct-06	34.79322374	-120.6011564	5	NA	10

Notes:

- AFB - Air Force Base
- bgs - below ground surface
- IRP - Installation Restoration Program
- ml - milliliters

Two rounds of baseline sampling were conducted at each probe, on October 12 and October 16, to verify that each probe was usable, that detectable VOC concentrations were present in each probe, and to determine the range of VOC concentrations present. The results indicated that all 15 probes were installed successfully and were usable for the investigation, and that TCE was present in samples from each probe at concentrations ranging from 93 to 2,800 $\mu\text{g}/\text{m}^3$. No other VOCs were detected in any of the samples. The results of the baseline sampling are presented in Table 2-2.

Purging for the baseline sampling was accomplished using a 60-ml syringe equipped with a three-way valve. The three-way valve was set to allow gas to be drawn from the vapor probe into the syringe and gas was drawn into the syringe by pulling back on the plunger at a controlled rate of 200 ml/min. When the syringe was full, the valve was set to seal the soil vapor probe and to allow the contents of the syringe to be expelled to the atmosphere. After expelling the gas in the syringe, the valve was reset and gas was again drawn from the probe. This process was repeated until the specified 3 system volumes were purged from the probe. After purging was complete, a 60-ml sample was collected in the syringe by again drawing gas in at an approximate rate of 200 ml/min, and then setting the three-way valve to seal the contents of the syringe. Figure 2-5 provides a schematic diagram of the sampling probe and syringe arrangement. Note that the diagram also illustrates the purge pump that was used for purge rates of 500

Table 2-2
Baseline Sampling Round Results
Vandenberg AFB, Site 15
Development of Active Soil Gas Sampling Method

Location	Sample ID	12-Oct-2006		16-Oct-2006	
		Sample Time	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Sample Time	TCE Concentration ($\mu\text{g}/\text{m}^3$)
15-SV-A1	V15SVA1-BL	9:20	260	10:47	210
15-SV-A2	V15SVA2-BL	9:21	2,000	10:50	1,200
15-SV-A3	V15SVA3-BL	9:22	2,050	10:59	2,100
15-SV-A4	V15SVA4-BL	10:00	1,000	11:09	890
15-SV-A5	V15SVA5-BL	10:00	490	11:17	510
15-SV-B1	V15SVB1-BL	12:52	120	10:03	93
15-SV-B2	V15SVB2-BL	12:51	150	10:10	500
15-SV-B3	V15SVB3-BL	11:46	720	10:20	1,350
15-SV-B4	V15SVB4-BL	11:45	430	10:28	590
15-SV-B5	V15SVB5-BL	12:50	120	10:39	100
15-SV-C2	V15SVC2-BL	16:41	1,800	11:24	2,000
15-SV-C3	V15SVC3-BL	16:40	2,650	11:31	1,400
15-SV-C4	V15SVC4-BL	15:45	2,800	11:38	1,700
15-SV-C5	V15SVC5-BL	15:45	420	11:46	350
15-SV-C6	V15SVC6-BL	16:10	660	11:54	670

Principal Parameter Settings:

Purge Rate - 200 ml/min
Purge Volume - 3 system volumes
Sample Size - 60 ml

Notes:

AFB - Air Force Base
IRP - Installation restoration Program
 $\mu\text{g}/\text{m}^3$ - micrograms per cubic meter
ml - milliliters
TCE - trichloroethene

ml/min or higher; however, for purge rates of less than 500 ml/min, the pump was not used and the probe was purged with the syringe as described above.

Following baseline sampling, the principal parameter evaluation sampling program was completed. In order to evaluate the effect of each of the principal parameters (purge rate, purge volume, and sample volume) separately, experiments were conducted to evaluate the effect of each principal parameter while holding all other principal parameters constant at the baseline settings. Specific details of the parameter sampling are provided in Section 3.0.

2.5 Mobile Laboratory

Soil gas samples collected for this investigation were analyzed on-site using a mobile laboratory operated by H&P Mobile Geochemistry (HPMG). Details of the analytical method, equipment, and detection levels are provided below.

2.5.1 Analytical Method

Soil gas samples were analyzed by direct injection using EPA method 8021. Method 8021 is a gas chromatography method using a photoionization detector (PID) and an electron capture detector (ECD). This method is faster, more sensitive, and has a larger linear dynamic operating range than gas chromatography/mass spectrometry (GC/MS) methods. The contaminants of concern at IRP Site 15 (i.e., TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and vinyl chloride) had been previously identified based on IRP investigation data (Section 2.3.3); therefore, the compound identification advantages of GC/MS were not warranted.

The target compound list for this project was restricted to TCE, *cis*-1,2-DCE, and *trans*-1,2-DCE. Vinyl chloride is known to be present in the groundwater at Site 15; however, it cannot be identified using method 8021.

Soil gas samples collected during this investigation were sub-sampled using a 10-ml syringe and injected directly into the gas chromatograph injection port. The injection syringes were flushed with the sample two times prior to injection to ensure the injected aliquot was representative of the field sample and were flushed several times with clean air between injections or discarded.

The analyses were performed using PID and ECD detectors and a DB-624 megabore capillary column following EPA method 8000 protocols, modified for soil gas. Modifications from the EPA method consisted of the project-specific analyte list, absence of matrix spike samples and surrogates, and changes in calibration protocols as discussed in Section 2.7.2.

2.5.2 Equipment

The following equipment was utilized by the mobile laboratory for this project.

- **Instrument:** Shimadzu GC-14 or SRI 8610 Gas Chromatograph
- **Column:** 30 to 75 meter DB-624, megabore capillary
- **Carrier flow:** Helium at 15 ml/min
- **Detectors:** PID and ECD
- **Column oven:** 45°C for 2 min, 45°C to 175°C at 5°C/min.

2.5.3 Detection Limits

The detection limit for the target compounds was 5 µg/m³.

2.6 Quality Assurance/Quality Control

2.6.1 Field Quality Control Protocols

It was determined in the field that a temporal control probe could provide useful data to monitor the variability in sample results unrelated to changes in the principal parameter settings. Location 15-SV-A3 was designated as a temporal control probe because this probe is centrally located within the probe array. Samples were collected from this probe three to four times a day during the investigation to monitor potential temporal variations in soil gas concentrations unrelated to the principal parameters of purge rate, purge volume, and sample volume. Each sample from 15-SV-A3 was collected using the base settings of the principal parameters under investigation (i.e., purge rate of 200 ml/min, purge volume of three system volumes, and sample size of 60 ml). The temporal control samples contained TCE at measured concentrations ranging from 1,600 to 2,500 $\mu\text{g}/\text{m}^3$ (Table 2-3).

Table 2-3
Temporal Control Sample Results
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Date	Time	Sample Type	TCE Concentration ($\mu\text{g}/\text{m}^3$)
16-Oct-2006	10:59	N	2,100
16-Oct-2006	12:04	N	2,500
16-Oct-2006	15:02	N	1,600
16-Oct-2006	16:48	N	2,350
17-Oct-2006	9:02	N	2,450
17-Oct-2006	11:55	N	2,250
17-Oct-2006	14:20	N	2,300
17-Oct-2006	14:21	FR	2,400
18-Oct-2006	9:00	N	2,150
18-Oct-2006	9:01	FR	2,400
18-Oct-2006	11:35	N	2,450
18-Oct-2006	11:40	FR	2,700
18-Oct-2006	13:44	N	2,400
18-Oct-2006	13:45	FR	1,900

Notes:

- AFB - Air Force Base
- FR - field replicate sample
- IRP - Installation Restoration Program
- $\mu\text{g}/\text{m}^3$ - micrograms per cubic meter
- N - normal sample
- TCE - trichloroethene

Field replicate samples were collected from the control probe (15-SV-A3) and from probe 15-SV-C5 during the sample volume test. Replicate samples were collected to measure the reproducibility and precision of the total sampling system. Five field replicates were collected during the field program. There were a total of 75 samples specified in the QAPP; therefore, replicates were collected at a rate of approximately 7 percent, slightly lower than the 10 percent specified in the QAPP.

Leak tests were performed at two probe locations to monitor the integrity of the probe system and surface seals. Leak tests consisted of placing a rag soaked in isopropyl alcohol (IPA) around the Nylaflow tubing at the surface. Leak checks were performed at location 15-SV-C4 throughout the purge volume testing and at location 15-SV-A4 while the probe was purged at 5,000 ml/min for 1 hour (approximately 4,000 purge volumes). No IPA was detected in any of the samples associated with the leak checks.

2.6.2 Laboratory Quality Control Protocols

The laboratory data package, including Chain-of-Custody forms, sampling logs, quality assurance/quality control (QA/QC) data, and sample results, is provided in Appendix C.

2.6.2.1 Laboratory Data Logs

The field chemist maintained analytical records, including date and time of analysis, sampler's name, chemist's name, sample identification number, concentrations of compounds detected, calibration data, and any unusual conditions.

2.6.2.2 Instrument Calibration

An initial 3-point calibration curve was performed at the start of the project. EPA method 8000 requires the use of five levels for an initial calibration curve; however, existing soil gas guidance from Cal/EPA DTSC only requires three calibration levels. A linearity check of the calibration curve for each compound was performed by computing a correlation coefficient and an average response factor.

Continuing calibration verification samples were analyzed a minimum of twice a day, including once at the beginning of each day as specified in the Quality Assurance Project Plan (QAPP) (Tetra Tech 2006). These standards were prepared from a traceable source at the middle concentration of the calibration curve. Acceptable continuing calibration agreement was set at ± 20 percent to the average response factor from the calibration curve. EPA method 8000 specifies a calibration verification requirement of ± 15 percent; however, the verification requirement was increased to ± 20 percent to provide flexibility for implementation of this project in the field.

2.6.2.3 Blanks

Laboratory blanks were analyzed at the start of each field day and at least once for every 20 field samples. A total of seven blank samples were run during the sampling conducted on October 16 through 18, 2006.

2.6.2.4 Laboratory Duplicates

Eight laboratory duplicates were analyzed over the course of the sampling program, which was conducted on October 16 through 18, 2006. Laboratory duplicates were performed by injecting a second aliquot from a field sample into the GC instrument.

2.6.3 Project QAPP Deviations and Additions

During the course of implementing the program, several deviations occurred from the guidelines discussed in the QAPP for the Development of Active Soil Gas Sampling Method (Tetra Tech 2006). Specific deviations are listed below, followed by the QAPP-specified parameter. In no case was a QAPP deviation considered to have impacted the outcome of the study, or the recommendations advanced as a result of the study.

- The probe length used at each installation was a 1-inch length gas-permeable membrane sampling probe, as opposed to a 6-inch length probe specified in the QAPP.
- The QAPP specified a sample volume of 100 milliliters to be evaluated. However, during procurement of field supplies, the most suitable disposable syringes used for soil gas sample collection were not available in this volume. Rather a 60 ml capacity syringe was procured for this purpose.
- The five probes to be repeatedly sampled for the study were selected at random for the purge volume and sample volume experiments to satisfy statistical treatment. This varies from the QAPP, which assigned individual rows of probes to be used in evaluating a single parameter (i.e., Row A for parameter 1, Row B for parameter 2, etc.). The purge rate test was conducted at Row B, consistent with the QAPP.
- The detection limit for the target compounds was $5 \mu\text{g}/\text{m}^3$, as opposed to a QAPP specification of $1 \mu\text{g}/\text{L}$ [equivalent to $1,000 \mu\text{g}/\text{m}^3$].
- A leak test procedure using a rag soaked with IPA wrapped around the Nylaflow tubing at ground surface was completed at two probe locations with no indications of leakage (i.e., detectable IPA in the collected soil gas sample) during this program. This deviates from a test at each location as specified in the QAPP. The absence of detectable IPA in any of the samples, particularly from one sample obtained from 15-SV-A4 under extreme purging conditions (i.e., 5,000 ml/min for one hour), indicated the sample probes were well sealed and no intrusion of ambient air was occurring. Based on these findings, use of leak test chemicals was discontinued for the remainder of the program.
- The QAPP specified collection of field replicates at a rate of 1 replicate for every 10 field samples. The QAPP specified 75 field samples; therefore, seven to eight replicates should have been collected. However, during the field effort it became clear that collecting field replicates would disrupt the sample sequencing, and potentially skew the experimental results, as each sample collected impacts the cumulative volume of gas removed from the probe. Therefore, the total number of field replicates collected was limited to five.
- For the purge rate experiment, the QAPP specified purging at rates of 100, 200, 500, 1,000 and 2,000 ml/min. Samples were collected at each probe after purging at these five rates. In addition, a purge rate of 5,000 ml/min was added to the sampling program at two of the probes (Section 3.3).
- For the purge volume experiment, the QAPP specified purging 1, 2, 3, 6, and 10 system volumes. Samples were collected at each probe after purging these five volumes. In addition, as the experiment progressed, purge volumes of 4, 5, 8, 20, 100, and 4,400 system volumes were added to the sampling program at a subset of the probes (Section 3.3).

3.0 Experimental Procedures

3.1 Summary of Experimental Approach

In order to evaluate the effect of each of the principal parameters (purge rate, purge volume, and sample volume) separately, experiments were conducted to evaluate the effect of each principal parameter while holding all other principal parameters constant at the baseline settings. Thus, purge rate was evaluated while holding purge volume and sample volume constant, purge volume was evaluated while holding purge rate and sample volume constant, and sample volume was evaluated while holding purge rate constant. As collection of samples necessarily involves drawing gas from the probes into sample containers, the cumulative purge volume for each probe increased over the course of the experiment, thus; total purge volume was not truly constant throughout the sample volume experiment. However, each of the three experiments was conducted on separate days, which allowed the sample probes to re-equilibrate over night and minimized the effect of total purge volume.

The objective of the research was to evaluate the independent effect that each of the parameters has on the sample results. It was not an objective of this project to evaluate interactive effects of the principal parameters.

A subset of 5 of the 15 soil vapor probes was selected for each of the experiments. Each of the five selected probes was sampled a minimum of five times, with the parameter under investigation at a different setting for each sample. Therefore, a minimum of 25 samples were collected for each experiment. Additional samples were collected for some of the experiments when time permitted and/or preliminary results warranted. Details of the parameter settings for each sample collected are summarized in Tables 3-1 through 3-3.

3.2 Principal Parameter Ranges

As described previously, the ranges of principal parameter settings tested during the experiment were selected to span the range of values commonly used by the industry as discovered during the literature review (Appendix A).

Purge Rate

The purge rate experiment was conducted with the following purge rate settings:

- 100 ml/min
- 200 ml/min
- 500 ml/min
- 1,000 ml/min
- 2,000 ml/min
- 5,000 ml/min

Purging at rates of 100 and 200 ml/min was accomplished using a 60-ml syringe, as discussed in Section 2.5. Purging at rates of 500 ml/min and higher was conducted using a battery operated pump placed downstream of the three-way valve as shown in Figure 2-5. Purge volume and sample volume were held at the baseline principal parameters for this test. Parameter settings for each sample collected for the purge rate experiment are summarized in Table 3-1.

Table 3-1
Purge Rate Experiment Sample Summary
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Location	Sample ID	Sample Time	Purge Volume (ml)	Purge Volume (system volumes)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Comments
15-SV-A2	V15SVA2-PV1	10:58	70	1	200	60	760	
	V15SVA2-PV2	11:00	140	2	200	60	1,000	
	V15SVA2-PV3	11:10	210	3	200	60	730	
	V15SVA2-PV4	11:12	280	4	200	60	1,100	
	V15SVA2-PV5	11:28	350	5	200	60	700	
	V15SVA2-PV6	11:29	420	6	200	60	1,000	
	V15SVA2-PV10	11:46	700	10	200	60	1,600	
	V15SVA2-PV20	11:55	1,400	20	200	60	2,200	
15-SV-A4	V15SVA4-PV1	12:03	68	1	200	60	570	
	V15SVA4-PV2	12:04	136	2	200	60	710	
	V15SVA4-PV3	12:11	204	3	200	60	480	
	V15SVA4-PV4	12:12	272	4	200	60	640	
	V15SVA4-PV5	12:22	340	5	200	60	520	
	V15SVA4-PV6	12:23	408	6	200	60	710	
	V15SVA4-PV8	12:38	544	8	200	60	880	
	V15SVA4-PV10	12:40	680	10	200	60	960	
	V15SVA4-PV20	12:54	1,360	20	200	60	1,200	
	V15SVA4-PV	14:12	300,000	4,400	5,000	60	1,100	Operated pump at 5,000 ml/min for 60 min
15-SV-B1	V15SVB1-PV1	9:34	68	1	200	60	55	
	V15SVB1-PV2	9:36	136	2	200	60	66	
	V15SVB1-PV3	9:46	204	3	200	60	57	
	V15SVB1-PV6	9:49	408	6	200	60	120	
	V15SVB1-PV10	9:57	680	10	200	60	140	
15-SV-B4	V15SVB4-PV1	10:09	74	1	200	60	470	
	V15SVB4-PV2	10:10	148	2	200	60	570	
	V15SVB4-PV3	10:20	222	3	200	60	370	
	V15SVB4-PV4	10:22	296	4	200	60	510	
	V15SVB4-PV5	10:32	370	5	200	60	550	
	V15SVB4-PV6	10:58	444	6	200	60	570	
	V15SVB4-PV10	11:00	740	10	200	60	980	

Table 3-1
Purge Rate Experiment Sample Summary
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method (Continued)

Location	Sample ID	Sample Time	Purge Volume (ml)	Purge Volume (system volumes)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Comments
15-SV-C4	V15SVC4-PV1	13:01	62	1	200	60	1,200	
	V15SVC4-PV2	13:02	124	2	200	60	1,500	
	V15SVC4-PV3	13:14	186	3	200	60	760	
	V15SVC4-PV4	13:15	248	4	200	60	1,000	
	V15SVC4-PV5	13:37	310	5	200	60	1,000 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV6	13:38	372	6	200	60	1,300 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV8	13:52	496	8	200	60	1,450 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV10	13:53	620	10	200	60	1,800 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV20	14:04	1,240	20	200	60	2,600 J	Laboratory duplicate out of RPD criterion
15-SV-C4HP	V15SVC4HP-PV1	14:46	10	1	200	60	180 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV2	14:47	20	2	200	60	470 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV3	15:00	30	3	200	60	400 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV6	15:01	60	6	200	60	570 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV10	15:15	100	10	200	60	660 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV20	15:16	200	20	200	60	590	
	V15SVC4HP-PV100	15:38	1,000	100	200	60	850	

Notes:

- $\mu\text{g}/\text{m}^3$ - micrograms per cubic meter
- ml/min - milliliters per minute
- ml - milliliters
- TCE - trichloroethene

Purge Volume

The purge volume experiment was conducted with the following settings:

- 1 system volume
- 2 system volumes
- 3 system volumes
- 4 system volume
- 5 system volume
- 6 system volumes
- 8 system volume
- 10 system volumes
- 20 system volume
- 100 system volume
- 4,400 system volume

All of the purge volume tests were conducted with a purge rate of 200 ml/min with the exception of the single 4,400-system-volume (300 liter) purge, which was conducted at a purge rate of 5,000 ml/minute. Parameter settings for each sample collected for the purge volume experiment are summarized in Table 3-2.

Sample Volume

Samples were collected over a range of sample volumes, as follows:

- 25 ml
- 60 ml
- 500 ml
- 1,000 ml
- 6,000 ml

The 25- and 60-ml samples were collected in 60-ml syringes. The 500- and 1,000-ml samples were collected in Tedlar bags. The 6,000 ml samples were collected in Summa canisters. A purge rate of 200 ml/min was used for all of the samples except the 6,000 ml Summa canisters which were filled at rates of 100 to 300 ml/min. Also, three system volumes were purged from each sample probe prior to collection of the first (25-ml) sample. As additional samples were collected, the cumulative purge volumes increased such that approximately 25 to 31 system volumes had been purged prior to collection of the 6,000 ml samples. Parameter settings for each sample collected for the sample volume experiment are summarized in Table 3-3.

Table 3-2
Purge Volume Experiment Sample Summary
17 October 2006
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Location	Sample ID	Sample Time	Purge Volume (ml)	Purge Volume (system volumes)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Comments
15-SV-A2	V15SVA2-PV1	10:58	70	1	200	60	760	
	V15SVA2-PV2	11:00	140	2	200	60	1,000	
	V15SVA2-PV3	11:10	210	3	200	60	730	
	V15SVA2-PV4	11:12	280	4	200	60	1,100	
	V15SVA2-PV5	11:28	350	5	200	60	700	
	V15SVA2-PV6	11:29	420	6	200	60	1,000	
	V15SVA2-PV10	11:46	700	10	200	60	1,600	
	V15SVA2-PV20	11:55	1,400	20	200	60	2,200	
15-SV-A4	V15SVA4-PV1	12:03	68	1	200	60	570	
	V15SVA4-PV2	12:04	136	2	200	60	710	
	V15SVA4-PV3	12:11	204	3	200	60	480	
	V15SVA4-PV4	12:12	272	4	200	60	640	
	V15SVA4-PV5	12:22	340	5	200	60	520	
	V15SVA4-PV6	12:23	408	6	200	60	710	
	V15SVA4-PV8	12:38	544	8	200	60	880	
	V15SVA4-PV10	12:40	680	10	200	60	960	
	V15SVA4-PV20	12:54	1,360	20	200	60	1,200	
	V15SVA4-PV	14:12	300,000	4,400	5,000	60	1,100	Operated pump at 5,000 ml/min for 60 min
15-SV-B1	V15SVB1-PV1	9:34	68	1	200	60	55	
	V15SVB1-PV2	9:36	136	2	200	60	66	
	V15SVB1-PV3	9:46	204	3	200	60	57	
	V15SVB1-PV6	9:49	408	6	200	60	120	
	V15SVB1-PV10	9:57	680	10	200	60	140	

Table 3-2
Purge Volume Experiment Sample Summary
17 October 2006
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method (Continued)

Location	Sample ID	Sample Time	Purge Volume (ml)	Purge Volume (system volumes)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Comments
15-SV-B4	V15SVB4-PV3	10:20	222	3	200	60	370	
	V15SVB4-PV4	10:22	296	4	200	60	510	
	V15SVB4-PV5	10:32	370	5	200	60	550	
	V15SVB4-PV6	10:58	444	6	200	60	570	
	V15SVB4-PV10	11:00	740	10	200	60	980	
15-SV-C4	V15SVC4-PV1	13:01	62	1	200	60	1,200	
	V15SVC4-PV2	13:02	124	2	200	60	1,500	
	V15SVC4-PV3	13:14	186	3	200	60	760	
	V15SVC4-PV4	13:15	248	4	200	60	1,000	
	V15SVC4-PV5	13:37	310	5	200	60	1,000 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV6	13:38	372	6	200	60	1,300 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV8	13:52	496	8	200	60	1,450 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV10	13:53	620	10	200	60	1,800 J	Laboratory duplicate out of RPD criterion
	V15SVC4-PV20	14:04	1,240	20	200	60	2,600 J	Laboratory duplicate out of RPD criterion
15-SV-C4HP	V15SVC4HP-PV1	14:46	10	1	200	60	180 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV2	14:47	20	2	200	60	470 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV3	15:00	30	3	200	60	400 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV6	15:01	60	6	200	60	570 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV10	15:15	100	10	200	60	660 J	Laboratory duplicate out of RPD criterion
	V15SVC4HP-PV20	15:16	200	20	200	60	590	
	V15SVC4HP-PV100	15:38	1,000	100	200	60	850	

Notes:

$\mu\text{g}/\text{m}^3$ - micrograms per cubic meter
 ml - milliliters
 ml/min - milliliters per minute
 TCE - trichloroethene

Table 3-3
Sample Volume Experiment Sample Summary
18 October 2006
Vandenberg AFB, Site 15
Development of Active Soil Gas Sampling Method

Location	Sample ID	Sample Time	System Volume (ml)	Purge Volume ¹ (ml)	Purge Volume ¹ (system volumes)	Total Volume Withdrawn ² (ml)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration ($\mu\text{g}/\text{m}^3$)	Comments
15-SV-A1	V15SVA1-SV25	9:25	70	210	3.0	235	200	25	220	Six-liter Summa canister filled in 20 minutes
	V15SVA1-SV60	9:26		235	3.4	295	200	60	160	
	V15SVA1-SV500	9:34		295	4.2	795	200	500	350	
	V15SVA1-SV1000	9:40		795	11.4	1,795	200	1,000	430	
	V15SVA1-SV6000	10:05		1,795	25.6	7,795	300	6,000	120	
15-SV-B2	V15SVB2-SV25	9:51	68	204	3.0	229	200	25	500	Six-liter Summa canister filled in 54 minutes
	V15SVB2-SV60	9:52		229	3.4	289	200	60	570	
	V15SVB2-SV500	9:58		289	4.3	789	200	500	780	
	V15SVB2-SV1000	10:02		789	11.6	1,789	200	1,000	830	
	V15SVB2-SV6000	10:56		1,789	26.3	7,789	111	6,000	690	
15-SV-B3	V15SVB3-SV25	10:30	72	216	3.0	241	200	25	820	Six-liter Summa canister filled in 52 minutes
	V15SVB3-SV60	10:29		241	3.3	301	200	60	1,600	
	V15SVB3-SV500	10:32		301	4.2	801	200	500	2,900	
	V15SVB3-SV1000	10:37		801	11.1	1,801	200	1,000	3,300	
	V15SVB3-SV6000	11:30		1,801	25.0	7,801	115	6,000	2,000	

Table 3-3
Sample Volume Experiment Sample Summary
18 October 2006
Vandenberg AFB, Site 15
Development of Active Soil Gas Sampling Method (Continued)

Location	Sample ID	Sample Time	System Volume (ml)	Purge Volume ¹ (ml)	Purge Volume ¹ (system volumes)	Total Volume Withdrawn ² (ml)	Purge Rate (ml/min)	Sample Volume (ml)	TCE Concentration (µg/m ³)	Comments
15-SV-C2	V15SVC2-SV25	11:14	56	168	3.0	193	200	25	2,500	Six-liter Summa canister filled in 60 minutes
	V15SVC2-SV60	11:15		193	3.4	253	200	60	1,500	
	V15SVC2-SV500	11:33		253	4.5	753	200	500	3,000	
	V15SVC2-SV1000	11:39		753	13.4	1,753	200	1,000	3,600	
	V15SVC2-SV6000	12:41		1,753	31.3	7,753	100	6,000	2,000	
15-SV-C5	V15SVC5-SV25	12:45	62	186	3.0	211	200	25	240	Replicate sample result = 650 Six-liter Summa canister filled in 49 minutes
	V15SVC5-SV60	12:46		211	3.4	271	200	60	350	
	V15SVC5-SV500	12:48		271	4.4	771	200	500	250	
	V15SVC5-SV1000	12:55		771	12.4	1,771	200	1,000	660	
	V15SVC5-SV6000	13:42		1,771	28.6	7,771	122	6,000	380	

Notes:

- ¹ - Volume of gas purged from probe prior to start of sample collection
- ² - Total cumulative volume of gas purged from probe at completion of sample collection
- µg/m³ - micrograms per cubic meter
- ml - milliliters
- ml/min - milliliters per minute
- TCE - trichloroethene

3.3 Sample Summary

Purge Rate Experiment

Samples for the purge rate experiment were collected on October 16, 2006 from the five probes installed along row B (Figure 2-4). Row B was selected because the baseline sampling indicated a broad range of TCE concentrations are present along this row. The purge volume for this experiment was set to three system volumes for each individual probe sampled, in accordance with the QAPP. Each of the probes were first purged at a rate of 100 ml/min, followed by purging each probe at rates of 200 ml/min, 500 ml/min, 1,000 ml/m, and 2,000 ml/min. After three system volumes were purged, 60 ml samples were collected from each probe using a syringe. The elapsed time between collection of consecutive samples at a single probe ranged from 28 to 75 minutes. A complete list of the principal parameter information for the purge rate experiment is provided in Table 3-1.

During the course of the experiment, a trend toward higher concentrations with increasing purge rates was apparent; therefore, additional samples were collected from two probes (15-SV-B1 and 15-SV-B3) using a higher purge rate of 5,000 ml/min to assess whether the apparent trend continued. Specifically, four samples were collected after purging at a rate of 5,000 ml/min, two from each of the two locations. These samples were collected after purging at 5,000 ml/min for approximately 7 seconds (approximately 8 system volumes) and after 3 minutes (approximately 208 and 221 system volumes) (Table 3-1). These samples were collected to assess the impacts of using an excessive purge rate and a total purge volume that is well above industry standards and considered likely to stress the system.

Purge Volume Experiment

Samples for the purge volume experiment were collected on October 17, 2006. Internal discussions following the purge-rate test on October 16 led to the determination that for purposes of satisfying assumptions used in statistical analysis, the sampling locations should be chosen randomly rather than selecting an individual row for conducting the tests. Therefore, five randomly selected probes were chosen for the purge volume test (15-SV-A2, 15-SV-A4, 15-SV-B1, 15-SV-B4, and 15-SV-C4). In accordance with the procedures outlined in the QAPP, 60 ml samples were collected from probe 15-SV-B1 after each of the 1, 2, 3, 6 and 10 system volumes were purged at 200 ml/min. Purging and sampling was conducted in sequence by tracking the cumulative purge volume, which consists of the volume purged and released from the system plus the volume of each sample collected (e.g., 15-SV-B1 has a system volume of 68 ml, thus 68 ml were purged followed by collection of a 60-ml sample [the 1-purge-volume sample] followed by purging of an additional 8 ml and collection of the next 60-ml sample [the 2-purge-volume sample]). All samples from an individual probe were collected consecutively before moving onto the next probe.

Analytical results appeared to show a step in detected soil gas concentrations between 3 and 6 purge volumes (Table 3-2); therefore, the next two probes (15-SV-B4 and 15-SV-A2) were sampled after purging 1, 2, 3, 4, 5, 6 and 10 system volumes. In addition, probe 15-SV-A2 was sampled after purging 20 system volumes. Analytical results from 15-SV-B4 and 15-SV-A2 suggested a step in soil gas concentrations between 6 and 10 purge volumes; therefore, a sample was collected after purging 8 and 20 system volumes at the subsequently sampled probes (15-SV-A4 and 15-SV-C4). An additional sampling test was performed at 15-SV-A4 to test a large volume purge, well above industry standard purge volumes. This probe was purged for one hour at a rate of 5,000 ml/m, or approximately 4,400 purge volumes, and then sampled.

As stated in Section 2.4, all 15 semipermanent probes were installed at depths approximately 2 to 4 feet above the water table. During the testing, it was postulated that a reason for the apparent step in soil

gas concentrations observed at higher purge volumes might be that the radius of influence around the sampling probe was intersecting the capillary fringe and altering the flow dynamics. To test this hypothesis, a boring was drilled using an electric rotary-hammer to a depth of 5 feet bgs at a location approximately 2 feet southeast of probe 15-SV-C4. A temporary probe (15-SV-C4HP) was installed at 5 feet bgs and the system was purged to 1, 2, 3, 6, 10, 20, and 100 system volumes; samples were collected after each purge. The rationale was that with a probe set at only 5 feet bgs, it was unlikely that the sphere of influence would intersect the capillary fringe and, therefore, the step in concentrations would not be observed.

Sample Volume Test

Samples for the sample volume experiment were collected on October 18, 2006. Samples were collected from five probes (15-SV-A1, 15-SV-B2, 15-SV-B3, 15-SV-C2 and 15-SV-C5) randomly selected to satisfy statistical analytical assumptions. In accordance with the procedures outlined in the QAPP, each probe was first purged at a rate of 200 ml/min to a total of three system volumes. Five different sample volumes (25, 60, 500, 1,000 and 6,000 ml) were then collected consecutively from each probe before moving onto the next probe. The 25 and 60 ml samples were collected in 60 ml syringes. The 500 and 1,000 ml samples were collected in 1-liter Tedlar bags. Six-liter Summa canisters were used to collect the 6,000 ml samples. A complete list of the principal parameter information for the sample volume experiment is provided in Table 3-3.

3.4 Data Evaluation and Quality Control

The analytical data generated during the sampling program were reviewed for quality, compliance with the QAPP, and usability. The QC elements reviewed were completeness, holding times, calibration, blanks, and duplicates. Complete laboratory QC results are provided in the laboratory data package in Appendix C.

Data Completeness

The QAPP specified collection and analysis of a total of 75 samples, composed of 25 samples from each of the three experiments. Each of the samples proposed in the QAPP was collected and successfully analyzed. Additional samples were added to the sampling program during the purge rate and purge volume experiments for a total of 102 samples. The data set is therefore considered complete.

Holding Times

All of the samples were analyzed on-site immediately after sampling. The data are considered compliant with holding time requirements.

Instrument Calibration

Initial calibrations were performed as specified in the QAPP. The QAPP-specified a single continuing calibration standard at the start of each day; however, the laboratory added additional calibration standards and ran three on October 16 and 17 and two on October 18. With one exception, all of the continuing calibration standards were within the QAPP-specified criterion of ± 20 percent. A standard run in the middle of the day on October 17 had a result of 75 percent recovery on the PID, slightly outside the ± 20 percent criterion. However, the result on the ECD was within the ± 20 percent criterion at 86 percent recovery and the standards run before and after this one were within the criterion. As this continuing calibration standard was only slightly outside the criterion for acceptable results, was bracketed by two

results within the ± 20 percent criterion, and was an additional standard not required by the QAPP, it was judged as not having a significant negative impact on data quality.

Method Blanks

A total of seven blank samples were run during the sampling conducted on October 16 through 18, 2006. The results were non-detect for all target compounds in all blanks.

Replicates and Duplicates

Field replicate samples were collected from the control probe, 15-SV-A3, and from 15-SV-C5 during the sample volume test. A total of five field replicates were collected during the sampling conducted on October 16 through 18. Replicate samples were collected from the temporal control probe 15-SV-A3. The results of the field replicate analyses indicated good agreement between replicate pairs, with the relative percent differences (RPDs) ranging from 2 to 23 percent (Table 3-4).

Nine laboratory duplicates were analyzed over the course of the sampling conducted on October 16 through 18. The RPD acceptance criterion for laboratory duplicates was ± 30 percent. The RPDs between all but one of the duplicate pairs ranged from 0 to 19 percent. One duplicate pair had an RPD of 33 percent (Table 3-5). This result is only slightly outside the ± 30 percent criterion and the laboratory duplicates collected before and after this sample were within the criterion; therefore, this result is considered unlikely to be indicative of a significant negative impact to the data quality or usability. Nevertheless, field samples analyzed between the two passing duplicates that bracketed the failed duplicate were "J" flagged as estimated concentrations.

Data Evaluation Summary

Based on the data review, the data set is considered complete and all of the data are considered usable for their intended purpose. No results were rejected.

Table 3-4
Field Replicate Summary
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Location	Sample ID	Sample Date	Sample Time	Purge Volume (ml)	Purge Volume (system volumes)	Purge Rate (ml/min)	Sample Volume (ml)	Sample Result ($\mu\text{g}/\text{m}^3$)	Replicate Result ($\mu\text{g}/\text{m}^3$)	RPD
15-SV-A3	V15SVA3	17-Oct-2006	14:20	204	3	200	60	2,300	2,400	4%
15-SV-A3	V15SVA3	18-Oct-2006	9:00	204	3	200	60	2,150	2,400	11%
15-SV-A3	V15SVA3	18-Oct-2006	11:35	204	3	200	60	2,450	2,700	10%
15-SV-C5	V15SVC5-SV1000	18-Oct-2006	12:55	771	12	200	1,000	660	650	2%
15-SV-A3	V15SVA3	18-Oct-2006	13:44	204	3	200	60	2,400	1,900	23%

Notes:

$\mu\text{g}/\text{m}^3$ - micrograms per cubic meter
 ml - milliliters
 ml/min - milliliters per minute
 RPD - relative percent difference

Table 3-5
Results for Laboratory Duplicate Samples
Vandenberg AFB, IRP Site 15
Development of Active Soil Gas Sampling Method

Sample ID	Sample Date	Sample Time	Sample Result ($\mu\text{g}/\text{m}^3$)	Duplicate Result ($\mu\text{g}/\text{m}^3$)	RPD
C4-PV2	17-Oct-2006	13:02	1,500	1,400	7%
C4-PV4	17-Oct-2006	13:15	1,000	1,000	0%
A4-PV300L	17-Oct-2006	14:12	1,100	790	33%
C4-PV20hp	17-Oct-2006	15:16	590	690	16%
C4-PV100hp	17-Oct-2006	15:38	850	760	11%
A1-PV60	18-Oct-2006	9:26	160	160	0%
A1-PV6000	18-Oct-2006	10:05	120	140	15%
B3-PV1000	18-Oct-2006	10:37	3,300	4,000	19%
C5-PV1000	18-Oct-2006	12:55	660	650	2%

Notes:

$\mu\text{g}/\text{m}^3$ - micrograms per cubic meter (TCE)
 RPD - relative percent difference

4.0 Results and Discussion

4.1 Statistical Analyses

4.1.1 Sample Numbers and Parameter Settings

Three separate experiments were conducted to assess the effects of purge rate, purge volume, and sample volume on measured soil gas concentrations. The results of each experiment are described below.

4.1.1.1 Purge Rate

In this experiment, five soil gas probes (15-SV-B1 through 15-SV-B5) were sampled. The sample volume was 60 ml for all samples collected. Purge volume was 3 system volumes for all samples except those purged at a rate of 5,000 ml/min. The 100, 200, 500, 1,000, and 2,000 ml/min purge rates were evaluated at each of the five probes used for this test. In addition, a purge rate of 5,000 ml/min was evaluated at probes 15-SV-B1 and 15-SV-B3 and two samples were collected from each. For the four samples with a purge rate of 5,000 ml/min, the purge volumes fell into 2 groups: approximately 8 system volumes and over 200 system volumes. The two samples that were collected with more than 200 system volumes purged (from 15-SV-B1 and 15-SV-B3) are far removed from the other purge volumes used and could bias the data analysis. Therefore, they were assumed to be outliers and were not included in the statistical analyses.

4.1.1.2 Purge Volume

In this experiment, six soil gas probes (15-SV-A2, 15-SV-A4, 15-SV-B1, 15-SV-B4, 15-SV-C4, and 15-SV-C4HP) were sampled. The first five of these probes were installed normally as discussed in Section 2.4. Probe 15-SV-C4HP was installed by hand to a depth of 5 feet bgs as described in Section 3.3.

The 1, 2, 3, 6, and 10 purge volumes were evaluated at each of the five probes used for this test. As described in Section 3.3, additional purge volumes were evaluated in some of the probes: 4, 5, and 20 purge volumes were evaluated at probe 15-SV-A2, 15-SV-A4, and 15-SV-C4; 4 and 5 purge volumes were also evaluated at probe 15-SV-B4; 20 purge volumes was also evaluated at probe 15-SV-C4HP; and 8 purge volumes were evaluated at probes 15-SV-A4 and 15-SV-C4. One sample was collected after purging 100 system volumes (15-SV-C4HP) and 4,400 system volumes (15-SV-A4); these two samples were considered outliers and were therefore excluded from the statistical analysis. Purge rate and sample volume for the remaining samples were set at 200 ml/min and 60 ml, respectively.

4.1.1.3 Sample Volume

In this experiment, five soil gas probes (15-SV-A1, 15-SV-B2, 15-SV-B3, 15-SV-C2, and 15-SV-C5) were sampled. The sample volumes were evaluated at each of the five probes used for this test. A purge rate of 200 ml/min was used for all samples except the 6,000 ml samples collected using a Summa canister. For these samples, the purge rate (fill rate of the Summa canister) was either approximately 100 ml/min or 300 ml/min. The purge volume for this test necessarily varied with each sample volume and ranged from 3 to 31.3 system volumes (Table 3-3).

The relationship between sample volume, purge volume, and purge rate for this experiment is illustrated in Figure 4-1.

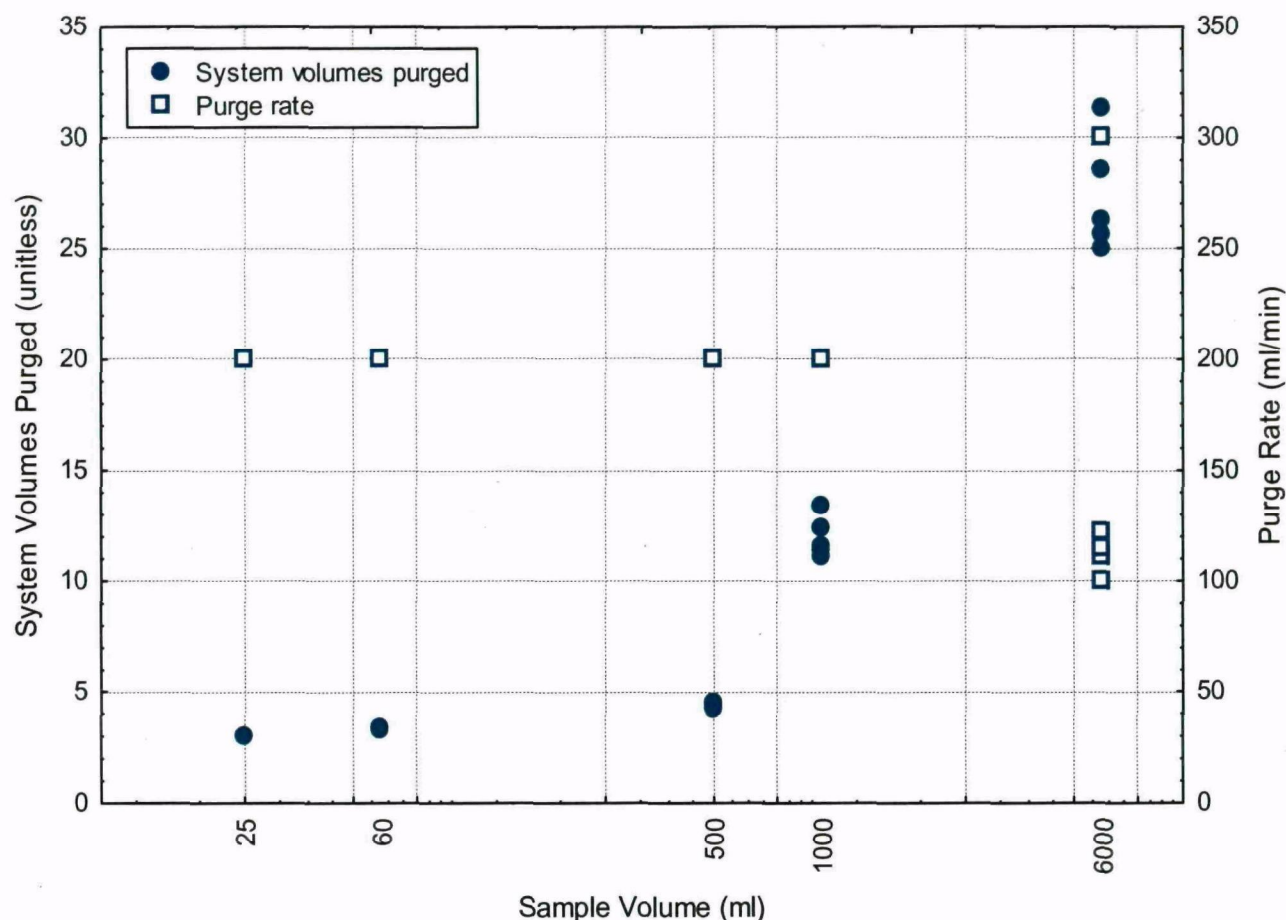


Figure 4-1. Summary of Parameter Settings for Samples Collected During the Sample Volume Experiment

4.1.2 Statistical Approach

Multiple linear regression analysis was performed on the results from the experiments to evaluate the effects of varying the three principal parameters. When parameters other than the parameter of interest varied in the experimental conditions (e.g., purge volume was also varied in the sample volume experiment), their effects were included in the analysis. For the purposes of the analyses presented here, it was assumed that each analytical result could be considered as a randomly collected independent sample. A detailed description of the statistical analyses performed for this investigation is provided in Appendix D.

4.1.2.1 Baseline Measurements

Prior to conducting the experiments, baseline conditions in the installed probes were measured using a purge rate of 200 ml/min, a purge volume of 3 system volumes, and a sample volume of 60 ml. Baseline concentrations varied from 93 $\mu\text{g}/\text{m}^3$ to 2,400 $\mu\text{g}/\text{m}^3$ amongst the probe array (Figure 4-2).

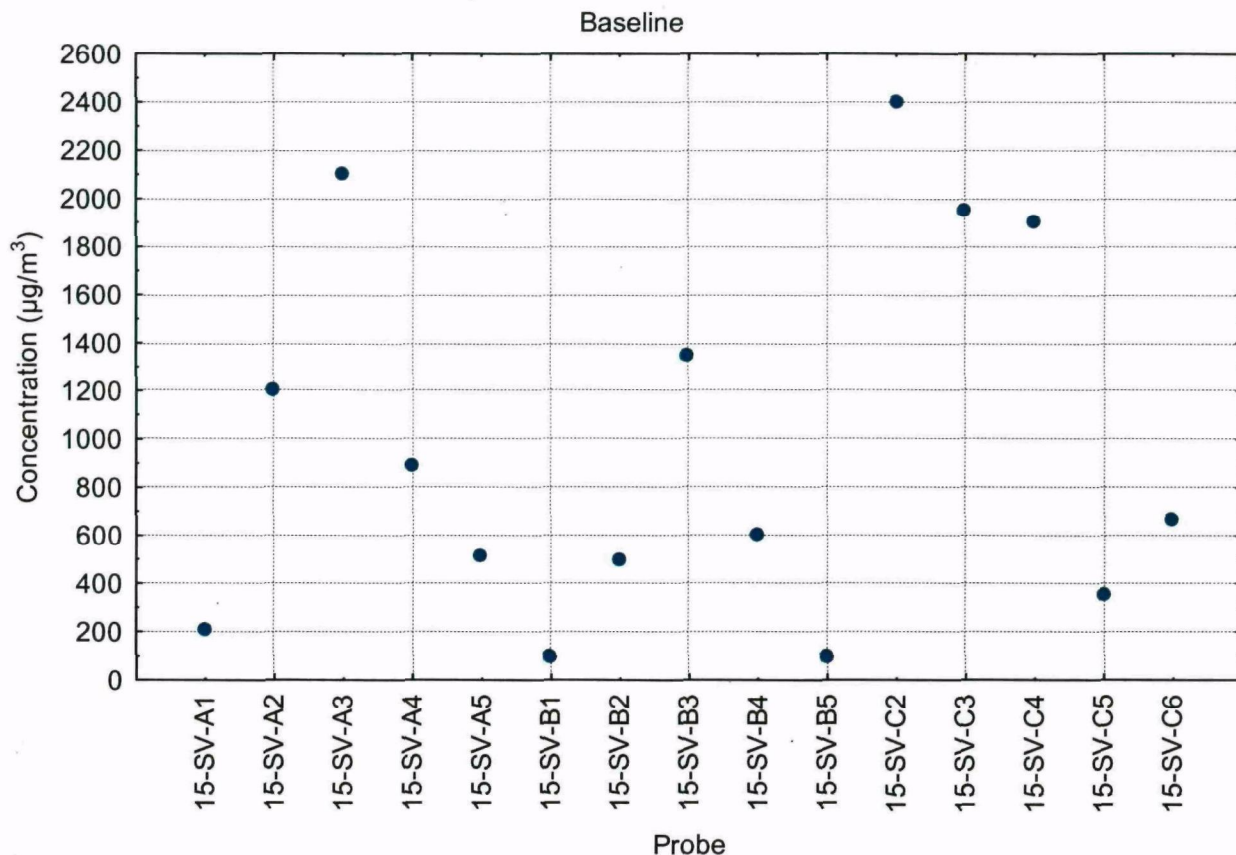


Figure 4-2. Plot of Baseline Concentrations by Probe

To account for the differences in baseline concentrations, baseline concentrations were included as a covariate in all of the statistical analyses. In addition to differences among probes in baseline concentrations, it was observed that probes with higher baseline concentrations had greater variability in results than those with relatively lower baseline concentrations. This observation is illustrated in Figure 4-3, which plots TCE concentrations measured during the purge volume experiment with baseline concentrations as the X-axis and the measured TCE concentrations as the Y-axis. This indicates that changes in the principal parameters have a greater influence on the final concentration with increasing baseline concentrations. The increase in variability with increasing baseline concentrations may in part be due to the inherent variability in laboratory analytical data, which is expected to be on the order of ± 20 percent.

To correct for the effect of increasing variance with increasing concentration, all data were natural logarithm transformed prior to statistical analysis.

The system volumes for each probe were also slightly different. This may affect both the baseline concentrations and the concentrations measured during each of the experiments. To account for the potential effect of the difference in system volumes among the wells, system volume was included as a covariate in the statistical analyses.

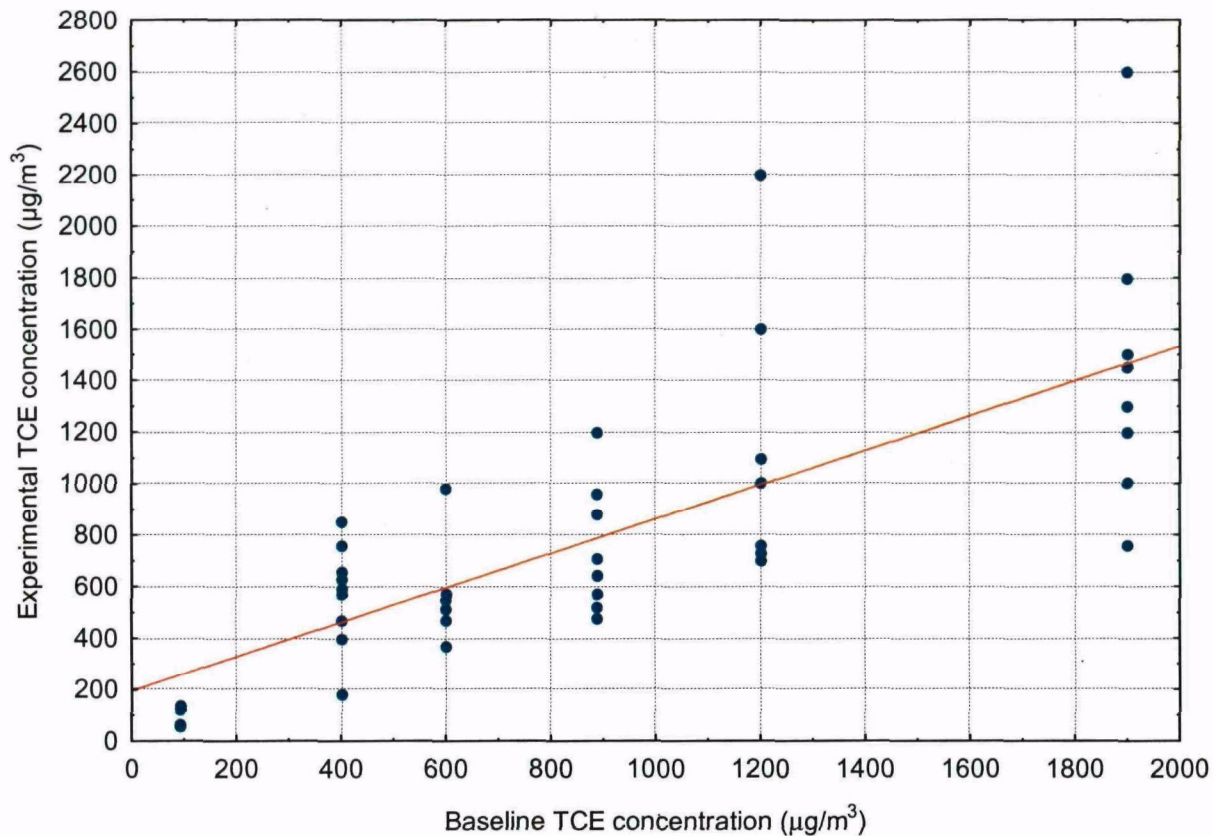


Figure 4-3. Effect of Baseline Concentrations on Variance in TCE Concentrations From Purge Volume Experiment

4.2 Experimental Results

4.2.1 Temporal Control

Samples were collected three to four times a day from probe 15-SV-A3 to monitor temporal variations in measured soil gas concentrations unrelated to changes in the principal parameter settings (Table 2-3). TCE concentrations measured in samples from 15-SV-A3 ranged from 1,600 to 2,700 $\mu\text{g}/\text{m}^3$. Measurements on October 17, 2006 exhibited the least variability, with concentrations ranging from 2,250 to 2,450 $\mu\text{g}/\text{m}^3$. Measurements on October 16 and October 18, 2006 showed more variability, with concentrations ranging from 1,600 to 2,500 $\mu\text{g}/\text{m}^3$ and 1,900 to 2,700 $\mu\text{g}/\text{m}^3$, respectively. The RPDs between the minimum and maximum concentrations detected in the temporal control samples on a single day varied from 9 percent to 44 percent. A plot of the TCE concentrations measured in temporal control samples is shown in Figure 4-4. The reason for the variability in RPDs over the three days is unclear. Insofar as the sample collection parameters were identical over the course of the temporal control sampling, the variability in RPDs is a good reminder of the inherent variability often encountered in environmental monitoring.

The data collected from soil vapor well 15-SV-A3 were analyzed to determine if there were significant temporal trends in the data using the nonparametric Mann-Kendall trend test. This test determines whether there is a monotonic (i.e., single-direction) trend in the data over time (e.g., is the concentration increasing or decreasing over time) and does not examine periodicity in the data. The results of the analysis indicate that, at the 95% confidence level, there was no significant trend over time in the data.

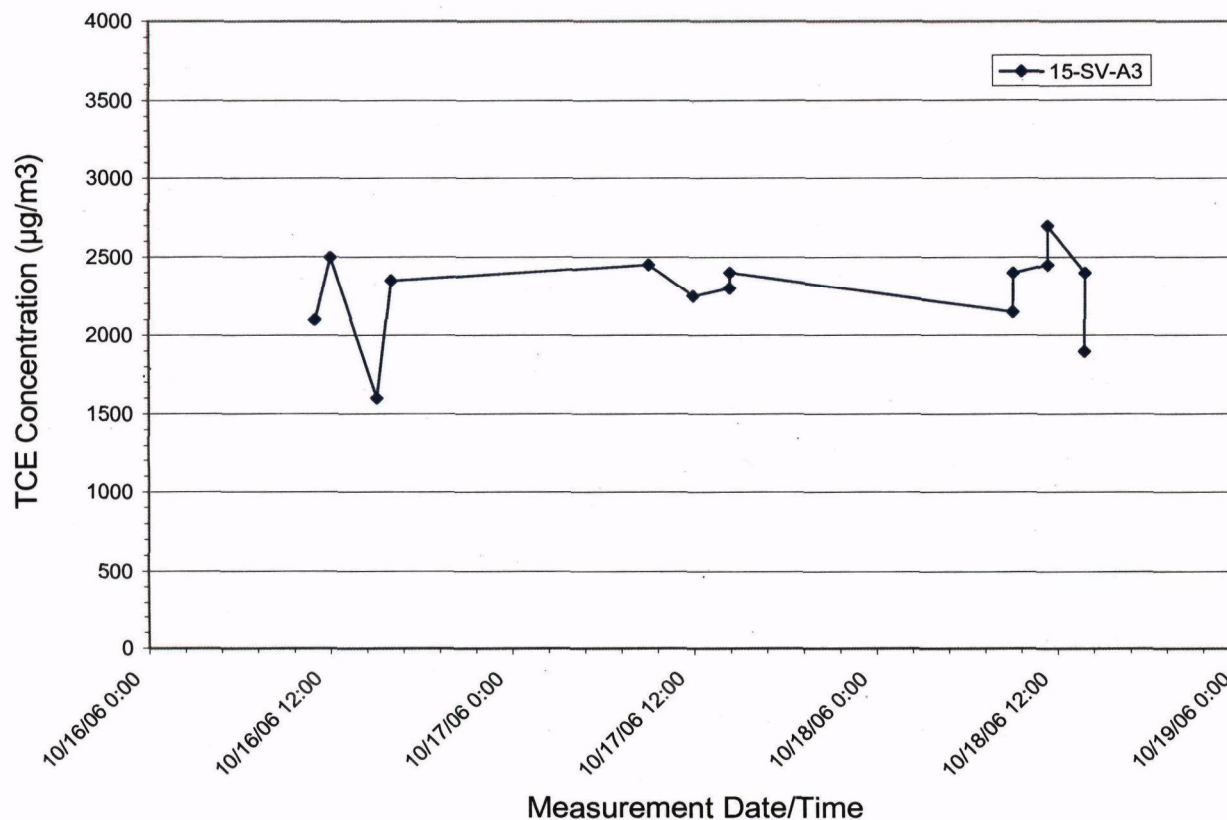


Figure 4-4. TCE Concentrations Measured in Temporal Control Samples

4.2.2 Purge Rate Experiment

The TCE concentrations that were observed during the purge rate experiment are summarized in Table 3-1 and a linear plot of the purge rate experiment data is shown in Figure 4-5. In general, there was a very modest increase in measured concentrations with increasing purge rate over the range of 100 to 5,000 ml/min. The sample results from 15-SV-B1 and 15-SV-B5 ranged from 63 to 150 $\mu\text{g}/\text{m}^3$ (B1) and 94 to 140 $\mu\text{g}/\text{m}^3$ (B5). Measured concentrations in samples from 15-SV-B2 and 15-SV-B4 ranged from 480 to 700 $\mu\text{g}/\text{m}^3$ (B2) and 540 to 960 $\mu\text{g}/\text{m}^3$ (B4); however, the maximum concentration detected at 15-SV-B2 was associated with the 1,000 ml/min purge rate, not the 2,000 ml/min rate. Concentrations measured in samples from 15-SV-B3 showed the widest range of concentrations, from 1,400 to 2,200 $\mu\text{g}/\text{m}^3$. While these data appear to show a trend toward increasing TCE concentrations with increased purge rate, changes in concentration of this magnitude would not be considered significant for site characterization or vapor intrusion applications. Furthermore, the ranges in measured concentrations at a single vapor probe are less than the range observed in the temporal control samples on the day the purge rate experiment was conducted (October 16, 2006) (Table 2-3, Figure 4-4). The RPDs between the maximum and minimum concentrations measured at individual probes (excluding the outlier samples) ranged from 37 to 56 percent with the exception of the results from probe 15-SV-B1, which had an RPD of 82 percent. These RPDs can be compared to the RPD for the temporal control sample of 44 percent.

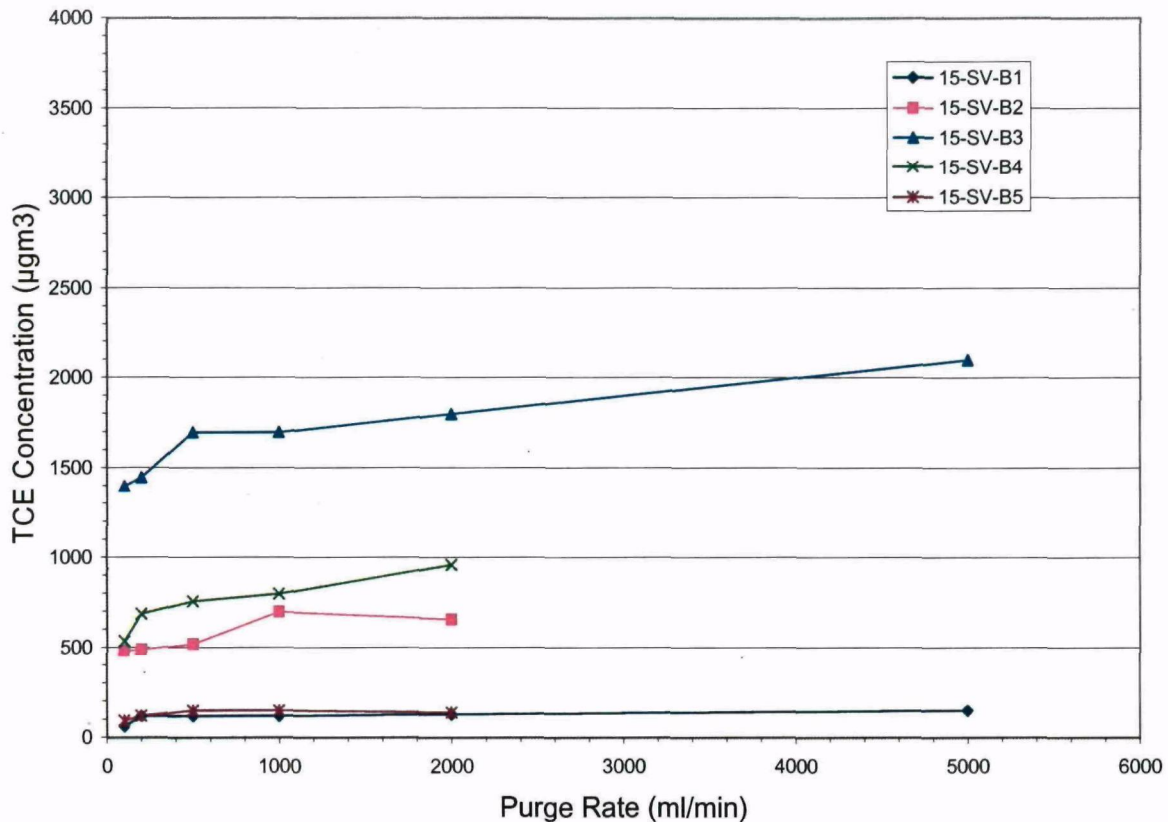


Figure 4-5. Linear Plot of Purge Rate Experiment Data

Quantitative Statistical Analysis

In the purge rate experiment, sample volume was held constant; however, there was some variation in the number of system volumes purged. Therefore, the independent variables used in the regression analysis were: 1) purge rate (parameter of interest), 2) system volumes purged (covariate), 3) baseline concentration (covariate), and 4) system volume (covariate). This resulted in a statistically significant multiple linear regression with the following resulting equation (see also Appendix D):

$$\ln(\text{TCE in } \mu\text{g/m}^3) = -4.85 + 0.14 \cdot \ln(\text{purge rate in ml/min}) - 0.044 \cdot \ln(\text{system volumes purged}) + 1.00 \cdot \ln(\text{system volume in ml}) + 0.99 \cdot \ln(\text{baseline TCE in } \mu\text{g/m}^3)$$

To directly illustrate the effect of purge rate on the measured TCE concentrations, the same regression as above was performed, but without purge rate, and the residuals were calculated. The residuals were then regressed on the purge rate. After accounting for the effect of the other variables, purge rate accounted for approximately 50 percent of the variance observed in the data (Figure 4-6).

The two measurements at far right in Figure 4-6 were collected after purging approximately 8 purge volumes, as opposed to 3 purge volumes for the other measurements. These two measurements fall somewhat below the regression line, suggesting there may be some degree of interaction between purge rate and purge volume; however, this cannot be rigorously evaluated given the existing data set.

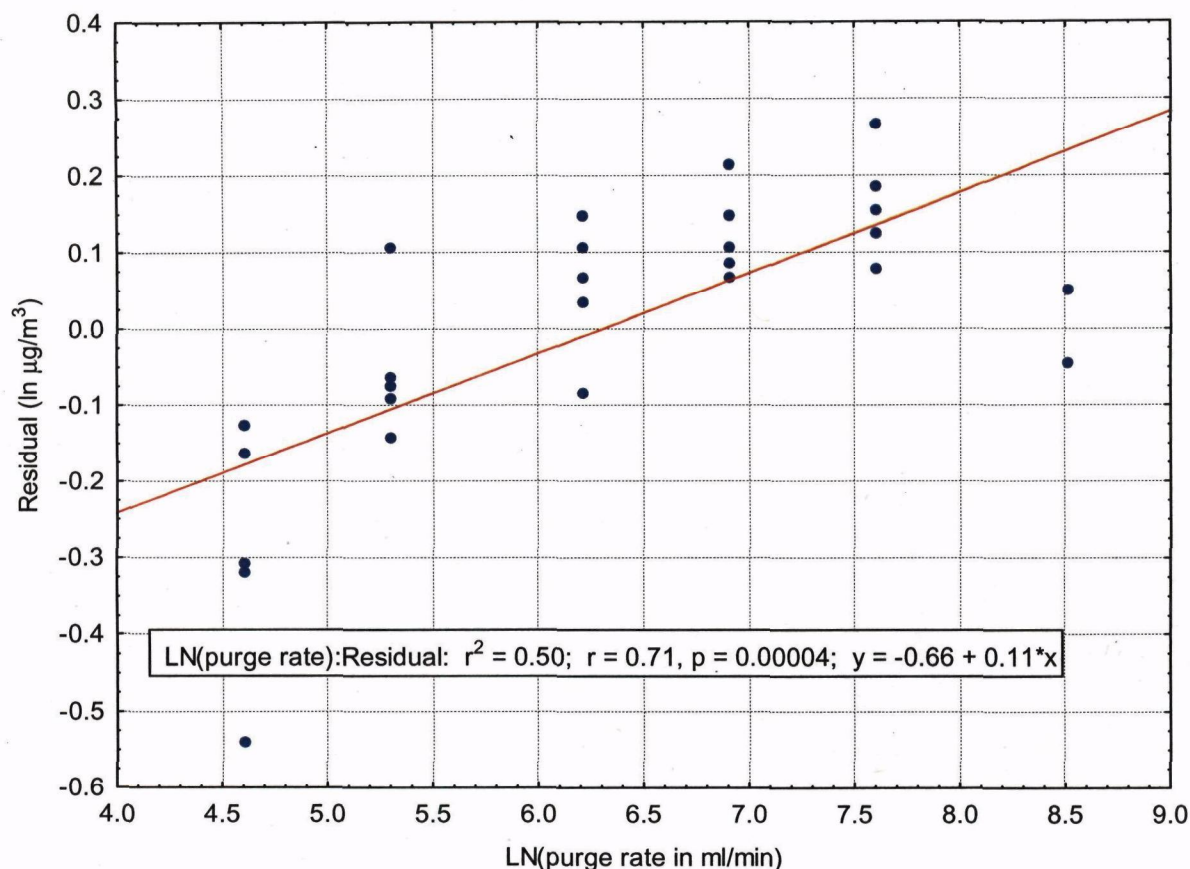


Figure 4-6. Effect of Purge Rate on Measured Soil Gas Concentrations, After Accounting for the Effects of Baseline Conditions, System Volumes Purged, and System Volume

To summarize, although there is a statistically significant positive correlation between the measured TCE concentrations and purge rate, the variability in measured concentrations would not be considered significant in the context of site characterization or vapor intrusion sampling. The data generally appear to show a sharp rise in detected TCE concentration from the sample collected at 100 ml/min to the sample collected at 200 ml/min, and then a moderate to slight increase with increasing purge rate. These results suggest that purge rates between 200 and 500 ml/min are the most suitable under the conditions sampled.

4.2.3 Purge Volume Experiment

The TCE concentrations that were observed during the purge volume experiment are summarized in Table 3-2 and a linear plot of the purge rate experiment data is shown in Figure 4-7. The measured TCE concentrations generally increased over the range of 5 to 20 purge volumes; however, there was no obvious trend toward higher TCE concentrations with increased purge volume over the range of 1 to 6 purge volumes. The measured concentrations from each probe appear to increase from 1 to 2 purge volumes, decrease from 2 to 3 purge volumes, increase again from 3 to 4 purge volumes, and decrease again at 5 purge volumes. The explanation for this behavior is not clear; however, the variability of the measured TCE concentrations over 1 to 5 purge volumes is small. The measured concentrations from each probe more than doubled from 5 to 20 purge volumes, with the exception of 15-SV-C4HP and 15-SV-B1, which was only tested to 10 purge volumes (but more than doubled in concentration from 3 to 10 purge volumes).

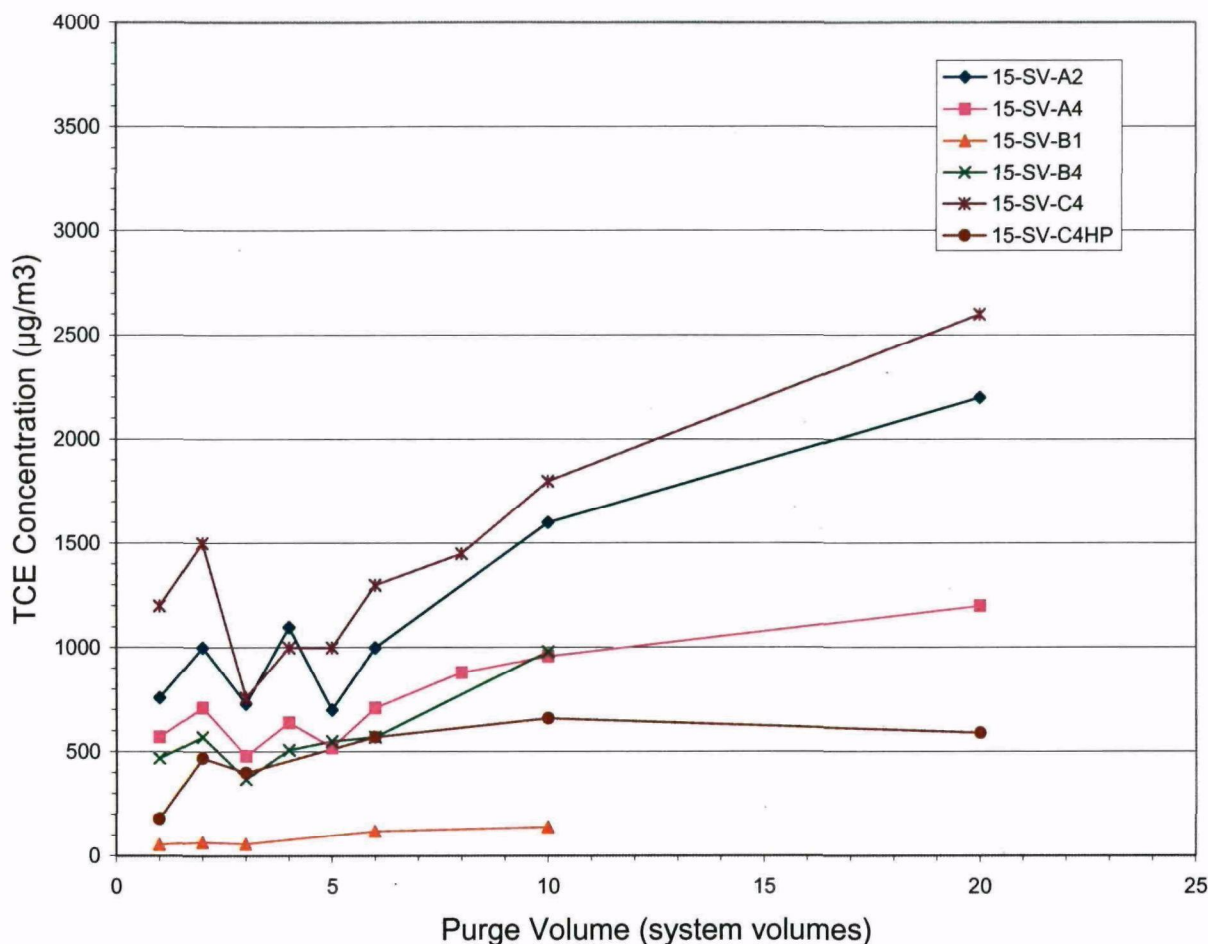


Figure 4-7. Linear Plot of Purge Volume Experiment Data

The ranges in concentrations observed in all of the probes sampled for the purge volume experiment, with the exception of 15-SV-B1, were significantly more than the range in concentrations observed in the temporal control samples collected on the same day (Table 2-3). The RPDs between the maximum and minimum concentrations measured at individual probes (excluding the outlier sample) ranged from 86 to 114 percent in the experimental samples as compared to 9 percent in the temporal control samples for that day.

As discussed in Section 3.3, during the purge volume experiment, additional purge volume settings were added to the sampling program, as the initial data suggested a “step” in soil gas concentrations. In addition, a shallow (5 feet bgs) temporary vapor probe (15-SV-C4HP) was installed to test the hypothesis that measured TCE concentrations were being affected by the sphere of influence around the vapor probes intersecting the capillary fringe. When taken as a complete data set, the results of the purge volume experiment do not appear to show a step in TCE concentrations; however, the TCE concentrations in samples from the shallow probe were the only ones to decrease between the 10 and 20 volume purges, suggesting the hypothesis regarding the sphere of influence may have some credence.

Quantitative Statistical Analysis

In the purge volume experiment, the only parameter that was varied was the purge volume, expressed as system volumes. Therefore, the independent variables used in the regression analysis were: 1) system volumes purged (parameter of interest), 2) baseline concentration (covariate), and 3) system volume (covariate). These parameters resulted in a statistically significant multiple linear regression with the following equation:

$$\ln(\text{TCE in } \mu\text{g/m}^3) = -6.71 + 0.29 \cdot \ln(\text{system volumes purged}) + 0.95 \cdot \ln(\text{baseline TCE in } \mu\text{g/m}^3) + 1.53 \cdot \ln(\text{system volume in ml})$$

To directly illustrate the effect of purge volume on the measured TCE concentration, the same regression was performed, but without the system-volumes purged term, and the residuals were then calculated. The residuals were then regressed on the number of system volumes purged. After accounting for the effect of the other variables, purge volume accounted for approximately 50 percent of the variance observed in the data (Figure 4-8).

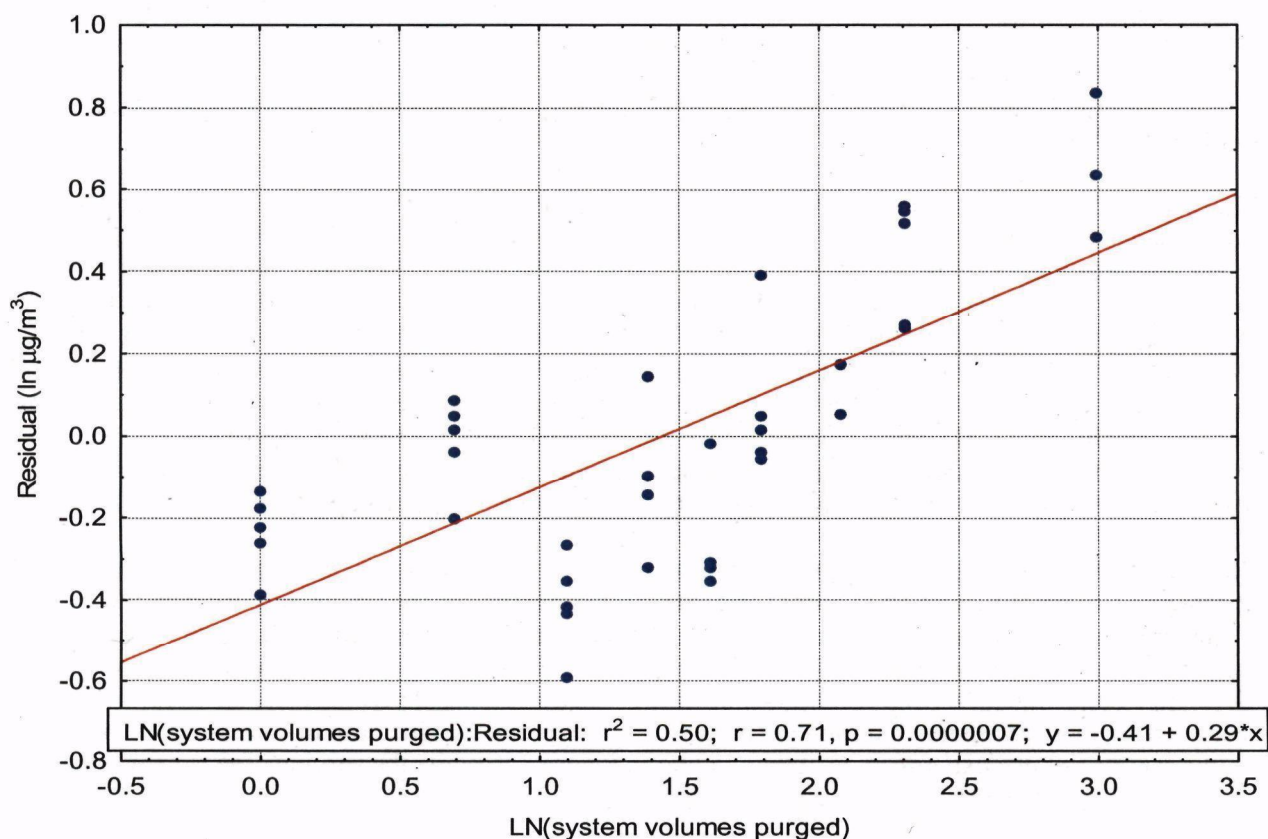


Figure 4-8. Effect of the Number of System Volumes Purged on Measured Soil Gas Concentrations, After Accounting for the Effect of Baseline Conditions and System Volume

To summarize, there is a statistically significant positive correlation between the measured TCE concentrations and purge volume. From a field investigation perspective, the effect of purge volume on the measured TCE concentrations was more pronounced than the effect of purge rate, with concentrations generally more than doubling over the range of purge volumes tested. However, this variability may not be significant in terms of site characterization. The data indicate that varying purge volume from 1 to 5 system volumes has relatively little effect on the sample results; however, increasing purge volume above 5 system volumes appears to result in higher measured TCE concentrations. The concentrations measured after purging 2 system volumes were consistently higher than those measured after withdrawing only one volume. Logic dictates that it is prudent to purge more than one system volume in order to ensure that ambient air is removed from the probe; based on this logic and the data presented here, it appears that purge volumes of 2 to 5 system volumes are most appropriate under the conditions sampled.

4.2.4 Sample Volume Experiment

The TCE concentrations that were observed during the sample volume experiment are summarized in Table 3-3 and a linear plot of the purge rate experiment data is shown in Figure 4-9. As noted in Section 4.1.1.3, the cumulative purge volume necessarily increased during this experiment as consecutive samples were collected; therefore, measured TCE concentrations may be effected by changes in both purge volume and sample volume.

In general, the measured concentrations of TCE increased somewhat with increasing sample size from 25 to 1,000 ml and then decreased in the 6,000 ml samples. This behavior is consistent with an interpretation of over-purging between the 1,000 and 6,000 ml volumes, possibly abetted by reduced equilibration times during the study.

The sample probes selected for the sample volume experiment fall into two groups: those with relatively low baseline concentrations between 210 and 500 $\mu\text{g}/\text{m}^3$ (15-SV-A1, 15-SV-B2, and 15-SV-C5) and those with relatively high baseline concentrations above 1,000 $\mu\text{g}/\text{m}^3$ (15-SV-B3 and 15-SV-C2). The variability in measured concentrations in the "low" group ranged from approximately 300 to 400 $\mu\text{g}/\text{m}^3$. The variability in measured concentration in the "high" group ranged from 2,100 to 2,480 $\mu\text{g}/\text{m}^3$. By comparison, the variability observed in the temporal control samples collected on the same day (October 18) was 800 $\mu\text{g}/\text{m}^3$. The temporal control probe yielded concentrations closer to the "high" group, but had lower variability (i.e., 800 $\mu\text{g}/\text{m}^3$ compared to 2,100 to 2,480 $\mu\text{g}/\text{m}^3$). The RPDs between the maximum and minimum concentrations measured at individual probes ranged from 50 to 100 percent in the experimental samples as compared to 35 percent in the temporal control samples.

It should be noted that during the purge volume experiment, the maximum volume of gas purged from a probe prior to sampling was on the order of 1,400 ml. During the sample volume experiment, the cumulative volume of gas withdrawn prior to collection of the 6,000 ml samples was on the order of 1,700 ml, and the total volume withdrawn after collection of the 6,000 ml samples was close to 8,000 ml. Thus, the total cumulative volume purged during the sample volume experiment was far greater than the cumulative amount withdrawn during the purge volume experiment. The drop in concentration observed in the sample volume experiment is clearly shown in Figure 4-9, while the varying effects between purge volume and sample volume are illustrated in Figure 4-10.

The drop in measured TCE concentrations from the 1,000 ml to the 6,000 ml samples (Figures 4-9 and 4-10) is noteworthy as the 6,000 ml sample volume is commonly used in the industry (i.e., 6-liter Summa canisters). The 6-liter Summa canister is the typical sample container for running EPA TO-15

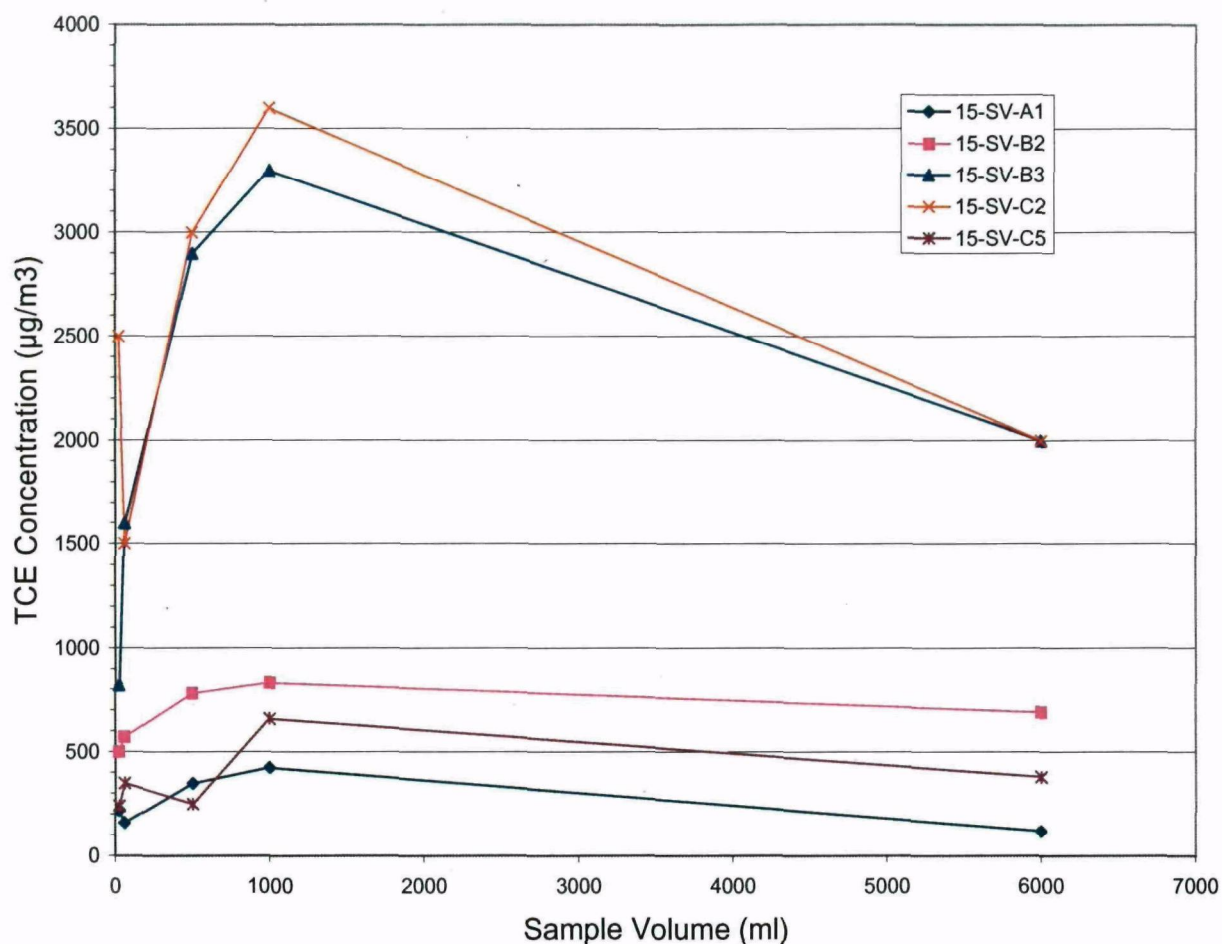


Figure 4-9. Linear Plot of Sample Volume Experiment Data

methodology, which is considered the industry standard for vapor analyses and is often utilized due to the very low detection levels achievable with this method. However, this study suggests that 6-liter samples may result in lower concentrations than 500 or 1,000 ml samples. As stated previously, the reason for the observed drop in measured TCE concentrations in the 6,000 ml samples is likely over-purging of the system.

Quantitative Statistical Analysis

In the sample volume experiment the variable of interest is sample volume; however, the cumulative number of system volumes purged progressively increased as sampling volume increased. Therefore, sample volume and system volumes purged are dependent variables (i.e., they co-vary) and these data cannot be evaluated using the multiple regression approach used for the previous two experiments.

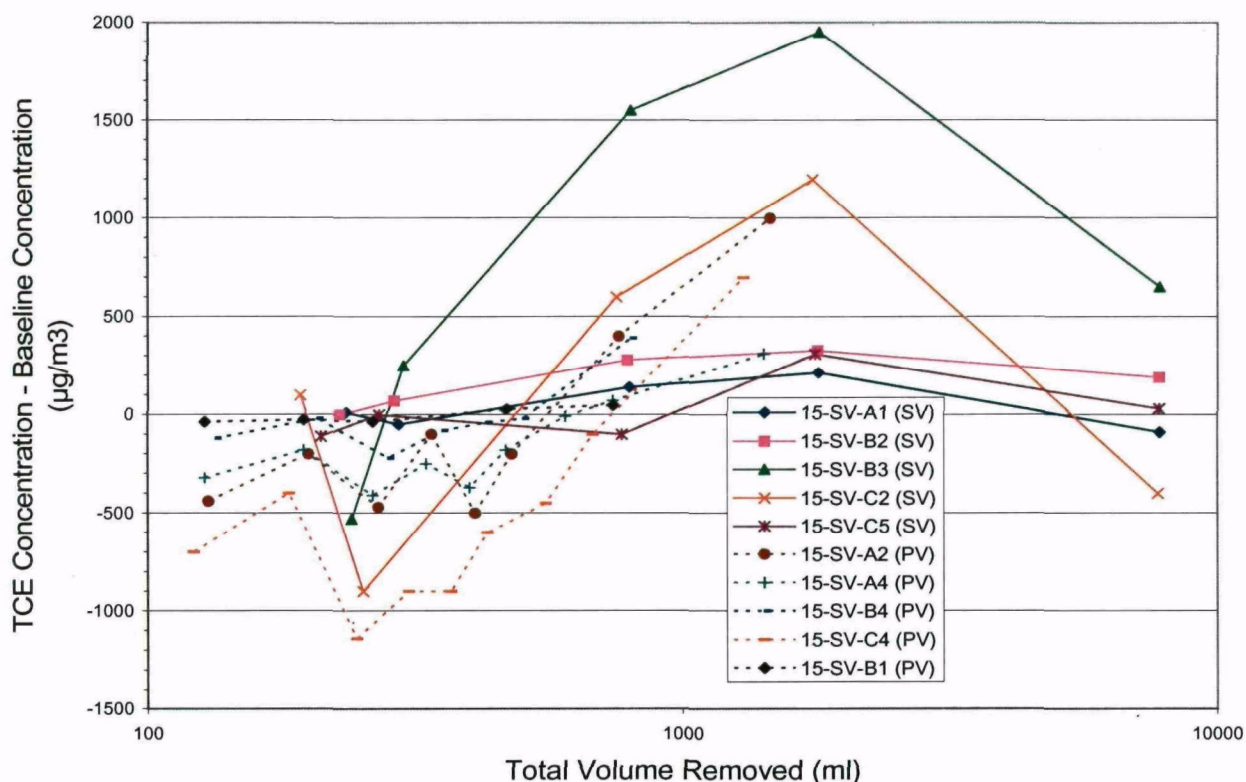


Figure 4-10. Plot of TCE Concentrations From the Purge Volume (PV) and Sample Volume (SV) Experiments vs. Total Volume of Gas Removed (purge volume + sample volume) on a Log Scale

The purge rate and sample fill rate for all but the 6,000-ml samples was held constant at 200 ml/min. The flow rate during filling of the 6,000-ml Summa canisters varied from approximately 100 to 300 ml/min. Therefore, purge rate was also considered a covariate in the statistical analyses.

To analyze the results of this experiment, sample volume was treated as an indicator of the combined experimental conditions, and as a categorical, rather than continuous, variable. An analysis of covariance (ANCOVA) was used to analyze the sample volume experiment data, with the natural-log-transformed baseline concentrations treated as a continuous covariate. System volume was examined and was not determined to have a significant effect in the analyses and was, therefore, not included as a covariate. The ANCOVA indicated that the experimental manipulations had a significant effect on the measured TCE concentrations after adjusting for baseline concentrations (Figure 4-11).

To determine which treatments are significantly different, the Newman-Kuels multiple range test was used. This test indicated that the TCE concentrations measured in the 25-ml, 60-ml, and 6,000-ml sample volumes were not significantly different from each other. In contrast, the 500-ml and 1,000-ml sample volumes were similar to each other, but were significantly different from the other treatments (Figure 4-11).

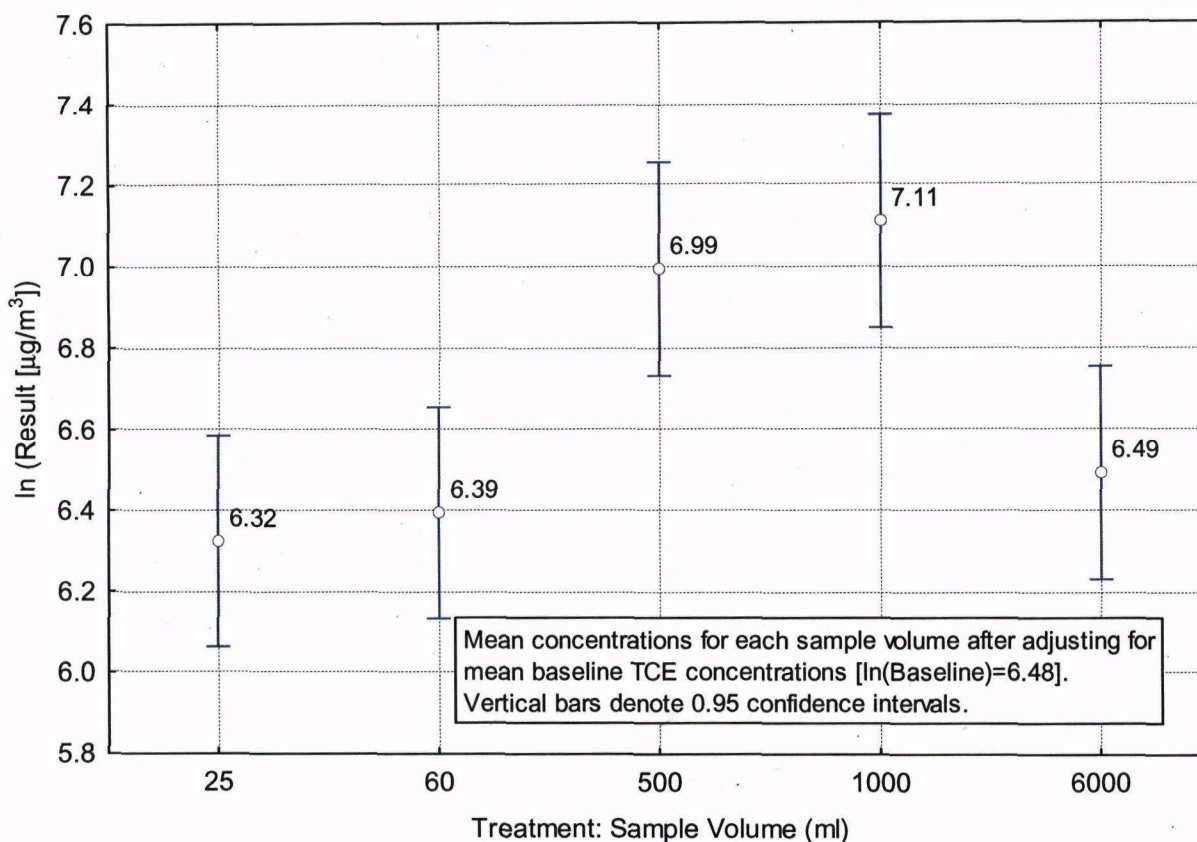


Figure 4-11. Graphical Representation of the Results of the Newman-Kuels Multiple Range Test for the Sample Volume Experiment. Samples Whose Confidence Intervals Overlap the Mean of Another Sample are not Significantly Different

To summarize, sample volume had a statistically significant effect on the measured TCE concentrations. The most noteworthy observation was the decrease in measured TCE concentration with the 6,000 ml samples. Additional experiments should be conducted to verify this effect. Based on the data obtained from this investigation, it appears that a sample volume of 1,000 ml should be recommended, as this volume appears to result in the highest measured concentrations. However, smaller sample volumes would appear to provide acceptable results for most site characterization needs.

5.0 Conclusions

Three experiments were conducted to assess the effect of varying purge rate, purge volume, and sample volume on measured VOC concentrations in soil gas samples.

Purge Rate Experiment

Samples were collected from five probes with purge rates ranging from 100 to 5,000 ml/min. The results of the experiment show a pronounced increase in measured TCE concentration from purge rates of 100 ml/min to 200 ml/min followed by a modest trend of increasing measured concentrations with increasing purge rate. However, the observed variability in measured VOC concentrations would not generally be considered significant from a site characterization or vapor intrusion perspective. Based on the data from this investigation, it appears that purge rates of 200 to 500 ml/min should be recommended for sites possessing similar subsurface conditions.

Purge Volume Experiment

Samples were collected from six probes, with purge volumes ranging from 1 to 4,400 system volumes. There was a statistically significant positive correlation between the measured TCE concentrations and purge volume, with concentrations typically more than doubling over the range of purge volumes tested. The effect of purge volume on the measured VOC concentrations was more pronounced than the effect of purge rate; however, this variability may not be significant in terms of site characterization. The data indicate that varying purge volume from 1 to 5 system volumes has relatively little effect on the sample results; however, increasing purge volume above 5 system volumes appears to result in higher measured TCE concentrations. The concentrations measured after purging 2 system volumes were consistently higher than those measured after withdrawing only one volume. Logic dictates that it is prudent to purge more than one system volume in order to ensure that ambient air is removed from the probe. Based on this logic and the experimental data, it appears that purge volumes of 2 to 5 system volumes are most appropriate.

Sample Volume Experiment

Samples were collected from five probes, with sample volumes ranging from 25 to 6,000 milliliters (ml). Measured TCE concentrations were observed to increase with increasing sample volume from 25 to 1,000 ml, but then drop off in the 6,000 ml samples. This observation is significant as the 6,000 ml sample size is commonly used to achieve very low detection levels with EPA method TO-15; however, the drop in measured TCE concentrations at a 6,000 ml sample volume suggests that the low detection levels achievable with large sample size may need to be balanced against the risk of over-purging. Based on the data obtained from this investigation, it appears that a sample volume of 1,000 ml should be recommended, as this volume appears to result in the highest measured concentrations. However, smaller sample volumes would appear to provide acceptable results for most site characterization needs.

Summary

Overall, the variability in trichloroethene (TCE) concentrations that resulted from varying the principal parameter settings was found to be similar to the variability measured in a single probe successively sampled over the course of the program (i.e., the temporal control probe). These results indicate that while the principal parameter settings do affect the measured TCE concentrations, the magnitude of their effect is similar to that of other variables that could not be controlled during this study. None of the principal parameters evaluated appear to dominate the variability in sample results. Further, site-specific factors may affect the degree to which each of these parameters affect sample results.

6.0 Recommendations

Based on the results of this study, we recommend the following:

- Conduct similar experiments at other sites with differing lithologies.
- Conduct similar experiments with differing system volumes.
- Further investigate/verify the apparent decrease in measured VOC concentrations associated with a 6-liter sample volume.
- Further investigate the effect of purge volume over the range of 1 to 6 system volumes and the effect of varying equilibration time between collection of subsequent samples from a single probe.
- Investigate other parameters such as probe installation method and equilibration time.
- Investigate the effects of atmospheric variables (i.e., temperature, barometric pressure, precipitation, wind speed, etc.).
- Collect samples from the temporal probe at the same frequency as the study probe array such that trends observed from the study array can be directly compared to those exhibited by the temporal probe data.

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Appendix A

Literature Review

April 2006

Development of Active Soil Vapor Sampling Method

Literature Review

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**EPA Contract #EP-C-05-061
Task Order No. 5**

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1.0 INTRODUCTION

Soil vapor data are widely used in site investigation and remediation projects to delineate volatile organic compound (VOC) vapor plumes, as a screening tool to refine soil and groundwater sampling efforts, to track the progress of soil remediation, and to identify potential risks from the inhalation of air associated with soil vapor migration. The overall goal of any monitoring or sampling program is to enable the collection of representative samples; that is samples that are representative of the environmental, chemical, and hydrogeological conditions present during the time of sample collection. Over a period of time, collection of a sequence of representative samples can enable a better understanding of trends in the data set regarding the fate and transport of the chemicals being monitored. However, due to numerous environmental as well as sampling and analytical variables, the representativeness of the sample can often be compromised, the degree of which is often not well understood or quantified.

A number of research groups and local, state, and federal agencies have developed guidance concerning sampling and analytical protocols for active soil vapor sampling with the overall objective of facilitating a technically correct approach to be employed during site investigations. However, the various guidance documents often omit a prescribed range of key parameters (e.g., purge rate ranges, purge volumes, and sample volumes) that may be used during sample collection, or if prescribed, lack a quantitative basis in terms of the net effect on the sampling result. As a result, adherence to any one specific guidance document may result in sampling and analytical bias when investigation results collected under one guidance document are compared to results obtained through adherence to another guidance document. This Literature Review presents, compares, and discusses some of the key parameters recommended in several widely cited and used soil vapor sampling guidance documents with the objective of identifying key parameters that potentially require further quantification in order to develop a defensible and standardized approach. This literature review focuses on recommendations and guidance related to purge rates, purge volumes, and sample volumes, but includes discussion of other parameters as appropriate.

2.0 TECHNICAL APPROACH

Initially, information in the form of guidance documents and technical articles from Federal and State entities, industrial consortiums, and the private sector were consulted for soil vapor guidance content. From this initial search, consideration was given to the relevance and importance of the material considered, and to the breadth of its audience. To this end, the considerable experience of the project team was relied upon to identify what was considered to be the most widely used and cited guidance documents and technical articles currently available. State guidance from California on the west coast, New York and New Jersey on the east coast, Missouri, and Canada were reviewed. Other sources of guidance included that from the American Petroleum Institute, the American Society of Testing Materials (ASTM), the U.S. EPA, and Technical Editorials published in periodicals (LUSTLine Bulletins, etc.). Sampling methodologies that were screened were weighted towards whole-air active soil vapor sampling approaches, but also included consideration of guidance related to vapor intrusion studies and surface flux chamber sampling protocols. In the interest of providing a current picture of the state of the understanding, some draft documents were also considered, including one from the International Regulatory Research Council (ITRC) vapor intrusion workgroup. It is notable that the majority of recent guidance documents focus attention on the vapor intrusion pathway into buildings; which has been recognized as an important risk pathway at contaminated sites.

During this review, the similarities and differences in specified approaches were compiled and evaluated for prescribed ranges of the principal test variables, including purge rate, purge volume, and sample volume. Information related to equipment and instrumentation, quality control (QC), and field and laboratory methodologies was also considered as it may affect the principle variables. Collected information from the various sources is discussed below and summarized in Table 1.

3.0 SOIL VAPOR MONITORING VARIABLES

Obtaining representative soil gas samples requires consideration of multiple variables associated with physical and hydrogeologic properties of the soil, atmospheric processes, physio-chemical properties of the targeted constituents, and sample collection and analytical methodologies. Physical soil properties that may influence soil vapor measurements include grain-size distribution and the shape and size of soil pores, moisture content (and thus air-filled porosity), temperature, organic carbon content, and microbial influences. Increased clay content decreases pore size, making collection of soil vapor samples slow, if not impossible. Grain-size distribution also affects the size of pores present in a soil sample; e.g., larger pores increase the potential for air transfer. Moisture content reduces the volume of pore space available to maintain air connectivity between pores. Increased organic carbon content increases the sorption of chemicals. Microbial influences can significantly change the soil atmosphere through biological processes, and alter the concentrations and types of chemicals present. These soil properties can, in turn, be affected by hydrogeologic processes such as fluctuating groundwater tables, rainfall, and the transport of volatiles in groundwater or surface water. Atmospheric processes may also influence soil vapor measurements through barometric pressure changes or dilution of subsurface gas via ambient air intrusion.

Chemical and physical properties of the organic compounds include consideration of vapor pressure and boiling point, aqueous solubility, Henry's Law constant, constituent concentration, molecular weight, density, and organic carbon distribution coefficient. Generally speaking, it has been stated that organic compounds that exhibit vapor pressures in excess of 10 mm Hg (at 20° C), or with boiling points less than 150° C are amenable to sampling and detection using soil vapor techniques.

Sampling methods can influence soil vapor measurements via differences in purge rates, purge volumes, sample volumes, the nature of the vapor sampling system installation, type of sampling train used, and the type of sampling container used (e.g., tedlar bags vs. SUMMA canisters). Further, there are several different analytical methods that can be used to analyze soil vapor (e.g., EPA methods TO-14 and TO-15, modified EPA methods SW8015, SW8021, SW8260, etc.). Each of these methods has different sensitivities. In general, air-specific EPA methods (i.e. the "TO" methods) allow for lower detection levels than other methods. However, the "TO" methods can not be readily performed in the field and are generally the most expensive analytical methods. SW-846 methods such as SW8015, SW8021, and SW8260 were specifically developed for the analysis of liquid and solid matrices, but can be readily modified for the analysis of gas matrix samples. These methods will typically provide higher detection levels than the TO methods, but are more suited for the higher concentrations typically observed in soil gas samples, are less expensive, and can be implemented in the field using a mobile laboratory.

It should be noted that the purge rate, purge volume, and sample volume variables are not necessarily independent parameters. Purge rate must be taken into consideration both during dead-space purging (i.e. purging vapor from the in-place sampling system to eliminate ambient air prior to sample collection) and during sampling. The total volume purged from the sampling system is the sum of the dead-space purge and the sample volume; in many cases, the sample volume may be significantly greater than the volume purged to clear the dead-space.

This literature review focuses discussion on the three sampling process variables of sample purge rate, sample purge volume, and sample volume, as discussed below.

3.1 Purge Rate

The purge rate refers to the volume or mass rate of flow at which a gas is extracted for purposes of purging or sampling. The principal issue to evaluate is whether elevated flow rates lead to a difference in soil vapor measurements by causing turbulent mixing and/or desorption from the soils or water. This issue is closely related to applied vacuums during purging as gas flow results from an induced pressure gradient. The impact of this "induced stripping" may vary depending upon the phase of the contamination; that is, dissolved (groundwater), sorbed (soil), or gas (soil vapor), the soil physical properties, and the contaminant.

Purge rate is measured during purging through use of an appropriate calibrated volumetric or mass flow meter attached to the sampling train. Vacuum is also directly measured during purging, using a vacuum gauge or similar device. Incidence of high measured vacuums during purging may be used to qualify the representativeness of the sample. Generally, vacuums approaching 10" Hg (136 inches of water) reflect relatively impermeable soils and may warrant resampling or moving to an alternate location or sampling depth (DTSC/LARWQCB 2003).

The general consensus of the documents reviewed is that purge rates should be minimized to limit potential short-circuiting of the sampling system (introduction of atmospheric air) and to reduce the potential for desorption. Specific recommendations range from 100 to 200 milliliters per minute (ml/min) (e.g., DTSC/LARWQCB 2003, MO-DNR 2005, NJ-DEP 2005, NY-DOH 2005, ITRC In preparation) to 1,000 ml/min (e.g., API 2005, EPA 2006). Golder Associates (2004) recommends a purge rate of 100 to 200 ml/min, and notes that the vacuum should not exceed 10 in-H₂O.

McAlary and Creamer (In Preparation) evaluated the effects of purge rate and volume on sub-slab soil vapor samples with purge rates of 1,000 ml/min and 10,000 ml/min and found no significant impact to detected gasoline range hydrocarbon concentrations. However, this study used soil-gas samples collected from sub-slab engineered fill material that is expected to have much greater gas permeability than many natural soils. In addition, the contamination source was in the immediate surrounding soils and at very high concentrations, creating a large soil vapor volume to draw upon. McAlary and Creamer (In Preparation) observed vacuums of approximately 10 inches of water (in-H₂O) at a purge rate of 10,000 ml/min.

Purge rates should generally be the same during dead-space purging and during sampling. With many low-volume soil vapor sampling systems, the dead-space volume is small relative to the sample volume (e.g., a 6-liter Summa canister), thus, the purge rate during sampling may have greater impact on the representativeness of the sample than the dead-space purge rate.

3.2 Dead-Space Purge Volume

Dead-space purge volume refers to the total volume of gas purged prior to sample collection. Most soil vapor sampling protocols developed over the past few years recognize that large "dead" volumes in sampling trains require correspondingly large purge volumes, leaving little flexibility to address this variable. If a complete mixing regime is assumed, three soil-gas purge volumes will flush out approximately 87 percent of the original air in the tube and four purge volumes will flush out approximately 92 percent of the original air in the tube. Smaller sampling systems using either 1/8-inch or 1/4-inch inert tubing offer much smaller dead volumes. Further, these internal diameters are sufficiently small such that the vapor is likely to move through the tubing almost as plug flow, with very little mixing. In a perfect plug flow scenario, one "dead volume" of the soil vapor probe plus tubing is all that is required before the *in-situ* soil vapor is drawn in to fill the tubing. Limiting dead-space purging requirements increases the likelihood that the sample is representative of a discrete, limited volume

immediately adjacent to the sampling location. When large purge volumes are utilized, the area around the probe that is sampled increases and the sample results may become representative of the “average” conditions within the larger purged area; however the area of influence is not known. In addition, in areas with very little localized vapor phase VOCs or relatively tight soils, it is possible to purge away the “available” VOC vapors, such that a false negative can result.

The general consensus of the documents reviewed is that purge volume should be minimized to increase the likelihood that the collected sample is representative of conditions immediately surrounding the sampling probe and to reduce the probability of short-circuiting the sampling system. However, few of the documents provide specific recommendations for purge volumes. DTSC/LARWQCB (2003) guidance stipulates that a step purge test be conducted by collecting samples after one, three, and seven dead-volumes have been purged. The purge volume that yields the highest concentrations of site contaminants of concern (COCs) should then be used for subsequent samples. In the event that the step test does not yield a definitive result, the DTSC/LARWQCB (2003) default is three volumes. MO-DNR (2005) and NJ-DEP (2005) recommend three volumes be purged prior to sampling. Health Canada (2004), recommends two to three volumes and NY-DOH (2005) recommends one to three volumes.

API (2005) recommends monitoring with a field PID or FID until the purged vapor stabilizes. As an alternative to a default value of three purge volumes, NJ-DEP recommends purging until CO₂ and O₂, as measured with a field instrument, have stabilized. These monitoring methods may or may not reach a stable value depending upon the strength of the contamination source and usually require larger volumes (>1 liter) to be purged.

McAlary and Creamer (In Preparation) collected sub-slab soil vapor samples after purging between 1 and 604 liters from the sampling system. The results for gasoline range hydrocarbons were similar for all samples, and suggested that the purge volume had little effect on sample results, even with extremely large purge volumes. As noted above, McAlary and Creamer (In Preparation) studied the effects of purge volume on vapor samples obtained from high permeability engineered fill material beneath a concrete slab with a nearby and strong source so their findings are likely inapplicable to most typical sites.

3.3 Sample Size

Sample size refers to the volume of soil gas sample to be collected. The principal issues affecting this variable are the required volumes necessary to achieve the desired detection limit using the specified analytical method, which in turn dictates the size and type of container used in the sample collection, and whether there exists a correlation between sample size and the total volume of vapor extracted. For vapor intrusion applications, this is of particular importance because samples are collected close to the soil surface, so there is a chance of breakthrough from the surface if large volumes are collected. In such cases, assessment of breakthrough is typically completed through addition of a tracer gas at the surface adjacent to the probe followed by analysis for the tracer in the collected sample. For site assessment applications, surface breakthrough is less of a concern as samples are usually collected at greater depths (>5 feet below ground surface [ft bgs]).

The documents reviewed provide few recommendations regarding sample volume beyond concerns related to detection levels. There appears to be some consensus that within the constraints imposed by analytical requirements, sample volume should be minimized for the same reasons that purge volume should be minimized. Common sample volumes cited range from 10 to 50 ml collected in glass bulbs or gas-tight syringes to 1-6-liter Summa canisters for TO-14/TO-15 analyses.

In general, larger sample volumes facilitate lower detection levels, and some methods specify particular sample container types (e.g., the TO methods require Summa canisters). For vapor intrusion applications,

the required detection levels for some compounds can only be achieved by the TO methods, and hence larger volumes are required. But for site assessment applications, required detection levels can be met by other methods using smaller volumes.

4.0 CONCLUSIONS

Except for the McAlary & Creamer paper, no published data were identified indicating whether purge flow rate has any effect on soil gas concentrations, and if so, at what levels. In general, the documents reviewed advocate minimizing the purge rate to reduce the potential for short-circuiting and/or desorption; however, few data are available to provide a rationale for specific limits on flow rate. For example, DTSC/LARWQCB (2003) specifies a flow rate of 100 to 200 ml/min, and other agencies (e.g. MO-DNR, NJ-DEP, NY-DOH) have adopted these limits; however, there do not appear to be any data in the published literature that provide a rationale in support of this guidance. A controlled study to quantify the effect of purge flow-rate on sample results is warranted.

Of the documents reviewed, only two published studies exist on the influence of purge volume on soil gas concentrations. Both of these studies showed no effect on soil gas concentrations over purge volumes ranging from approximately 1 to 10 liters (EPA 2006) and 1 to 600 liters (McAlary & Creamer, 2006). Both studies involved sub-slab soil gas samples with extremely different site conditions. No published data exist for deeper soil gas samples collected in more typical site investigation application. Quantification of the effect of changing purge volume and sample volume on soil gas results in a controlled study is also warranted.

Soil-vapor sample size is commonly constrained by detection limit requirements and the selected analytical methods. Therefore, there is less flexibility in this variable, and if sample volume guidance is developed it will need to be couched within the context of project specific analytical method and detection level requirements. Nevertheless, there are no data in the published literature indicating what, if any, effect sample volume has on the analytical results, and a controlled study to evaluate the potential effects is warranted.

The results of this literature review indicate there are few data available in the published literature on the effects of purge rate, purge volume, or sample volume on soil vapor sample results. Much attention has been paid recently to the issue of soil vapor intrusion into indoor air, and this process has been identified as a significant concern at, and adjacent to, many contaminated sites. Thus, there is a critical need for collection of representative, accurate, and defensible soil vapor data in support of hazardous waste site investigations. A carefully designed scientific study of the effects of the key variables discussed here will be an important first step in developing a quantitative understanding of the impact of these variables on sample results, and will be the foundation for developing guidance for use by soil-vapor investigators.

5.0 RECOMMENDATIONS

It is recommended that a well controlled, scientific study be conducted to investigate the effects of purge rate, purge volume, and sample volume on soil-vapor sample results in a "real-world" site setting. In light of the number of variables that may affect soil gas sample results, any rigorous program that is designed to quantify the effect of changing one or more variables on a sample result must hold constant, or as nearly constant as possible, any remaining variables. Thus, the recommended study should have the following attributes:

The site selected for conducting the study should have an effectively homogeneous vadose zone that is amenable to soil vapor sampling (i.e. sufficient permeability).

- Subsurface contamination at the selected site should be well characterized and understood.
- The selected site should have only a limited number of contaminants of concern, and those contaminants should be present in the soil vapor at concentrations that fall within the normal calibration range of the analytical method and equipment selected.
- The study should be conducted during a sustained dry season to eliminate variability associated with rainfall events.
- All sampling probes used for the study should be installed using consistent procedures and equipment.
- All sampling probes should be allowed to equilibrate for a period sufficient to eliminate equilibration time as a variable.
- All sampling should be conducted following the same procedures and utilizing the same equipment.
- All sample analyses should be conducted by a single analytical laboratory using the same analytical method and equipment.

While it is not possible to completely eliminate other variables, and many of the variables associated with soil gas sampling are inter-related (e.g. purge rate and vacuum, purge volume and sample volume), observance of the above conditions can serve to minimize the effects of other variables and facilitate the isolation of the key variables in question.

For the controlled field study, it is important that the method be consistent with the best and most widely used guidance. The base soil gas method we propose to use for this program is the semi-permanent method described by DTSC/LARWQCB (2003) and currently being adopted by many regulatory agencies around the country. This method consists of the burial of a small diameter (either 1/8" or 1/4" OD) inert tube to a target depth with subsequent sampling of the soil gas after a period of time. The sampling tubes will be buried in boreholes created with a direct-push rig. Porous probe tips attached to the tubing will be installed at each prescribed depth interval, centered in 6 inch sand packs and sealed to the surface with bentonite. Soil vapor samples will be withdrawn from the end of the inert tubing using a syringe. Syringe samples will be immediately transferred to the mobile lab for analysis within minutes of collection.

An alternative approach to collecting actual soil gas for the field study is to concentrate the soil gas on an adsorbent. Sample collection on sorbent tubes requires drawing air at a calibrated flow rate through a hollow tube containing adsorbent media over a specified time period. However, a number of disadvantages exist with the adsorbent method. A primary disadvantage is that only one analysis is possible from a tube, with no possibility for a replicate analysis. Other complications are compound breakthrough, sorbent contamination from passive adsorption of VOCs requiring extensive quality control (i.e., duplicates, field blanks, lab blanks), more complicated field procedures, higher sample volumes, and lack of real-time analysis. For these reasons, it is recommended that the field study use direct on-site analysis in a mobile laboratory, following soil gas collection in a syringe, as the base method.

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2006 *Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples*. Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, OH, EPA/600/R-05/147 EPA/540/1-89/002. March

Table 1
Summary of Literature Review Results
Active Soil Vapor Sampling

Document	Method Scope	Purge Rate	Purge Volume	Sample Volume	Other Variables	Comments	Author/Date	Weblink
API Soil Gas Sampling Guidance	Guidance generally discusses active vapor sampling considerations for vapor intrusion applications, although passive samplers and flux chambers are addressed as alternatives. Describes (rather than prescribes) general considerations in sampling design, and addresses various available options while providing the reference associated with each option discussed and the attendant advantages/disadvantages for each option. No single standard method is endorsed.	No specific recommendation. Minimize flow rate and vacuum during sampling. Rates should not exceed 1 L/min. Monitor and record the vacuum during sampling	No specific recommendation. Minimizing the purge volume is appropriate. Purge volume may be based on procedures such as DTSC purge test or monitoring with a PID/FID until stabilization. Purge volume should be the same at all locations.	Document more slanted towards smaller sample volumes using syringes as photos show.		Document focuses on subsurface-vapor-to-indoor-air pathway and petroleum related hydrocarbons.	American Petroleum Institute, November 2005	http://groundwater.epi.org/soilgas/
EPA Sub-slab guidance	Document reports on investigations conducted at 16 separate sites (15 homes, 1 business). Specific methods varied at each site; all were actively sampled. A total of 55 probes installed through basement slabs in 16 buildings, with average of 1 probe every 220 ft ² . Generally, 1 sub-slab probe was centered, while the remaining two were placed 1-2 meters from building walls. "Permanent" probe installation consisted of 1-2" length metal piping embedded in slab. Samples were collected using 6-Liter Summa canisters which collected samples over 1-hour and 24-hour periods. Samples were analyzed for VOCs via TO-15. Also, four radon gas samples were collected using open face activated carbon canisters and analyzed using EPA 402-R-93-004.	6-liter canisters filled (close to atmospheric pressure) in 1 to 2 minutes. 1-liter Tedlar bags filled in approximately 1 minute. Purge rate prior to sample collection generally 1 liter per minute. Concludes that 100 to 200 ml/min sample rate is consistent with theoretical calculations showing little effects due to turbulence.	Sequentially collected five one-liter Tedlar bag samples at a flow rate of 1 standard liter per minute and compared vapor concentration of four VOCs. This was performed at three locations with little effect on sample concentration. Simulations showed that after 5 purge volumes, the exiting vapor concentration was 99 percent of the entering concentration even if vapor concentration inside the sample system had been reduced to zero concentration prior to sampling. One purge volume was typically less than 10 ml. Generally, 2 liters were purged (200 volumes), followed by collection of 1-liter Tedlar bag, followed by 1 liter purge, followed by collection of 5 liters in canister (over 1 to 2 minutes).	1-liter Tedlar bags compared to 5-liter samples in 6-liter canisters with similar results.	6-liter summas and 1-liter tedlars were collected at the same probes with good agreement in results. Equilibration time of 2 hours for sub slab soil (sand) should be sufficient	Document primarily concerned with collection of sub-slab samples.	U.S. Environmental Protection Agency, March 2006	http://www.epa.gov/ada/download/reports/600R05147/600R05147.pdf

Table 1
Summary of Literature Review Results
Active Soil Vapor Sampling

Document	Method Scope	Purge Rate	Purge Volume	Sample Volume	Other Variables	Comments	Author/Date	Weblink
Health Canada 2004	Guidance document that is geared for use by risk assessment professionals for site screening of vapor intrusion applications. General protocols for sampling and analysis of soil vapor are described in Appendix II. Describes (rather than prescribes) general considerations in sampling design, and addresses various available options while providing the reference associated with each option discussed and the attendant advantages/disadvantages for each option. No single standard method is endorsed, other than a recommended purge procedure described in following cells.	Cites recommendations of 1 L/hr to 1 L/min from others. Higher purge rates may increase probability of short circuiting, leaking, or volatilization of light end components. Recommend 100 to 200 ml/min (based on CRWQCB recommendations). Do not exceed vacuum of 10 inches water. Purge rate should be consistent across site. Use same flow rate for sampling and purging.	Cites recommendations of 1 to 5 volumes from others. Minimize purge volume. Recommend purge 2 to 3 volumes, then allow vacuum to dissipate before sampling. Purge volume should be consistent across site.	Should be less than a 6-liter summa. Minimize sample volume	Equilibration time for driven (direct push) probes is a few minutes to hours.	Document is primarily guidance for indoor vapor intrusion. Guidance on sampling protocol provided as Appendix II.	Golder Associates, November 2004	http://www.hc-sc.gc.ca/cwh-scgm/contam/site/proj_pubs/journal_c.html
DTSC/CRWQCB 2003	Guidance applies to active vapor sampling only (passive sampling and flux chamber sampling are not addressed). Guidance specifies soil lithologic logging in selecting locations and depths of sampling points. Soil gas "probes" that are considered acceptable include permanent and semi-permanent, along with soil vapor wells, provided DTSC staff are consulted in advance. Installation methods preclude use of mud rotary drilling technique and discourage the air rotary technique. Direct-push installation requires 20 minutes equilibration time prior to sampling; hollow stem auger (HSA) requires 48 hour equilibration time. Tracer gas for leak check required at 100% frequency. Recommended analytical methods include US EPA methods 8260B, 8021B, and 8015B.	Recommended purge rate of 100 to 200 ml/min. Rates may be modified based on individual conditions encountered.	Conduct step purge-test at one, three, and seven purge volumes. Default volume is three. Additional purge tests should be performed if widely different soils encountered.	Use glass bulbs or syringes wrapped in foil, or Summa canisters. Smaller volume Summas (1L) preferred, but not required.	Equilibration time for semi-permanent probes installed with direct-push is 30 minutes. Equilibration time for HSA boreholes is 48 hours. Prohibits use of Tedlar bags Samples should be analyzed on-site within 30 minutes (extended to 4 hours if surrogates added). 72-hour hold time on Summa canisters	Leak tests should be performed with a tracer gas at all locations.	Department of Toxic Substances Control and California Regional Water Quality Control Board, LA Region, January 2003	http://www.dtsc.ca.gov/LawsPolicies/Policy/SiteCleanup/upload/SMBR_ADV_active_vapor_sampling.pdf

Table 1
Summary of Literature Review Results
Active Soil Vapor Sampling

Document	Method Scope	Purge Rate	Purge Volume	Sample Volume	Other Variables	Comments	Author/Date	Weblink
LUSTLine Bulletin 42	Document opines on issues associated with use of soil gas sampling on the vapor intrusion pathway; scope addresses active soil gas sample collection. Document describes sampling factors which influence soil gas results. Specific recommendations include: collection of samples 5-feet below grade at corner or sides of foundation to identify hot spot(s); step out near hot spot(s) for delineation (assess vertical and lateral distribution); iteratively use J&E model to assess health risk.	Should be limited to avoid turbulent flow and excess vacuum. Cites Cal/EPA guidance of less than 200 ml/min	Cites common use of one to five purge volumes. Recommends purge tests only for sample volumes greater than 500cc	10 to 40 cc for DLs of 100 µg/m ³ Larger volumes (>1,000cc) for DLs of 1 to 10 µg/m ³	Includes brief discussion of ambient temperature, barometric pressure, precipitation, and gravitational effects. Concludes that impacts are generally minor, particularly with deep (> 5 feet bgs) samples	Cites use of Summa canisters, teller bags, and glass or stainless vials	Hartman, Blayne October 2002	http://www.lcgcnv.com/documents/L42.Blayne.pdf
MO-DNR Soil Gas Protocol	Guidance applies to soil gas sampling at petroleum storage tank sites. Guidance does not include sub-slab sampling, and defers such to US EPA guidance. Deviations from this scope must be detailed in work plans submitted to MDNR. Base case: Specify uniform sample depths (minimum 18" below grade); first depth generally at 5-feet followed by a second depth near groundwater; sampling point spacing at 50-feet; sample probe accessed by small diameter tubing (1/8 to 1/4"); probe installation using HSA (48 hr equilibration time) or direct push (30 minutes equilibration time); probe tip installed in center of sand pack extending 6" above and below probe tip; grout between sample points in nested installation; two sampling events minimum per site, spaced at 3 month intervals; tracer gas used for leak check. Recommended analyses include TO-15 or SW-846 Methods 8260B and 8021.	Recommends initial flow rate of 200 ml/min, which can be modified for field conditions. If flow rate exceeds 200 ml/min then data must be flagged.	Purge 3 volumes at flow rate and vacuum similar to sampling conditions.	Recommends 500 ml or 1 L Summas. No recommendations for Tedlar or syringe size	Equilibration time for semi-permanent probes installed with direct-push is 30 minutes. Equilibration time for HSA boreholes is 48 hours. Sample containers should be syringes or Tedlar bags for on-site analysis and Tedlar bags or Summas for off-site analysis. Recommends vacuum of less than 100 inches of water	Leak tests should be performed with a tracer gas at all locations. Guidance appears to be based largely on CRWQCB/DTSC 2003	Missouri Department of Natural Resources April 2005	http://www.dnr.mo.gov/cn/v/hwp/tanks/docs/soil-gas-protocol-2005-04-21.pdf

Table I
Summary of Literature Review Results
Active Soil Vapor Sampling

Document	Method Scope	Purge Rate	Purge Volume	Sample Volume	Other Variables	Comments	Author/Date	Weblink
NJ-DEP Vapor Intrusion Guidance	Guidance applies to soil vapor intrusion investigation in New Jersey State. A generalized description of soil gas sampling methods is contained in Section 6.3.2; specifics are to be proposed in work plans. Sub-slab sampling is addressed in Section 6.4; specifics are drawn from US EPA Guidance (March 2006), and specify embedded pipe segments in floor slab for permanent probes, and 1/8 to 3/8" tubing inserts for temporary probes. Sub-slab sample locations should be centered beneath slab. Indoor air sampling is also discussed along with appropriate analytical methods.	Maximum of 200 ml/min	Purge 3 volumes. Alternative approach is to purge until field parameters (CO2 and O2) have stabilized. Purge volume should be minimized.	Cites 1-liter and 6-liter Summas as the most common, but recommends small sample size.	Holding time for Tedlar bags should not exceed 3 hours. Holding time for a glass bulb is 24 hours	Stipulates that the lab must be certified for an appropriate AIR method, and cites TO-15 as the most common. Discusses sample collection through drive-rods, not semi-permanent sampling points.	New Jersey Department of Environmental Protection, October 2005 (updated March 2006).	http://www.state.nj.us/dep/erp/guidance/vaporintrusion/vig.htm
NY-DOH Soil Vapor Intrusion Guidance	Guidance applies to soil vapor intrusion investigation in New York State. Sample types include soil vapor, sub-slab, indoor air, and outdoor air; all are active samples. Sampling to occur during period of structure heating (November through March), and at one other time for comparison. Sample locations to include vicinity of building foundation, along foundation perimeter, and below foundation at footing depth. Permanent probes are recommended. Probe tip installed in center of sand pack via direct-push or HSA, with 1/8 to 1/4" tubing extending up to grade. Sampling to occur after 24 hours equilibration. Tracer gas used in all samples, tracer gas injected under a ground covering tarp or within enclosure covering sample location. Analytical recommendations include TO-15, NYSDOH Method 311-9.	Maximum of 200 ml/min	One to three volumes. Appears to imply that this should be done only once after probe installation.	Dependent on volume required to meet DLs	Equilibration time of 24 hours for permanent probes is implied. For temporary probes, purging should begin "shortly after installation"	Samples must be collected using "conventional methods" and in "appropriate containers." Requires use of tracer gas to verify an adequate seal, but states that once this has been demonstrated use of the tracer can be reconsidered, but must be at least 10 percent of subsequent samples.	New York State Department of Health, February 2005 (public comment draft)	http://www.health.state.ny.us/nysdoh/gas/svi_guidance/toe.htm
ASTM D4314-92(2001)	Very broad guidance document that includes discussion of methods and materials associated with passive and active soil gas sampling using a variety of sampling, process, and analytical methods; no base case scenario discussed.	NA	NA	NA		ASTM Standard does not speak to purge rate, purge volume, or sample volume.	American Society for Testing and Materials, 1992 (updated 2001)	http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D4314.htm?L+mystore+krq2800+1144733377

Table 1
Summary of Literature Review Results
Active Soil Vapor Sampling

Document	Method Scope	Purge Rate	Purge Volume	Sample Volume	Other Variables	Comments	Author/Date	Weblink
McAlary & Creamer	Paper researching purge rate and purge volume on sample result for sub-slab vapor sample collection. Standard method used was accessing existing sub-slab probes for high volume purging and sampling; helium was used as tracer during purging; samples collected in Tedlar bags for field analysis (oxygen, carbon dioxide, and VOCs (using PID)), and for lab analysis of gasoline range hydrocarbons using TO-3.	Purged discrete samples at <150 ml/min. Followed by study of purge rate and volume effects with purge rates of 1 L/min and 10 L/min	Purged approximately 0.7 L for discrete samples, volume of sample system deadspace not specified. Purged up to 600 L for study of purge rate and volume effects.	Not specified	Vacuum at 1 L/min purge rate was ~1 inch H ₂ O. Vacuum at 10 L/min was ~10 inches H ₂ O.	Study evaluated results for C5 to C10 hydrocarbons in soil vapor sampled from subslab engineered fill material. Goal was to compare the mean results from a number of "discrete" (low purge rate, low purge volume) samples to "representative elemental volume" samples expected to be representative of average subslab conditions (high purge rate, high volume).	McAlary, T. and Creamer, T., in preparation	NA
ITRC Vapor Intrusion Guidance	Guidance document that is geared for use by regulators, consultants, and stakeholders for assessing the vapor intrusion pathway. Protocols for sampling and analysis of soil vapor are described in an Appendix. Describes (rather than prescribes) general considerations in sampling design, and addresses various available options, while providing the reference associated with each option discussed, and the attendant advantages/disadvantages for each option. No single standard method is endorsed, other than a recommended purge procedure.	References 200 ml/min standard required by most agencies.	Recommends minimum of three to four purge volumes. Purge volume test optional.	Volumes <1 liter recommended for shallow (<3' bgs) samples.	References most agencies require vacuums less than 15 percent of atmospheric (5 in Hg).	Document going through final review, but criteria listed here unlikely to change.	ITRC Vapor Intrusion Team, in preparation	www.itrcnet.org

Appendix B
Sampling Trip Report

SAMPLING TRIP REPORT

for

DEVELOPMENT OF ACTIVE SOIL GAS SAMPLING METHOD

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**EPA Contract #EP-C-05-061
Task Order No. 5**

November 2006

Prepared for:

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1.0 INTRODUCTION

This Trip Report provides a summary of the sampling activities that were conducted between October 10 and October 18, 2006 at Vandenberg Air Force Base (AFB) Installation Restoration Program (IRP) Site 15. The sampling was conducted on behalf of the U.S. Environmental Protection Agency (EPA), Office of Research and Development, in support of the project titled *Development of Active Soil Gas Sampling Method*, conducted under EPA Contract Number EP-C-05-061, Task Order Number 5 (TO-05).

Vandenberg AFB is located on the south-central coast of California, approximately halfway between San Diego and San Francisco. The base covers approximately 98,000 acres in western Santa Barbara County and is headquarters for the 30th Space Wing. IRP Site 15 consists of three coffin-type missile launchers that were used to launch Atlas missiles from 1960 to 1967. Site 15 is located immediately southeast of the intersection of Umbra and Tethys Roads, on north Vandenberg AFB (Figure 1). The survey site consists of an open area of sand dunes directly south of Building 1833 (Figure 2).

The project field team included environmental consultants from Tetra Tech, Inc. (James Elliot, David Springer, Michele Mykris, and Joachim Eberharter), technicians from H&P Mobile Geochemistry (Tamara Davis, Blayne Hartman, and Dave Balkenbush), and drill rig operators from Interphase Environmental, Inc. (Erik Alvarez and Danny Alvarez). Observers on site during the study included Mike Martin (EPA), Andy Edwards and Pablo Martinez (Vandenberg AFB IRP), Kathy Gerber (Air Force Center for Environmental Excellence), Linda Stone (Regional Water Quality Control Board) and Matt Peterson and Paul LeCheminant (Tetra Tech). Personnel from Tetra Tech, H & P, and Interphase arrived at the survey site on Tuesday October 10. Field work continued through October 18 and included exploratory drilling, soil-gas probe installation, and soil gas sampling and analysis. Photographs of the field effort are provided in Appendix A.

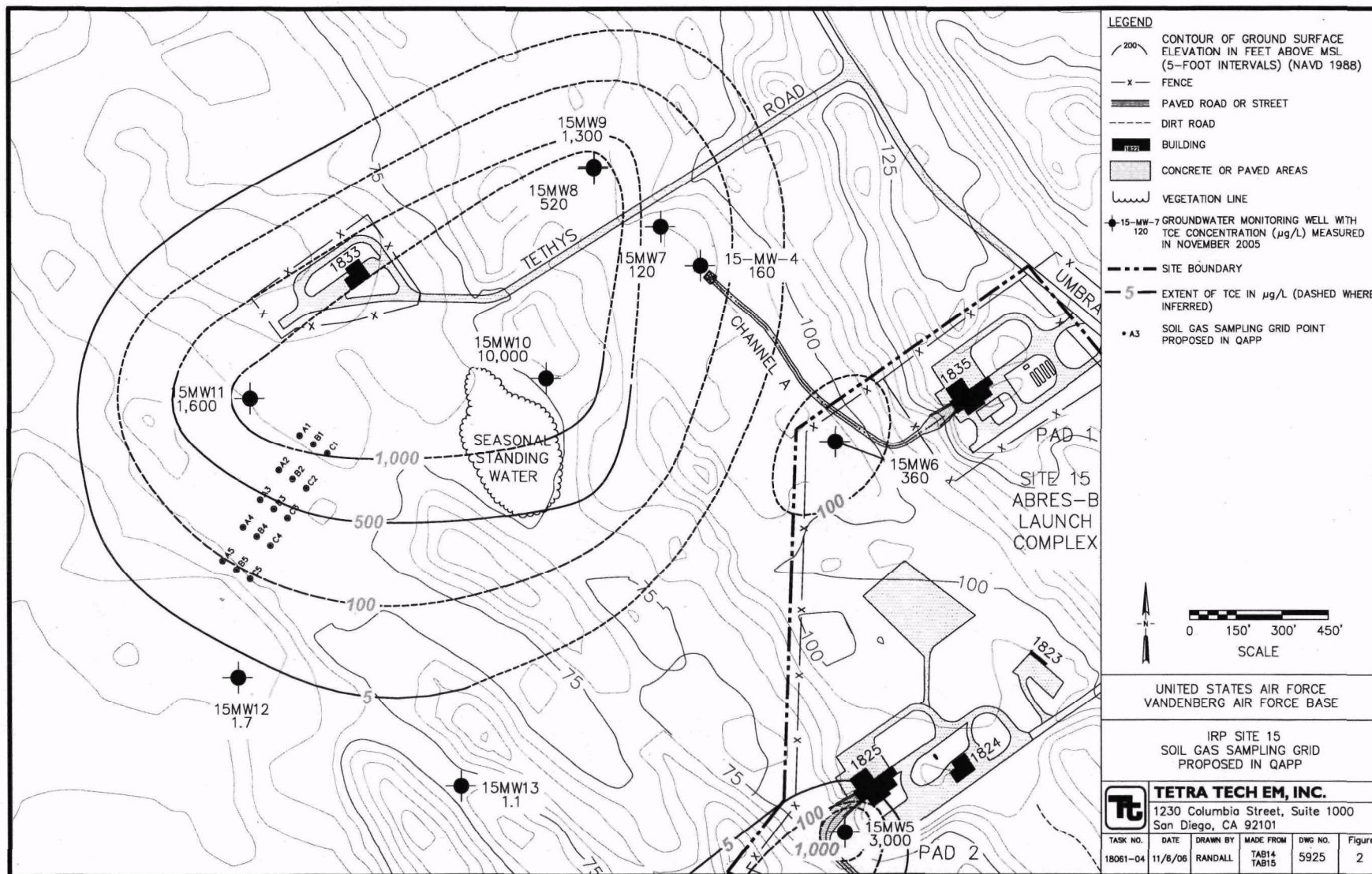
2.0 WEEK ONE: DRILLING AND PROBE INSTALLATION

For clarity, the following nomenclature is used in discussing the field effort. The term "temporary sampling point" is used to refer to soil gas sampling locations that were installed with the intention of sampling only once to qualitatively assess the concentrations of soil gas present. The term "soil gas probe" is used to refer to sampling locations that were constructed according to the guidelines presented in the Quality Assurance Project Plan (QAPP) and that were installed with the intention of sampling as part of the method development testing.

Exploratory Drilling and Grid Planning

The objective of the first phase of the field investigation was to identify a suitable area of Site 15 to install the soil-gas probe grid. The strategy used was to collect soil gas samples from temporary sampling points in geoprobe borings and then use the information obtained for subsequent borehole/sampling point placement, until an appropriate area was identified to install the semi-permanent probe grid. A total of 17 boreholes were drilled and sampled during this effort, over a 1.5-day period.

The first week of the field study began on Tuesday, October 10. The project field team began work with exploratory drilling and probe location planning. Mr. James Elliot, Site Superintendent, was primarily responsible for field coordination and was assisted by Michele Mykris. Ms. Tamara Davis, analytical chemist, operated all mobile lab instruments and collected soil gas samples. Erik Alvarez and Danny Alvarez, drill rig operators with InterPhase, were responsible for operating the 6610DT GeoProbe direct push drill rig (Appendix A: Photograph 1). A drill rig mounted on tracks was chosen for this project due its maneuverability on sand dunes where traditional four-wheel-drive trucks are not practical.



Site field operations began with the measurement of groundwater elevation at the existing monitoring wells 15MW11 and 15MW12 (Figure 2). At well 15MW11, groundwater was encountered at approximately 18.5 feet below ground surface (bgs). Groundwater in well 15MW12 was approximately 22.4 feet bgs.

Trichloroethene (TCE) concentrations in groundwater at IRP Site 15 have been investigated through the Vandenberg IRP and the groundwater plume is reasonably well understood. Figure 2 shows groundwater TCE concentrations contours, based on data collected in November 2005, which were used to identify the approximate location for the soil gas sampling grid, as proposed in the QAPP. However, no previous soil gas samples had been collected in the specific area of Site 15 proposed for this investigation; therefore, a preliminary soil gas survey was necessary to gather soil gas data and optimize placement of the sampling grid. Using the proposed soil gas probe location map prepared for the QAPP, temporary sampling points were placed at locations A1 and C1 (Figure 2, Appendix A: Photograph 2). Locations A1 and C1 were drilled to a depth of 18 feet bgs in an attempt to sample soil gas directly above the water table. The targeted sampling depths were selected based on the depth to groundwater at well 15MW11 and the estimated difference in surface elevation between well 15MW11 and the boring locations. Temporary sampling points were placed at the bottom of each boring by placing an expendable steel drive point on the drill rod, drilling to the target sampling depth, threading 1/4-inch Nylaflo tubing onto the expendable drive point, and pulling the drill rod up approximately 6 to 12 inches leaving the drive tip in place. After allowing 30 minutes for re-equilibration, soil gas samples were collected from the temporary sampling points and analyzed for TCE, *cis*-1,2-dichloroethene (DCE), and *trans*-1,2-DCE by the on-site mobile laboratory operated by H&P Mobile Geochemistry. The results for samples A1 and C1 were non-detect (ND) for all three compounds. Step-out locations were completed to the north of locations A1 and C1 and to the south of locations A5, and C5. Results for soil gas samples collected from south of locations A5 and C5 were ND; however, the samples collected north of locations A1 and C1 contained TCE at concentrations ranging from 120 to 210 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). Based on these results, it was determined that subsequent soil gas sampling would focus on areas to the north of the grid proposed in the QAPP, where higher groundwater concentrations were known to exist and where detectable levels of TCE were present in soil gas.

Additional borings were completed at locations near 15MW11 and in areas to the northeast of the QAPP sampling grid. Results for soil gas samples collected from these borings ranged from ND to $400 \mu\text{g}/\text{m}^3$ for TCE. A temporary sampling point was left in the ground overnight at a location approximately 350 feet northeast of location B1, where a TCE concentration of $300 \mu\text{g}/\text{m}^3$ was measured; other sampling points were abandoned after initial sampling results were recorded.

On October 11, project personnel returned to the Site and resampled the point that had been left in the ground overnight. TCE was measured at a concentration of $3,300 \mu\text{g}/\text{m}^3$. This point was resampled twice more throughout the day, with results of $5,500$ and $2,000 \mu\text{g}/\text{m}^3$ for TCE. Based on these observations, it became apparent that while the concentrations obtained on the previous day (October 10) were relatively low, the relatively low measured concentrations may have been due to the short time between sampling point installation and sample collection.

Additional exploratory borings at location B1 and areas to the north were advanced on October 11. Temporary sampling points were installed in each boring, and were allowed to equilibrate while other borings were advanced. Results from location B1 were ND; however, results from three borings to the south of Building 1833 ranged from 940 to $2,300 \mu\text{g}/\text{m}^3$ for TCE.

Semi-Permanent Soil-Gas Probe Installation

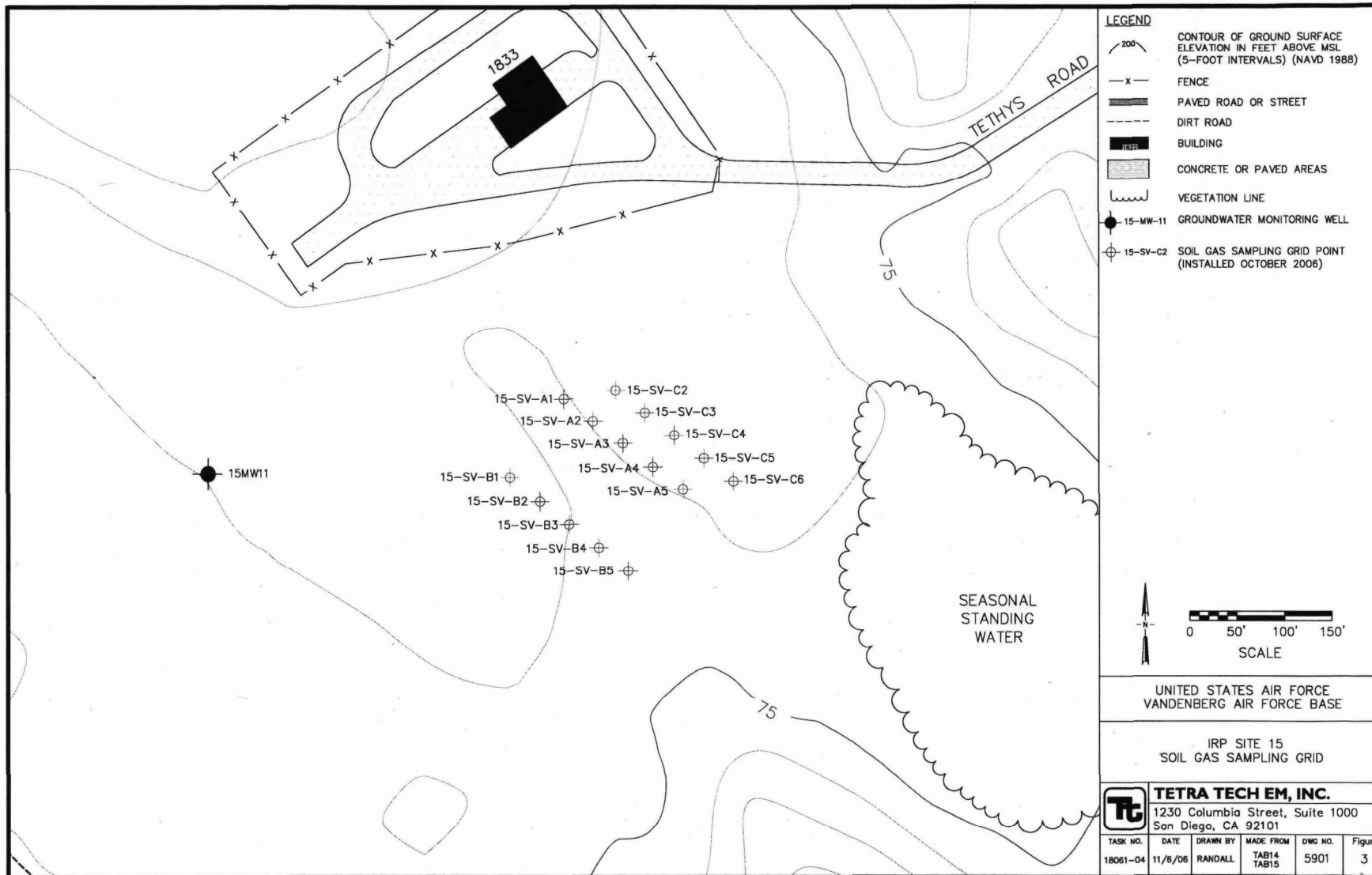
Based on preliminary soil gas results, it was determined that soil gas concentrations were highest in an area to the northeast of the grid location proposed in the QAPP, south of Building 1833, and northwest of the area of seasonal standing water shown on Figure 2; therefore, the semi-permanent probe grid was developed within this area.

After identifying the final grid area and orientation, five probes for the Site 15 "A" tract were installed on October 11 and 12 with a spacing of 40 feet between each probe along a bearing of N50°W (to parallel the orientation of sand dune swales) (Figure 3, Appendix A: Photograph 3). The A tract probes were designated 15-SV-A1 through 15-SV-A5. The "B" and "C" tracts were completed on October 12. The five tract "B" probes were completed along the same bearing and with the same spacing as tract A, but the tract was located 100 feet to the south-southwest. Tract B probes were designated 15-SV-B1 through 15-SV-B5. Tract C probes were completed with the same bearing and spacing as tract A, but the tract was located 40 feet to the north-northeast of tract A (Appendix A: Photograph 4). The tract C probes were offset by 40 feet to the southeast and were designated 15-SV-C2 through 15-SV-C6. The latitude and longitude of each installed probe is summarized in Table 1 and the locations are plotted on Figure 3. One probe location within each tract was continuously cored using acetate soil sleeves in order to log the subsurface lithology. These locations were 15-SV-A1, 15-SV-B3, and 15-SV-C5 (Appendix A: Photographs 5 and 6).

Most pilot holes were advanced to the planned depth, which ranged from 14 to 19 feet bgs, as needed to position the sampling probes a targeted distance of 2 to 4 feet above the groundwater table (Table 1). Pilot holes for probes 15-S-A1, 15-SV-B3, and 15-SV-C5 were installed to depths of 24, 24, and 22 feet bgs, respectively, for soil logging purposes, and then backfilled with 2/12 sand to the planned probe depth.

Sampling probes were constructed as follows. Approximately 4 inches of 2/12 sand was poured into the bottom of the borehole. A 1-inch long gas-permeable membrane sampling probe, attached to 1/4-inch Nylaflow tubing, was then lowered through the drill rod to the top of the 2/12 sand. Additional 2/12 sand was then poured around the sampling probe until it extended approximately 2 inches above the membrane to comprise a sand pack. Approximately 12 inches of dry bentonite was then placed on top of the sand pack, followed by hydrated bentonite to the surface. The sampling probes were completed at the surface with approximately 18 inches of Nylaflow tubing extending out of the borehole and with a Swagelok valve inserted at the end of the tubing to seal it. The surface completions were protected with 3-inch diameter acrylonitrile butadiene styrene (ABS) plastic pipes with slip-cap covers. The procedure for installing the soil gas sampling probes was repeated at all of the borings. Borings that were drilled deeper than the intended probe installation depth were backfilled with sand to the target probe depth. In these borings, sand packs were recorded as the total length of the sand from the bottom of the boring to a depth approximately 2 inches above the soil gas probe (Table 1).

All 15 soil gas probes were sampled on October 12 (no less than 30 minutes after installation) and analyzed for TCE, *cis*-1,2-DCE, and *trans*-1,2-DCE. Probes were purged at a rate of 200 milliliters per minute (ml/min) to a total volume equal to three times the system volume. A 60 milliliter (ml) sample was then collected using a syringe. Soil gas probe installation data and the October 12 sample results are presented in Table 1. TCE was the only compound detected in any of the samples; no *cis*- or *trans*-1,2-DCE was detected.



LEGEND

- 200' CONTOUR OF GROUND SURFACE ELEVATION IN FEET ABOVE MSL (5-FOOT INTERVALS) (NAVD 1988)
- X FENCE
- PAVED ROAD OR STREET
- DIRT ROAD
- 1833 BUILDING
- CONCRETE OR PAVED AREAS
- VEGETATION LINE
- 15-MW-11 GROUNDWATER MONITORING WELL
- 15-SV-C2 SOIL GAS SAMPLING GRID POINT (INSTALLED OCTOBER 2006)



0 50' 100' 150'
SCALE

UNITED STATES AIR FORCE
VANDENBERG AIR FORCE BASE

IRP SITE 15
SOIL GAS SAMPLING GRID



TETRA TECH EM, INC.
1230 Columbia Street, Suite 1000
San Diego, CA 92101

TASK NO.	DATE	DRAWN BY	MADE FROM	DWG NO.	Figure
18061-04	11/8/06	RANDALL	TAB14 TAB15	5901	3

Table 1
Soil Gas Probe Installation Details

Location	Installation Date	Coordinates (latitude and longitude)	Probe Depth (feet bgs)	Length of Sandpack (inches)	System Volume (ml)	October 12 TCE Result ($\mu\text{g}/\text{m}^3$)
15-SV-A1	October 11, 2006	34.79330957, -120.6015641	17.5	84	70	260
15-SV-A2	October 11, 2006	34.79325593, -120.6014622	16.5	12	66	1400
15-SV-A3	October 12, 2006	34.79318619, -120.6013549	17	6	68	1700
15-SV-A4	October 12, 2006	34.79313254, -120.6012423	17	6	68	840
15-SV-A5	October 12, 2006	34.79306817, -120.6011296	17	6	68	490
15-SV-B1	October 12, 2006	34.79308963, -120.6017573	17	6	68	120
15-SV-B2	October 12, 2006	34.79301453, -120.6016553	17	6	68	140
15-SV-B3	October 12, 2006	34.79296088, -120.6015534	18	58	72	720
15-SV-B4	October 12, 2006	34.79289115, -120.6014461	18.5	6	74	430
15-SV-B5	October 12, 2006	34.79283214, -120.6013388	19	6	76	120
15-SV-C2	October 12, 2006	34.79336321, -120.6013764	14	6	56	1600
15-SV-C3	October 12, 2006	34.79328275, -120.6012691	15.5	6	62	2300
15-SV-C4	October 12, 2006	34.79322374, -120.6011564	15.5	6	62	2400
15-SV-C5	October 12, 2006	34.793154, -120.6010652	15.5	20	62	420
15-SV-C6	October 12, 2006	34.79308963, -120.6009472,	15	6	60	660

Notes:

bgs – below ground surface
 $\mu\text{g}/\text{m}^3$ – micrograms per cubic meter
ml – milliliters
TCE – trichloroethene

3.0 WEEK TWO: SAMPLE COLLECTION

Analytical data collected during the first week of sampling were considered screening level data only and were therefore not subject to careful quality control (QC) review. Analytical data collected during the second week are considered the quantitative data upon which the results of this investigation will be based. These data are currently under QC review and are therefore considered draft data and are not presented in this report. All of the analytical data will be presented in the final project report.

Baseline Sampling

During the second week of the field study, the Tetra Tech field team (James Elliot, David Springer, and Joachim Eberharter) were responsible for field coordination. H&P Mobile Geochemistry personnel (Tamara Davis, Blayne Hartman, and David Balkenbush) operated all mobile lab instruments and collected all soil gas samples (Appendix A: Photographs 7 and 8). The first day of sampling (Monday October 16) began with baseline sampling of all of the probes installed during the prior week. Sample probes were purged at a rate of 200 ml/min to a total volume equal to three system volumes. The system volume was considered the volume of the 1/4-inch Nylaflow tubing plus the volume of the probe, and was calculated using 4 ml per foot as the tubing volume. System volumes for each probe are shown on Table 1. The sample volume for all baseline samples was 60 ml. Results of the October 16 baseline sampling will be included in the final report.

Purge Rate Test

The sampling test to explore the affect of purge rate on analytical results was performed on October 16. All samples for the test were collected from the five probes installed along the B tract (Figure 3). The B tract was selected because the baseline sampling indicated a broad range of TCE concentrations are present along this tract. Purge volumes were equal to three system volumes for each individual probe. According to procedures outlined in the QAPP, three system volumes were purged from each probe for each sample collected. Each of the probes was first purged at a rate of 100 ml/min, followed by purging each probe at rates of 200 ml/min, 500 ml/min, 1,000 ml/m, and 2,000 ml/min. Purging at 100 and 200 ml/min was performed using a syringe. Purging at faster rates was performed using a portable, battery operated pump (Appendix A: Photograph 9). After purging, 60 ml samples were collected from each probe using a syringe.

With time available at the end of the first day of sampling, additional variations were tested. Two samples each were collected from probes 15-SV-B1 and 15-SV-B3 using the pump to purge at a rate of 5,000 ml/min. For the first sample, the probes were purged for 6 seconds, or approximately seven system volumes. For the second sample, the probes were purged for 3 minutes, or approximately 200 system volumes. These samples were collected to assess the impacts of using an excessive purge rate and a total purge volume that is well above industry standards and considered likely to stress the system.

Purge Volume Test

The sampling test to explore the effect of purge volumes on analytical results was performed on October 17. Internal discussions following the purge-rate test the previous day led to the determination that the sampling locations should be chosen randomly rather than selecting an individual tract for conducting the tests. Therefore, five randomly selected probes were chosen for the purge volume test: 15-SV-B1, 15-SV-B4, 15-SV-A2, 15-SV-A4 and 15-SV-C4. In accordance with the procedures outlined in the QAPP, probe 15-SV-B1 was purged to 1, 2, 3, 6 and 10 system volumes with 60 ml samples collected after each purge interval. Purging and sampling was conducted in sequence by tracking the cumulative purge volume, which consists of the volume purged and released from the system plus the volume of each

sample collected (e.g. 15-SV-B1 has a system volume of 68 ml, thus 68 ml were purged followed by collection of a 60 ml sample [the 1-purge-volume sample] followed by purging of an additional 8 ml and collection of the next 60 ml sample [the 2-purge-volume sample]). Analytical results appeared to show a step in detected soil gas concentrations between 3 and 6 purge volumes; therefore, the next two probes (15-SV-B4 and 15-SV-A2) were sampled after purging 1, 2, 3, 4, 5, 6 and 10 system volumes. In addition, probe 15-SV-A2 was sampled after purging 20 system volumes. Analytical results from 15-SV-B4 and 15-SV-A2 suggested a step in soil gas concentrations between 6 and 10 purge volumes. For this reason, a sample was collected after purging 8 and 20 system volumes at subsequent probes (15-SV-A4 and 15-SV-C4). An additional sampling test was performed at 15-SV-A4 to test a large volume purge, well above industry standard purge volumes. The probe was purged for one hour at a rate of 5,000 ml/m, or approximately 4,000 purge volumes, and then sampled.

As stated above, all fifteen semi-permanent probes were installed at depths approximately 2 to 4 feet above the water table. During the testing, it was postulated that the reason for the apparent step in soil gas concentrations observed at higher purge volumes might be that the radius of influence around the sampling probe was intersecting the capillary fringe and altering the flow dynamics. To test this hypothesis, a boring was drilled using an electric rotohammer to a depth of 5 feet bgs at a location approximately 2 feet southeast of probe 15-SV-C4. A temporary probe was installed at 5 feet bgs and the system was purged to 1, 2, 3, 6, 10, 20, and 120 system volumes; samples were collected after each purge. The rationale was that with a probe set at only 5 feet bgs, it was unlikely that the sphere of influence would intersect the capillary fringe and, therefore, the step in concentrations would not be observed. The analytical results suggest a step may have been observed between 20 and 120 system volumes; however, it remains to be determined if the apparent step is statistically significant.

Sample Volume Test

The sampling test to explore the affect of sample volume on analytical results was performed on October 18. Samples were collected from five randomly selected probes: 15-SV-A1, 15-SV-B2, 15-SV-B3, 15-SV-C2 and 15-SV-C5. In accordance with the procedures outlined in the QAPP, each probe was first purged at a rate of 200 ml/min to a volume equal to three system volumes. Five different sample volumes were collected from each probe: 25, 60, 500, 1,000 and 6,000 ml. The 25 and 60 ml samples were collected in 60 ml syringes. The 500 and 1,000 ml samples were collected in 1-liter Tedlar bags. Six-liter SUMMA canisters were used to collect the 6,000 ml samples (Appendix A: Photograph 10).

4.0 FIELD QUALITY CONTROL

Beginning on the first day of quantitative sample collection (October 16), location 15-SV-A3 was designated as the control probe. Samples were collected from this probe three to four times a day throughout test sampling to monitor potential temporal variations in soil gas concentrations unrelated to the principal parameters of purge rate, purge volume, and sample volume. Each sample from 15-SV-A3 was collected using the base settings of the principal parameters under investigation (i.e., purge rate of 200 ml/min, purge volume of three system volumes, and sample size of 60 ml).

Field replicate samples were collected from the control probe, 15-SV-A3, from 15-SV-C4 during the purge volume test, and from 15-SV-A1 and 15-SV-C5 during the sample volume test. Replicate samples were collected to measure the reproducibility and precision of the total sampling system. Field replicates were collected at a rate of approximately one replicate for every 10 QAPP specified field samples.

Leak tests were performed at two probe locations to monitor the integrity of the probe system and surface seals. Leak tests consisted of placing a rag soaked in isopropyl alcohol (IPA) around the Nylaflow tubing at the surface. Leak checks were performed at locations 15-SV-A4 and 15-SV-C4 during the purge

volume test. The leak test was performed at 15-SV-C4 throughout the purge volume test sampling at this location. The leak test was performed at 15-SV-A4 while the probe was purged at 5,000 ml/min for 1 hour (approximately 4,000 purge volumes). No IPA was detected in any of the samples associated with the leak checks. The absence of detectable IPA in any of the samples, particularly the sample obtained from 15-SV-A4 under extreme purging conditions (5,000 ml/min for one hour) indicated the sample probes were well sealed and no intrusion of ambient air was occurring. Based on these findings, use of leak test chemicals was discontinued for the remainder of the program.

5.0 HEALTH AND SAFETY

Each field team member was required to sign a form acknowledging they had received and understood the site-specific health and safety plan. Each day of field work began with a Tailgate Health and Safety meeting followed by equipment checking and preparation. The daily health and safety meetings were conducted by the Tetra Tech site supervisor and covered site-specific health and safety concerns (including physical, chemical, and biological hazards).

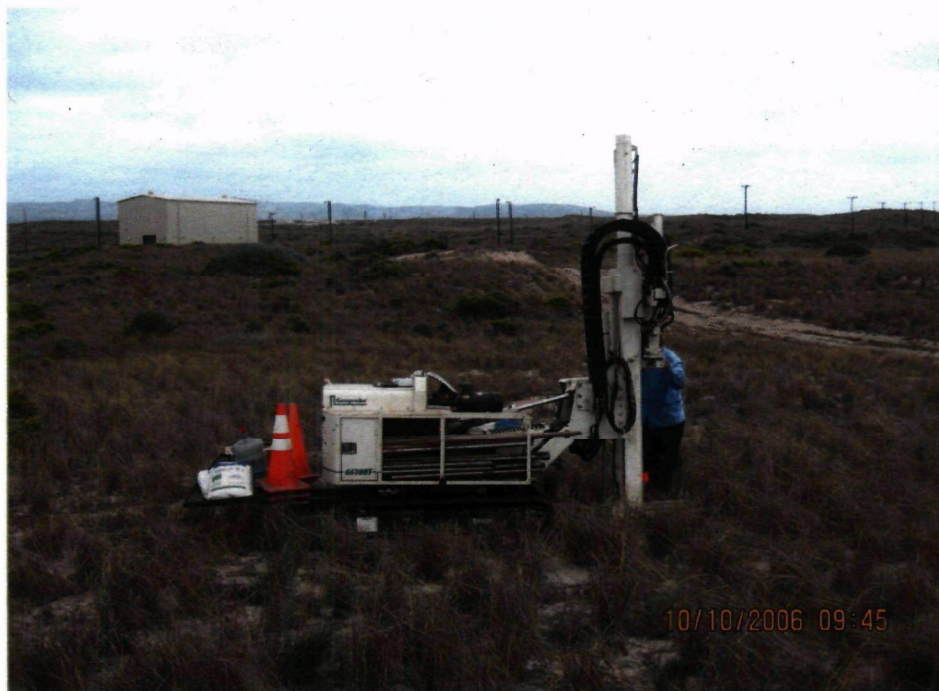
A hand held MiniRAE photoionization detector (PID) was used throughout the two weeks of field work to monitor for potential volatile organic compounds (VOCs) in the ambient breathing space air. The MiniRAE PID did not indicate the presence of any VOCs elevated above background at any time.

There were no accidents or other health and safety incidents during the field program.

APPENDIX A SITE PHOTOGRAPHS



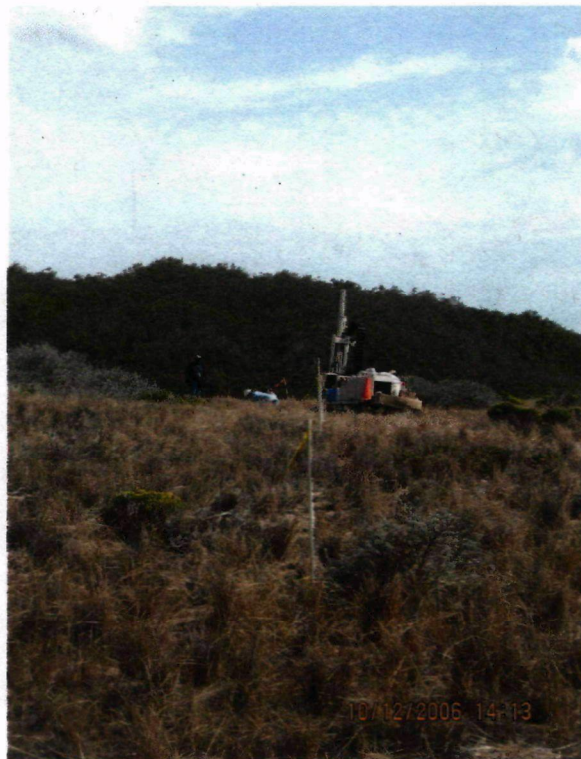
Photograph 1 – Geoprobe 6610DT track mounted direct push drill rig.



Photograph 2 – Drilling at location C1



Photograph 3 – “A” Tract soil vapor probes.



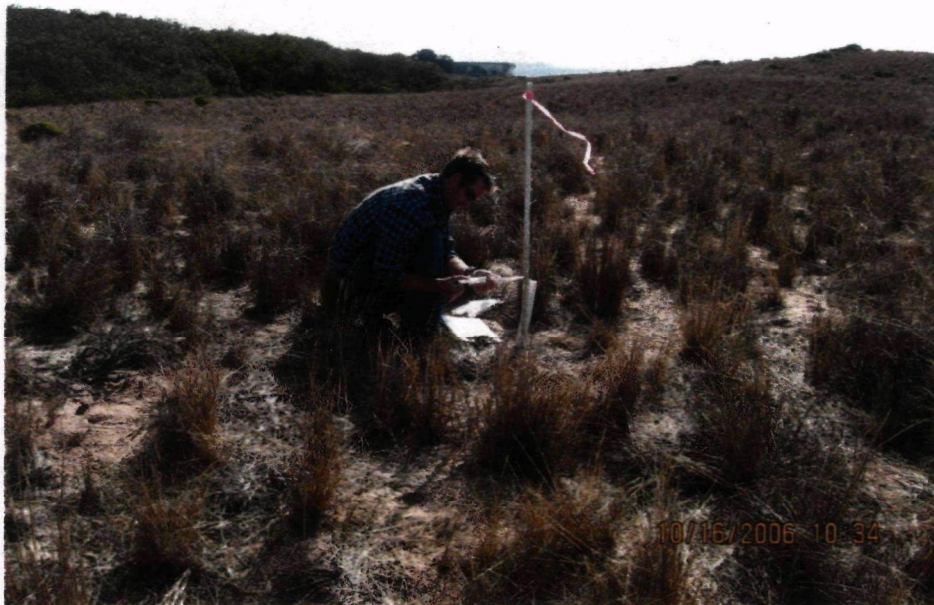
Photograph 4 – Installation of “C” Tract probes



Photograph 5 – Soil cores from 15-SV-A1. Soils increase in depth from right to left and from bottom to top of field of view. Each acetate sleeve is 4 feet long. Soils from greater depths are darker due to higher moisture content; soil type and composition is homogeneous throughout borehole.



Photograph 6 – Close-up of soil cores from 15-SV-A1.



Photograph 7 – Sampling at 15-SV-B5



Photograph 8 – Gas chromatograph used for study.



Photograph 9 – Sampling using battery operated pump to purge and 60 ml syringe for sample collection.



Photograph 10 – Sampling using a 6-liter SUMMA canister.

Appendix C

Laboratory Data Package

October 30, 2006

Mr. Greg Swanson
Tetra Tech EMI Inc.
1230 Columbia Street
10th Floor, Suite 1000
San Diego, CA 92101

**SUBJECT: DATA REPORT – IRP SITE 15 STREAMS – VANDENBERG AFB, CA –
TETRA TECH EMI PROJECT #06LW-P0013**

H&P Project # TT101006-L5

Mr. Swanson:

Please find enclosed a data report for the above referenced location. Vapor samples were analyzed on-site in H&P's mobile laboratory.

Project Summary

The following analyses were conducted:

- 202 vapors for TCE by EPA Method 8021

The samples were received on-site in appropriate containers with appropriate labels, seals, and chain-of-custody documentation.

Project Narrative

The results for all analyses and required QA/QC analyses are summarized in the enclosed tables. All calibrations, blanks, surrogates, and spike recoveries fulfill quality control criteria. No data qualifiers (flags) apply to any of the reported data.

H&P Mobile GeoChemistry appreciates the opportunity to provide analytical services to Tetra Tech EMI Inc. on this project. If you have any questions relating to this data or report, please do not hesitate to contact us.

Sincerely,


Dr. Blayne Hartman





TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
A1	10/10/06	11:15	ND
C1	10/10/06	11:15	10
A5-1	10/10/06	11:53	ND
C5	10/10/06	11:53	ND
C1-1	10/10/06	12:40	210
C1-1 dupe	10/10/06	12:40	230
15M211	10/10/06	13:08	ND
C1-2	10/10/06	14:24	10
A1-1	10/10/06	15:10	180
A1-1 dupe	10/10/06	15:10	120
B1-1	10/10/06	15:44	460
B1-1 dupe	10/10/06	15:44	380
B1-2	10/10/06	16:10	230
C1-2B	10/10/06	16:10	15
B1-3	10/10/06	16:40	200
B1-3 dupe	10/10/06	16:40	200
A1-2	10/10/06	17:16	400

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
B1-1	10/11/06	8:21	3,300
A1-4	10/11/06	8:57	2,100
A1-3	10/11/06	9:18	940
B1-4	10/11/06	9:36	1,800
C-5	10/11/06	10:02	170
A5-1	10/11/06	10:02	32
B-1	10/11/06	11:37	ND
B1-1 R	10/11/06	12:10	5,500
15-SV-A-1	10/11/06	16:50	110
15-SV-A-2	10/11/06	16:55	770

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
B-1	10/12/06	8:05	ND
B-1-1	10/12/06	8:05	6,400
B-1-1 dupe	10/12/06	8:05	6,000
A5-1	10/12/06	8:30	ND
B-3	10/12/06	8:35	ND
C5-1	10/12/06	8:20	ND
B1-5	10/12/06	8:40	230
15-SV-A1	10/12/06	9:20	260
15-SV-A2	10/12/06	9:21	2,000
15-SV-A3	10/12/06	9:22	2,050
15-SV-A4	10/12/06	10:00	1,000
15-SV-A5	10/12/06	10:00	490
A5-1	10/12/06	11:40	ND
C5-1	10/12/06	11:41	ND
B-3	10/12/06	11:42	ND
15-SV-B4	10/12/06	11:45	430
15-SV-B3	10/12/06	11:46	720
15-SV-B5	10/12/06	12:50	120
15-SV-B2	10/12/06	12:51	150
15-SV-B1	10/12/06	12:52	120
B-1-1 resample	10/12/06	13:15	7,000
15-SV-C4	10/12/06	15:45	2,800
15-SV-C5	10/12/06	15:45	420
15-SV-C6	10/12/06	16:10	660
B-1-1 resample	10/12/06	16:12	4,500
B-1-1 resample dupe	10/12/06	16:12	4,500
15-SV-C3	10/12/06	16:40	2,650
15-SV-C2	10/12/06	16:41	1,800

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
B1-BL	10/16/06	10:03	93
B2-BL	10/16/06	10:10	500
B3-BL	10/16/06	10:20	1,350
B4-BL	10/16/06	10:28	590
B5-BL	10/16/06	10:39	100
A1-BL	10/16/06	10:47	210
A2-BL	10/16/06	10:52	1,200
A3-BL	10/16/06	10:59	2,100
A4-BL	10/16/06	11:09	890
A5-BL	10/16/06	11:17	510
C2-BL	10/16/06	11:24	2,000
C3-BL	10/16/06	11:31	1,400
C4-BL	10/16/06	11:38	1,700
C5-BL	10/16/06	11:46	350
C6-BL	10/16/06	11:54	670
A3-BL 1200	10/16/06	12:04	2,500
B2-BL 1200	10/16/06	12:14	470
B1-PR100	10/16/06	12:27	63
B2-PR100	10/16/06	12:35	480
B3-PR100	10/16/06	12:44	1,400
B4-PR100	10/16/06	12:50	540
B5-PR100	10/16/06	12:56	94
B1-PR200	10/16/06	13:06	120
B2-PR200	10/16/06	13:17	490
B3-PR200	10/16/06	13:12	1,450
B4-PR200	10/16/06	13:47	690
B5-PR200	10/16/06	13:53	120

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
B1-PR500	10/16/06	16:13	120
B2-PR500	10/16/06	14:20	520
B3-PR500	10/16/06	14:27	1,700
B4-PR500	10/16/06	14:33	760
B5-PR500	10/16/06	14:40	150
B1-PR1000	10/16/06	14:54	120
A3-BL 1500	10/16/06	15:03	1,600
B2-PR1000	10/16/06	15:10	700
B3-PR1000	10/16/06	15:18	1,700
B4-PR1000	10/16/06	15:24	800
B5-PR1000	10/16/06	15:30	150
B1-PR2000	10/16/06	15:44	130
B2-PR2000	10/16/06	15:50	660
B3-PR2000	10/16/06	15:55	1,800
B4-PR2000	10/16/06	16:02	960
B5-PR2000	10/16/06	16:08	140
B1-PR5000	10/16/06	16:27	150
B1-PR5000A rep	10/16/06	16:31	150
B3-PR5000	10/16/06	16:35	2,100
B3-PR5000A rep	10/16/06	16:41	2,200
A3-BL 1548	10/16/06	16:48	2,350

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

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ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
BLANK	10/17/06	8:55	ND
A3-BL 09:00	10/17/06	9:02	2,450
B1-PV1	10/17/06	9:34	55
B1-PV2	10/17/06	9:36	66
B1-PV3	10/17/06	9:46	57
B1-PV6	10/17/06	9:49	120
B1-PV10	10/17/06	9:57	140
B4-PV1	10/17/06	10:09	470
B4-PV2	10/17/06	10:10	570
B4-PV3	10/17/06	10:20	370
B4-PV4	10/17/06	10:22	510
B4-PV5	10/17/06	10:32	550
B4-PV6	10/17/06	10:33	570
B4-PV10	10/17/06	10:46	980
A2-PV1	10/17/06	10:58	760
A2-PV2	10/17/06	11:00	1,000
A2-PV3	10/17/06	11:10	730
A2-PV4	10/17/06	11:12	1,100
A2-PV5	10/17/06	11:28	700
A2-PV6	10/17/06	11:29	1,000
A2-PV10	10/17/06	11:37	1,600
A2-PV20	10/17/06	11:46	2,200
A3-BL 12:00	10/17/06	11:55	2,250
A4-PV1	10/17/06	12:03	570
A4-PV2	10/17/06	12:04	710
A4-PV3	10/17/06	12:11	480
A4-PV4	10/17/06	12:12	640
A4-PV5	10/17/06	12:22	520
A4-PV6	10/17/06	12:23	710
A4-PV8	10/17/06	12:38	880
A4-PV10	10/17/06	12:40	960
A4-PV20	10/17/06	12:54	1,200

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
C4-PV1	10/17/06	13:01	1,200
C4-PV2	10/17/06	13:02	1,500
C4-PV2 dupe	10/17/06	13:02	1,400
C4-PV3	10/17/06	13:14	760
C4-PV4	10/17/06	13:15	1,000
C4-PV4 dupe	10/17/06	13:15	1,000
C4-PV5	10/17/06	13:37	1,000
C4-PV6	10/17/06	13:38	1,300
C4-PV8	10/17/06	13:52	1,450
C4-PV10	10/17/06	13:53	1,800
C4-PV20	10/17/06	14:04	2,600
A4-PV300L	10/17/06	14:12	1,100
A4-PV300L dupe	10/17/06	14:12	790
A3-BL 14:20	10/17/06	14:20	2,300
A3-BL REP	10/17/06	14:21	2,400
A5-BL	10/17/06	14:37	670
A1-BL	10/17/06	14:39	270
C4-PV1hp	10/17/06	14:46	180
C4-PV2hp	10/17/06	14:47	470
C4-PV3hp	10/17/06	15:00	400
C4-PV6hp	10/17/06	15:01	570
C4-PV10hp	10/17/06	15:15	660
C4-PV20hp	10/17/06	15:16	590
C4-PV20hp dupe	10/17/06	15:16	690
C4-PV100hp	10/17/16	15:38	850
C4-PV100hp dupe	10/17/06	15:38	760

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
 IRP SITE 15 STREAMS
 VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
A3-BL	10/18/06	9:00	2,150
A3-BL REP	10/18/06	9:01	2,400
A1-PV25	10/18/06	9:25	220
A1-PV60	10/18/06	9:26	160
A1-PV60 dupe	10/18/06	9:26	160
A1-PV500	10/18/06	9:31	350
A1-PV1000	10/18/06	9:40	430
B2-PV25	10/18/06	9:51	500
B2-PV60	10/18/06	9:52	570
B2-PV500	10/18/06	9:58	780
B2-PV1000	10/18/06	10:02	830
A1-PV6000	10/18/06	10:05	120
A1-PV6000 dupe	10/18/06	10:05	140
B3-PV25	10/18/06	10:30	820
B3-PV60	10/18/06	10:29	1,600
SB3-PV500	10/18/06	10:32	2,900
B3-PV1000	10/18/06	10:37	3,300
B3-PV1000 dupe	10/18/06	10:37	4,000
B2-PV6000	10/18/06	10:56	690
C2-PV25	10/18/06	11:14	2,500
C2-PV60	10/18/06	11:15	1,500
A3-BL	10/18/06	11:35	2,450
A3-BL REP	10/18/06	11:40	2,700
B3-PV6000	10/18/06	11:30	2,000
C2-PV500	10/18/06	11:33	3,000
C2-PV1000	10/18/06	11:39	3,600
A1 after 6L	10/18/06	12:11	280
C2-PV6000	10/18/06	12:41	2,000
C5-PV25	10/18/06	12:45	240
C5-PV60	10/18/06	12:46	350
C5-PV500	10/18/06	12:48	250
C5-PV1000	10/18/06	12:55	660
C5-PV1000 dupe	10/18/06	12:55	650
A3-BL	10/18/06	13:44	2,400
A3-BL REP	10/18/06	13:45	1,900
C5 PV6000	10/18/06	13:42	380

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
C1-1	10/10/06	12:40	210
C1-1 dupe	10/10/06	12:40	230
A1-1	10/10/06	15:10	120
A1-1 dupe	10/10/06	15:10	120
B1-1	10/10/06	3:44	300
B1-1 dupe	10/10/06	3:44	340
B1-3	10/10/06	16:40	190
B1-3 dupe	10/10/06	16:40	200
B-1-1	10/12/06	8:05	6,400
B-1-1 dupe	10/12/06	8:05	6,000
B-1-1 resample	10/12/06	16:12	4,500
B-1-1 resample dupe	10/12/06	16:12	4,500
B1-PR5000	10/16/06	16:27	150
B1-PR5000A rep	10/16/06	16:31	150
B3-PR5000	10/16/06	16:35	2,100
B3-PR5000A rep	10/16/06	16:41	2,200
C4-PV2	10/17/06	13:02	1,500
C4-PV2 dupe	10/17/06	13:02	1,400
C4-PV4	10/17/06	13:15	1,000
C4-PV4 dupe	10/17/06	13:15	1,000

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
A4-PV300L	10/17/06	14:12	1,100
A4-PV300L dupe	10/17/06	14:12	790
A3-BL 14:20	10/17/06	14:20	2,300
A3-BL REP	10/17/06	14:21	2,400
C4-PV20hp	10/17/06	15:16	590
C4-PV20hp dupe	10/17/06	15:16	690
C4-PV100hp	10/17/16	15:38	850
C4-PV100hp dupe	10/17/06	15:38	760
A3-BL	10/18/06	9:00	2,200
A3-BL REP	10/18/06	9:01	2,400
A1-PV60	10/18/06	9:26	160
A1-PV60 dupe	10/18/06	9:26	160
A1-PV6000	10/18/06	10:05	120
A1-PV6000 dupe	10/18/06	10:05	140
B3-PV1000	10/18/06	10:37	3,300
B3-PV1000 dupe	10/18/06	10:37	4,000
A3-BL	10/18/06	11:35	2,450
A3-BL REP	10/18/06	11:40	2,700
C5-PV1000	10/18/06	12:55	660
C5-PV1000 dupe	10/18/06	12:55	650
A3-BL	10/18/06	13:44	2,400
A3-BL REP	10/18/06	13:45	1,900

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TCE (ug/m3)
A1-PV6000	11/03/06	180
B2-PV6000	11/03/06	530
B3-PV6000	11/03/06	2,200
C2-PV6000	11/03/06	2,700
C5-PV6000	11/03/06	400

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. JANIS VILLARREAL

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (ug/m3)
BLANK	10/10/06	11:02	ND
BLANK	10/11/06	11:25	ND
BLANK	10/12/06	8:01	ND
BLANK	10/12/06	11:26	ND
BLANK	10/16/06	9:19	ND
BLANK	10/16/06	12:17	ND
BLANK	10/17/06	9:01	ND
BLANK	10/17/06	11:02	ND
BLANK	10/17/06	14:13	ND
BLANK	10/18/06	9:09	ND
BLANK	10/18/06	12:09	ND

DETECTION LIMITS

5

ND INDICATES NOT DETECTED AT LISTED DETECTION LIMITS

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN

Blayne Hartman



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	TIME	TCE (%) ECD	TCE (%) PID
CCAL	10/10/06	12:21	112%	108%
CCAL	10/10/06	17:12	--	83%
CCAL	10/10/06	17:44	120%	--
CCAL	10/11/06	8:00	96%	--
CCAL	10/11/06	8:24	--	98%
CCAL	10/11/06	11:52	98%	84%
CCAL	10/11/06	17:35	99%	83%
CCAL	10/12/06	7:52	114%	105%
CCAL	10/12/06	14:00	124%	87%
CCAL	10/12/06	17:07	122%	91%
CCAL	10/16/06	9:09	90%	85%
CCAL	10/16/06	12:12	107%	94%
CCAL	10/16/06	17:07	104%	100%
CCAL	10/17/06	8:54	102%	87%
CCAL	10/17/06	13:03	86%	75%
CCAL	10/17/06	16:03	116%	85%
CCAL	10/18/06	10:53	98%	112%
CCAL	10/18/06	14:21	98%	87%

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY

ANALYSES PERFORMED BY: MS. TAMARA DAVIS

ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN

Blayne Hartman



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	AMOUNT (ug/m3)	AREA (counts)	RF
ICAL - ECD	10/10/06	0	0	
		5	13.6	0.37
		25	67	0.37
		75	188	0.40
		100	256	0.39
AVERAGE				0.38
STDEV				0.01
RSD				3%

ICAL - PID	10/10/06	0	0	
		100	6	17.2
		1000	39	25.6
		10000	350	28.6
		100000	4921	20.3
AVERAGE				22.9
STDEV				4.4
RSD				19%

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY
ANALYSES PERFORMED BY: MS. TAMARA DAVIS
ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN

Blayne Hartman



TETRA TECH PROJECT #06LW-P0013
IRP SITE 15 STREAMS
VANDENBERG AFB, CA

H&P Project #TT101006-L5

TCE (EPA METHOD 8021) ANALYSES OF SOIL VAPOR

Sample ID	DATE	AMOUNT (ug/m3)	AREA (counts)	RF
ICAL - ECD	10/18/06	0	0	
		5	23.3	0.21
		25	106	0.24
		100	418	0.24
		500	1798	0.28
AVERAGE				0.24
STDEV				0.02
RSD				9%

ICAL - PID	10/18/06	0	0	
		500	11.4	43.9
		1000	21.8	45.9
		10000	197	50.8
AVERAGE				46.8
STDEV				2.9
RSD				6%

ANALYSES PERFORMED IN H&P'S MOBILE LABORATORY
ANALYSES PERFORMED BY: MS. TAMARA DAVIS
ANALYSES REVIEWED BY: DR. BLAYNE HARTMAN



Chain of Custody Record

- ☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469
☐ 432 N. Cedros Ave., Solana Beach, CA 92075 • ph 858.793.0401 • fax 858.793.0404
☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Date: 10/10/06
 H&P Project # _____
 Outside Lab: _____

Client: TetraTech Collector: _____ Page: 1 of 1
 Address: _____ Client Project # _____ Project Manager James Elliott
 Location: VAFB IRPSite 15 STREAMS
 Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____		EDF: Yes / No			Sample Receipt		8260B												Total # of containers						
					Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases								
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type																			
A1			1115	10/10	SW	SW																			
C1			1115																						
A5-1			1153																						
C5			1153																						
C1-1			1240																						
15m well			1308																						
C1-2			1424																						
A1-1			1510																						
B1-1			1514																						
B1-2			1610																						
C1-2B			1610																						
B1-3			1610																						
A1-2			1714																						

Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

- ☐ Disposal @ \$2.00 each
 ☐ Return to client
 ☐ Pickup

H&P

- ☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469
☐ 432 N. Cedros Ave., Solana Beach, CA 92075 • ph 858.793.0401 • fax 858.793.0404
☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Chain of Custody RecordDate: 10/11/06

H&P Project # _____

Outside Lab: _____

Client: Tetra Tech Collector: _____ Page: 1 Of 1
 Address: _____ Client Project # _____ Project Manager _____
 Location: _____
 Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____		EDF: Yes / No			Sample Receipt		8260B												Total # of containers	
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type	TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases			
-BI-1			8:21	10/11	SV	Syn														
-A1-4			8:57																	
-A1-3			9:18																	
-B1-4			9:36																	
-C-5			10:02																	
-A5-1			10:02																	
-B-1			11:37																	
-B1-1 R			12:10																	
-B-1 Resampler			13:10																	
-B-1 Resampler			16:00																	
-B1-1 Resampler			16:55																	
SV-A-1	Set @ 16:20		16:50																	
15-SV-A-2	Set @ 16:00		16:55																	
Relinquished by: (Signature)		(company)			Received by: (Signature)		(company)												Date:	Time:
Relinquished by: (Signature)		(company)			Received by: (Signature)		(company)												Date:	Time:
Relinquished by: (Signature)		(company)			Received by: (Signature)		(company)												Date:	Time:

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Sample disposal instruction:

☐ Disposal @ \$2.00 each☐ Return to client☐ Pickup



Chain of Custody Record

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☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Date: 10/12/06
 H&P Project # _____
 Outside Lab: _____

Client: TetraTech Collector: _____ Page: 1 of 2
 Address: _____ Client Project # _____ Project Manager _____
 Phone: _____ Fax: _____ Location: _____
 Turn around time: _____

Global ID: _____		EDF: Yes / No		Sample Receipt		8260B												Total # of containers
				Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases		
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type												
B-1			0805	10/12	SV	Sign											X	
B-1-1			0805														X	
A5-1			0830														X	
B-3			0835														X	
C5-1			0820														X	
B1-5			0840														X	
15-SV-A-1			0920														X	
15-SV-A-2			0921														X	
15-SV-A-3			0922														X	
15-SV-A-4			1000														X	
15-SV-A-5			1000														X	
A5-1			1140														X	
C5-1			1141														X	
B-3			1142														X	

Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

- ☐ Disposal @ \$2.00 each
 ☐ Return to client
 ☐ Pickup

☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469

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☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Chain of Custody Record

Date: 10/12/06

H&P Project # _____

Outside Lab: _____

Client: Tetra Tech Collector: _____ Page: 2 Of 2
Address: _____ Client Project # _____ Project Manager _____

Location: _____
Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____					EDF: Yes / No		Sample Receipt		8260B														Total # of containers				
							Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases								
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type																					
15-SV-B4		1145	10/10		SV	Syr																					
15-SV-B3		1146																									
15-SV-B5		1250																									
15-SV-B2		1251																									
15-SV-B1		1252																									
B-1-1 105 sample		1355																									
15-SV-C4		1545																									
15-SV-C5		1545																									
15-SV-C6		1610																									
B-1-1 105 sample		1612																									
15-SV-C3		1640																									
15-SV-C2		1641																									
Relinquished by: (Signature)					(company)		Received by: (Signature)					(company)					Date:		Time:								
Relinquished by: (Signature)					(company)		Received by: (Signature)					(company)					Date:		Time:								
Relinquished by: (Signature)					(company)		Received by: (Signature)					(company)					Date:		Time:								

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

☐ Disposal @ \$2.00 each☐ *Return to client*☐ Pickup



Chain of Custody Record

- ☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469
☐ 432 N. Cedros Ave., Solana Beach, CA 92075 • ph 858.793.0401 • fax 858.793.0404
☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Date: 10/16/06
H&P Project # _____
Outside Lab: _____

Client: Tekratech Collector: Dave Page: 1 Of 4
Address: _____ Client Project # _____ Project Manager _____
Phone: _____ Fax: _____ Location: VAFB Site 15
Turn around time: _____

Global ID: _____		EDF: Yes / No			Sample Receipt		8260B												Total # of containers
					Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases		
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type													
B1-BL			1003	10/16	SV	Sup				X									
B2-BL			1010							X									
B3-BL			1020							X									
B4-BL			1028							X									
B5-BL			1039							X									
A1-BL			1047							X									
A2-BL			1058							X									
A3-BL			1059							X									
A4-BL			1109							X									
A5-BL			1117							X									
C2-BL			1124							X									
C3-BL			1131							X									
C4-BL			1138							X									
C5-BL			1144							X									
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date: <u>10/16</u>		Time: <u>1700</u>									
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date: _____		Time: _____									
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date: _____		Time: _____									

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

- ☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup



Chain of Custody Record

- ☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469
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☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Date: 10/16/06
H&P Project # _____
Outside Lab: _____

Client: Tetra Tech Collector: Dave Page: 2 Of 4
Address: _____ Client Project # _____ Project Manager _____
Location: _____
Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____ EDF: Yes / No					Sample Receipt		8260B												Total # of containers		
					Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases				
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type															
C6-BL			154	10/16	SV	Syn				X											
A3-BL 1200			1204							X											
B2-BL 1200			1214							X											
B1-RR 100			1227							X											
B2-PR 100			1235							X											
B3-PR 100			1244							X											
B4-PR 100			1250							X											
B5-PR 100			1256							X											
B1-PR 200			1306							X											
B2-PR 200			1317							X											
B3-PR 200			1318							X											
B4-PR 200			1347							X											
B5-PR 200			1353							X											
B1-PR 500			1413							X											
Relinquished by: (Signature)					(company)					Received by: (Signature) <u>Jamala Davis</u>					(company)					Date: <u>10/16/06</u>	Time: <u>1700</u>
Relinquished by: (Signature)					(company)					Received by: (Signature)					(company)					Date:	Time:
Relinquished by: (Signature)					(company)					Received by: (Signature)					(company)					Date:	Time:

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

- ☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup



Chain of Custody Record

- ☐ 148 S. Vinewood St., Escondido, CA 92029 • ph 760.735.3208 • fax 760.735.2469
☐ 432 N. Cedros Ave., Solana Beach, CA 92075 • ph 858.793.0401 • fax 858.793.0404
☐ 3825 Industry Avenue, Lakewood, CA 90712 • ph 562.426.6991 • fax 562.426.6995

Date: 10/16/06
H&P Project # _____
Outside Lab: _____

Client: Tetra Tech Collector: Dave Page: 3 Of 4
Address: _____ Client Project # _____ Project Manager _____
Phone: _____ Fax: _____ Location: _____
Turn around time: _____

Global ID: _____		EDF: Yes / No		Sample Receipt		8260B												Total # of containers
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type	TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases	
B2-PR500			1420	10/16	SV	SV				X								
B3-PR500			1427							X								
B4-PR500			1433							X								
B5-PR500			1440							X								
B1-PR1000			1454							X								
A3-BL 1500			1503							X								
B2-PR1000			1510							X								
B3-PR1000			1518							X								
B4-PR1000			1524							X								
B5-PR1000			1530							X								
B1-PR2000			1544							X								
B2-PR2000			1550							X								
B3-PR2000			1555							X								
B4-PR2000			1600							X								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date: <u>10/16/06</u>		Time: <u>1700</u>								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:								

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back.

Sample disposal instruction:

- ☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup

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Date: 10/16/06
H&P Project # _____
Outside Lab: _____

Client: _____ Collector: Dwyer Page: 4 Of 4
Address: _____ Client Project # _____ Project Manager _____
_____ Location: _____
Phone: _____ Fax: _____ Turn around time: _____

[illegible]

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Sample disposal instruction:

☐ Disposal @ \$2.00 each☐ *Return to client*☐ Pickup

Chain of Custody Record

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Date: 10/17/06
H&P Project # _____
Outside Lab: _____

Client: Tetrakch Collector: Dave Page: 1 of 9
Address: _____ Client Project # _____ Project Manager James Elliott
Phone: _____ Fax: _____ Location: _____
Turn around time: _____

Global ID: _____		EDF: Yes / No		Sample Receipt		8260B												Total # of containers
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type	TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases	
- Blank			0855	10/17	SV	Syr				X								
- A3-BL 09:00			0902							X								
- B1-PV1			0934							X								
- B1-PV2			0936							X								
- B1-PV3			0946							X								
- B1-PV4			0949							X								
- B1-PV10			0957							X								
- B4-PV1			1009							X								
- B1-PV2			1010							X								
- B1-PV3			1020							X								
- B4-PV4			1022							X								
- B1-PV5			1032							X								
- B1-PV6			1033							X								
- B1-PV10			1046							X								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:								
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:								

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Sample disposal instruction:

☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup

Chain of Custody Record

Client: Tetrahedron Collector: Dave Page: 2 Of 4
Address: _____ Client Project # _____ Project Manager Jim Elliot

Location: _____
Phone: _____ Fax: _____ Turn around time: _____

*Signature constitutes authorization to proceed with analysis and acceptance of condition on back. Sample disposal instruction: ☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup



Chain of Custody Record

Date: 10/17/06
H&P Project # _____
Outside Lab: _____

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Client: Tetra Tech Collector: _____ Page: 3 of 4
Address: _____ Client Project # _____ Project Manager _____
Phone: _____ Fax: _____ Location: _____
Turn around time: _____

Global ID: _____		EDF: Yes / No		Sample Receipt		8260B														Total # of containers				
				Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No Seal Intact: <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A Cold: <input type="checkbox"/> Yes <input type="checkbox"/> No N/A (Received on Site)		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases								
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type																		
A4-PV5			1222	10/17	SV	Syr																		
A4-PV6			1223																					
A4-PV8			1238																					
A4-PV10			1240																					
A4-PV20			1254																					
C4-PV1			1301																					
C4-PV2			1302																					
C4-PV3			1314																					
C4-PV4			1315																					
C4-PV5			1332																					
C4-PV6			1338																					
C4-PV8			1352																					
C4-PV10			1353																					
C4-PV20			1404																					
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:														
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:														
Relinquished by: (Signature)		(company)		Received by: (Signature)		(company)		Date:		Time:														

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Sample disposal instruction:

- ☐ Disposal @ \$2.00 each ☐ Return to client ☐ Pickup

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Date: 10/17/06

H&P Project # _____

Outside Lab: _____

Client: Tetratich Collector: _____ Page: 1 Of 4
Address: _____ Client Project # _____ Project Manager _____

Location: _____
Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____					EDF: Yes / No		Sample Receipt		TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated compounds	418.1 TRPH	8260B				Methane	Fixed Gases						Total # of containers
Sample Name		Field Point Name	Depth	Time	Date	Sample Type	Container Type	BTEX / Oxygenates						Oxygenates	VOC's	VOC's and Oxygenates									
A4- PV 300L				1413	1/17																				
A3- BL				1420	14																				
A3 BL Drip Rep				1421																					
A5- BL				1437																					
A1- BL				1439																					
C4- PV 1 hp				1446																					
C4- PV 2 hp				1447																					
C4- PV 3 hp				1500																					
C4- PV 6 hp				1501																					
C4- PV 10 hp				1515																					
C4- PV 20 hp				1516																					
C4- PV 100 hp				1538																					
Relinquished by: (Signature) _____ (company) _____						Received by: (Signature) _____ (company) _____						Date: _____		Time: _____											
Relinquished by: (Signature) _____ (company) _____						Received by: (Signature) _____ (company) _____						Date: _____		Time: _____											
Relinquished by: (Signature) _____ (company) _____						Received by: (Signature) _____ (company) _____						Date: _____		Time: _____											

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Sample disposal instruction:

☐ Disposal @ \$2.00 each☐ *Return to client*☐ Pickup



Chain of Custody Record

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Date: 10/18/06
 H&P Project # _____
 Outside Lab: _____

Client: Tetra Tech Collector: Dave Page: 1 Of 3
 Address: _____ Client Project # _____ Project Manager _____
 Location: _____
 Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____ EDF: Yes / No					Sample Receipt		8260B												Total # of containers
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type	TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated Compounds	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases		
A3-BL			0900	10/18	SV	Syr				X									
A3-BL Rep			0901							X									
A1-SV25			0925							X									
A1-SV60			0926							X									
A1-SV500			0931			Tedlar				X								1	
A1 SV 1000			0940			Tedlar				X								2	
A2-SV25			0951			Syr				X									
B2-SV60			0950							X									
B2-SV500			0958			Tedlar				X									
B2-SV1000			1002							X									
A1-SV6000			1005		6L	Summa				X									
B3-SV25			1030			Syr				X									
B3-SV60			1029							X									
B3-SV500			1032			Tedlar				X									

Relinquished by: (Signature) _____ (company) _____ Received by: (Signature) _____ (company) _____ Date: _____ Time: _____
 Relinquished by: (Signature) _____ (company) _____ Received by: (Signature) _____ (company) _____ Date: _____ Time: _____
 Relinquished by: (Signature) _____ (company) _____ Received by: (Signature) _____ (company) _____ Date: _____ Time: _____

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Sample disposal instruction:

☐ Disposal @ \$2.00 each

☐ Return to client

☐ Pickup



Chain of Custody Record

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Date: 10/18/06
 H&P Project # _____
 Outside Lab: _____

Client: Tetratex Collector: _____ Page: 2 Of 3
 Address: _____ Client Project # _____ Project Manager _____
 Location: _____
 Phone: _____ Fax: _____ Turn around time: _____

Global ID: _____ EDF: Yes / No					Sample Receipt		8260B												Total # of containers
Sample Name	Field Point Name	Depth	Time	Date	Sample Type	Container Type	TPH gasoline / diesel	TPH extended	8021 for BTEX/MTBE	8021 for Halogenated hydrocarbons	418.1 TRPH	BTEX / Oxygenates	Oxygenates	VOC's	VOC's and Oxygenates	Methane	Fixed Gases		
B3-SV1000			1037	10/18	SAV	Tedlar				X									
B2-SV6000			1056		6L Summa					X									
C2-25PV25			1114		Syr					X									
C2-PV60			1115							X									
A3-BL			1118							X									
A3-BL Rep			1117							X									
B3-SV6000			1130		Summa					X									
C2-SV500			1133		Tedlar					X									
C2-SV1000			1139							X									
A1-after 6L			1211		Syr.					X									
C2-SV6000			1211		Summa					X									
C5-SV25			1245		Syr					X									
C5-SV60			1246		Syr					X									
C5-SV500			1248		Ted					X									

Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:
Relinquished by: (Signature)	(company)	Received by: (Signature)	(company)	Date:	Time:

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Sample disposal instruction:

- ☐ Disposal @ \$2.00 each
 ☐ Return to client
 ☐ Pickup

H&P

Baseline Samples

Soil Vapor Survey Sheet

Project Name & Location: TT 10/606 TECH

Vanderburg AFB

Date: 10/16/06

Ident: Tetra Tech

Field Rep: Jones

Start Time:

&P Operator: Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Molsture Content	Field Notes
1	B1-BL	200ml/min		1003	17'	18'	216ml		Base line
2	B2-BL	"		1010	17'	18'	216ml		Sample 5
3	B3-BL	"		1020	18'	19'	228ml		3 PV
4	B4-BL	"		1028	18.5'	19.5'	234ml		200ml/min Flow rate
5	B5-BL	"		1039	19'	20'	240ml		60ml syringe
6	A1-BL	"		1047	17.5'	18.5'	222ml		
7	A2-BL	"		1052	16.5'	17.5'	210ml		
8	A3-BL	"		1059	17'	18'	216ml		
9	A4-BL	"		1109	17'	18'	216ml		
10	A5-BL	"		1117	17'	18'	216ml		
11	C2-BL	"		1124	14'	15'	180ml		
12	C3-BL	"		1131	15.5'	16.5'	198ml		
13	C4-BL	"		1138	15.5'	16.5'	198ml		
14	C5-BL	"		1146	15.5'	16.5'	198ml		
15	C6-BL	"		1154	15'	16'	192ml		
16									
17	A3-BL a	"		1204	17'	18'	216ml		resample
18	B2-BL	"		1215	17'	18'	216ml		resample
19	A3-BL b	"		1502	17'	18'	216ml		"
20	A3-BL c	"		1648	17'	18'	216ml		
21									
22									
23									
24									
25									

Broken/Unrecovered Tools:

Overtime:

Accepted By:

H&P

Soil Vapor Survey Sheet

Flow Rates

Project Name & Location: TT101606TECH

Vanderburg AFB

Date: 10/16/02

Ident: Tefra Tech

Field Rep: James

Start Time:

S&P Operator: James

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	B1 - PR100	100ml/min		1227	17'	18'	216ml		Purge Rate Test
2	B2 - PR100	"		1235	17'	18'	216ml		
3	B3 - PR100	"		1244	18'	19'	228ml		
4	B4 - PR100	"		1250	18.5'	19.5'	234ml		
5	B5 - PR100	"		1256	19'	20'	240ml		
6	B1 - PR200	200ml/min		1306	17'	18'	216ml		
7	B2 - PR200	"		1312 1317	17'	18'	216ml		
8	B3 - PR200	"		1312	18'	19'	228ml		
9	B4 - PR200	"		1347	18.5'	19.5'	234ml		
10	B5 - PR200	"		1353	19'	20'	240ml		
11	B1 - PR500	500ml/min		1413	17'	18'	216ml	Used Pump	26secs
12	B2 - PR500	"		1420	17'	18'	216ml		27secs
13	B3 - PR500	"		1427	18'	19'	228ml		27secs
14	B4 - PR500	"		1433	18.5'	19.5'	234ml		28secs
15	B5 - PR500	"		1440	19'	20'	240ml		29secs
16	B1 - PR1000	1L/min		1454	17'	18'	216ml		13secs
17	B2 - PR1000	"		1510	17'	18'	216ml		13secs
18	B3 - PR1000	"		1518	18'	19'	228ml		13.7secs 13.7secs
19	B4 - PR1000	"		1524	18.5'	19.5'	234ml		14secs
20	B5 - PR1000	"		1530	19'	20'	240ml		14.4secs
21	B1 - PR2000	2L/min		1544	17'	18'	216ml		6.5secs
22	B2 - PR2000	"		1550	17'	18'	216ml		6.5secs
23	B3 - PR2000	"		1555	18'	19'	228ml		6.8secs
24	B4 - PR2000	"		1602	18.5'	19.5'	234ml		7secs
25	B5 - PR2000	"		1608	19'	20'	240ml		7.2secs

Broken/Unrecovered Tools:

Overtime:

Accepted By:

2/27



Soil Vapor Survey Sheet

Project Name & Location TT101606TECH

Vanderburg AFB

Date: 10/16/06

Client: Tetra Tech

Field Rep: James

Start Time:

S&P Operator Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	B1-PR5000+	50 5L/min		1627	17	18"	276		6.5 sec
2	B1-PR5000a	5L/min		1631	"	"	-		3 minutes
3	B3-PR5000	"		1635	18"	19"	225		6.8 sec
4	B3-PR5000a	"		1641	"	"			3 minutes
5		"		1648					
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

Broken/Unrecovered Tools:

Overtime:

Accepted By:

H&P

Purge Volume Tests

Soil Vapor Survey Sheet

Project Name & Location: TT 101606 TELL

Van derburg AFB

Date: 10/17/06

Client: Tetra Tech

Field Rep: James / Yokum

Start Time: 0830

S&P Operator: Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	B1-PV1	200ml/min		0934	17	18	72ml	132	1PV
2	B1-PV2	"		0936	"	"	144ml	204	2PV
3	B1-PV3	"		0946	"	"	216ml	276	3PV
4	B1-PV6	"		0949	"	"	432ml	462	6PV
5	B1-PV10	"		0957	"	"	720ml	780	10PV
6	B4-PV1	"		1008	18.5	19.5	78ml	188	18
7	B4-PV2	"		1010	"	"	156ml	216	15
8	B4-PV3	"		1020	"	"	234ml	294	
9	B4-PV4	"		1022	"	"	468ml	312	3828
10	B4-PV5	"		1032	"	"	780ml	372	
11	B4-PV6	"		1033	"	"	468ml	311	
12	B4-PV10	"		1046	16.5	17.5	780ml		
13	A2-PV1	"		1058	16.5	17.5	70ml		
14	A2-PV2	"		1100	"	"	140ml	10	
15	A2-PV3	"		1110	"	"	210ml	10	
16	A2-PV4	"		1112	"	"	280ml	10	
17	A2-PV5	"		1128	"	"	350ml	10	
18	A2-PV6	"		1129	"	"	420ml	10	
19	A2-PV10	"		1138	"	"	700ml	220ml	
20	A2-PV20	"		1146	"	"	1400ml		
21	A4-PV1	"		1203	17'	18'	72ml	"	
22	A4-PV2	"		1204	"	"	144ml	12	
23	A4-PV3	"		1211	"	"	216ml	12	
24	A4-PV4	"		1212	"	"	288ml		
25	A4-PV5	"		1222	"	"	360ml		

Token/Unrecovered Tools:

Overtime:

Accepted By:

B1, A2, A4, C4, D4

H&P

Soil Vapor Survey Sheet

Purge Volume Tests

Project Name & Location TT101706TECH

Vandenberg AFB

Date: 10/17/06

Client: Tetra Tech

Field Rep: James

Start Time:

H&P Operator Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	A4-PV6	200 ml/min		1223	17'	18'	430ml		
2	A4-PV8	"		1238	"	"	576ml	34	
3	A4-PV10	"		1240	"	"	720ml	88	
4	A4-PV20	"		1254	"	"	1440ml	66ml	
5	C4-PV1	"		1301	15.5	16.5	66ml		
6	C4-PV2	"		1302	"	"	132ml		
7	C4-PV3	"		1314	"	"	198ml		
8	C4-PV4	"		1315	"	"	264ml		
9	C4-PV5	"		1337	"	"	330ml		
10	C4-PV6	"		1338	"	"	396ml		
11	C4-PV8	"		1352	"	"	528ml	72	
12	C4-PV10	"		1353	"	"	660ml	77	
13	C4-PV20	"		1404	"	"	1320ml		
14									
15	A4-PV40DL	5L/min		1412					
16					Depth	Flowing			Ran pump @ 5L/min for 1 hr
17	C4-PV1 hp	200 ml/min		1446	5'	10'	10ml		
18	C4-PV2 hp	"		1447	"	"	20ml		
19	C4-PV3 hp	"		1500	"	"	30ml		
20	C4-PV5 hp	"		1501	"	"	60ml		
21	C4-PV10 hp	"		1515	"	"	100ml		
22	C4-PV20 hp	"					200ml		
23	C4-PV100 hp			1530			1000ml		
24									
25									

Broken/Unrecovered Tools:

Overtime:

Accepted By:

Control BL Sample

H&P

Soil Vapor Survey Sheet

Project Name & Location TT101706 TECH

Vanderburg AFB

Date: 10/17/06

Client: Tetra Tech

Field Rep: Jones

Start Time: 0830

&P Operator Dan B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	A3-BL d	200 ml/min		0902	17'	18'	216 gal		
2	A3-BL e	"			"	"	216 gal		
3	A3-BL f	"		1420	"	"	216 gal		
4	A3-BL dup	"		1421	"	"	276 gal		duplicate
5									
6									
7									
8									
9									
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11									
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20									
21									
22									
23									
24									
25									

Broken/Unrecovered Tools:

Overtime:

Accepted By:

Sample Volume

H&P

Soil Vapor Survey Sheet

Project Name & Location TT101606TECH

Vanderburg AFB

Date: 10/18/00

Ident: Tetra Tech

Field Rep: James

Start Time:

&P Operator Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	A1-SV25	200 ml/min		0925	12.5	18.5	222 ml		
2	A1-SV60	"		0926	"	"			
3	A1-SV500	"		0934	"	"			
4	A1-SV1000	"		0940	"	"			Start Air
5	A1-SV6000	100 ml/min		1004	"	"			0940
6	B2-SV25	200 ml/min		0951	17	18	216 ml		
7	B2-SV60	"		0952	17	"			
8	B2-SV500	"		0958	"	"			
9	B2-SV1000	"		1002	"	"			Start
10	B2-SV6000	"		1056	"	"			1002
11	B3-SV25	"		1029	18	19	228 ml		
12	B3-SV60	"		1030	"	"			
13	B3-SV500	"		1032	"	"			
14	B3-SV1000	"		1037	"	"			Start
15	B3-SV6000	"		1130					1038
16	C2-SV25	"		1114	14	15	180 ml		
17	C2-SV60	"		1115	"	"	"		
18	C2-SV500	"		1133	"	"	"		
19	C2-SV1000	"		1139	"	"	"		
20	C2-SV6000	"		1241	"	"			1140
21	C5-SV25	"		1245	15.5	16.5	198 ml		
22	C5-SV60	"		1246	"	"	"		
23	C5-SV500	"		1248	"	"	"		
24	C5-SV1000	"		1255	"	"	"		
25	C5-SV6000	"		1342	"	"	"		1253

Broken/Unrecovered Tools:

Overtime:

Accepted By:

A1 B2 B3 C2 C5

Control Baseline

H&P

Soil Vapor Survey Sheet

Project Name & Location TTIO/606TECH

Vandenberg AFB

Date: 10/18/06

Ident: Tetra Tech

Field Rep: James

Start Time:

&P Operator Dave B

Finish Time:

Weather Conditions:

Bags of Bentonite:

	Point ID	Flow Rate	Time Placed	Time Sampled	Target Depth	Actual Depth	Purge Volume	Moisture Content	Field Notes
1	A5-BL _g	200 ml/min		0900	17'	18	216 ml		
2	A3-BL rep	"		0901	"	"	216 ml		replicate
3	A3-BL			1345	"	"	"		
4	A3-BL rep			1346	"	"	"		
5									
6									
7									
8									
9									
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Broken/Unrecovered Tools:

Overtime:

Accepted By:

Appendix D

Statistical Analyses

Appendix D
Statistical Analyses
Development of Active Soil Gas Sampling Method

Experimental Design

Three separate experiments were conducted to assess the primary effects of purge rate, purge volume, and sample volume on measured soil gas concentrations. The experimental designs for each of these experiments are described below. Full experimental designs and results from these experiments are provided in Sections 3.0 and 4.0 of the Project Report for the Development of Active Soil Gas Sampling Method (Tetra Tech EMI 2007).

Purge Volume

In this experiment, five permanent, and one temporary, soil gas probes were sampled:

- 15-SV-A2
- 15-SV-A4
- 15-SV-B1
- 15-SV-B4
- 15-SV-C4
- 15-SV-C4HP (temporary)

The purge volumes that were tested included the following:

- 1 system volumes
- 2 system volumes
- 3 system volumes
- 4 system volumes
- 5 system volumes
- 6 system volumes
- 10 system volumes
- 20 system volumes

Purge rate and sample volume were the same in all of the samples collected; i.e., 200 ml/min and 60 ml, respectively. At the highest purge volume used in the experiment (i.e., 4,400 system volumes from 15-SV-A4), only one sample was collected and that purge volume was more than 100 times greater than the next highest purge volume. This data point can be considered an outlier that may bias the data analysis as the system volume purged is very far removed from all other system volumes measured. Therefore, this data point was removed from the analyses.

Purge Rate

In this experiment, five permanent soil gas probes were sampled:

- 15-SV-B1
- 15-SV-B2
- 15-SV-B3
- 15-SV-B4
- 15-SV-B5

The purge rates that were tested included the following:

- 100 ml/min
- 200 ml/min
- 500 ml/min
- 1,000 ml/min
- 2,000 ml/min
- 5,000 ml/min

Sample volume was the same in all samples collected (i.e., 60 ml). Purge volume was the same in the majority of the samples collected; i.e., 3 system volumes (204–228 ml). For the four samples with a purge rate of 5,000 ml/min, the number of system volumes purged fell into 2 groups: 8 and 208–221 system volumes purged. The two samples that were collected with more than 200 system volumes purged (from 15-SV-B1 and 15-SV-B3) are far removed from the other purge volumes used and may bias the data analysis. Therefore, they were assumed to be outliers and were not included in the analyses.

Sample Volume

The third experiment varied sample volume, while intending to hold purge rate constant. In this experiment, five permanent soil gas probes were sampled:

- 15-SV-A1
- 15-SV-B2
- 15-SV-B3
- 15-SV-C2
- 15-SV-C5

The sample volumes that were tested included the following:

- 25 ml (syringe)
- 60 ml (syringe)
- 500 ml (Tedlar bag)
- 1,000 ml (Tedlar bag)
- 6,000 ml (stainless steel Summa canister)

A purge rate of 200 ml/min used was for all samples except the 6,000 ml samples collected using a Summa canister. For this sample volume, a purge rate of either approximately 100 ml/min (100 – 122 ml/min; 4 probes) or 300 ml/min (1 probe) was used (Figure D-1). The number of system volumes purged necessarily increased with increasing sample volume, and ranged from 3 to 31.3 system volumes (Figure D-1).

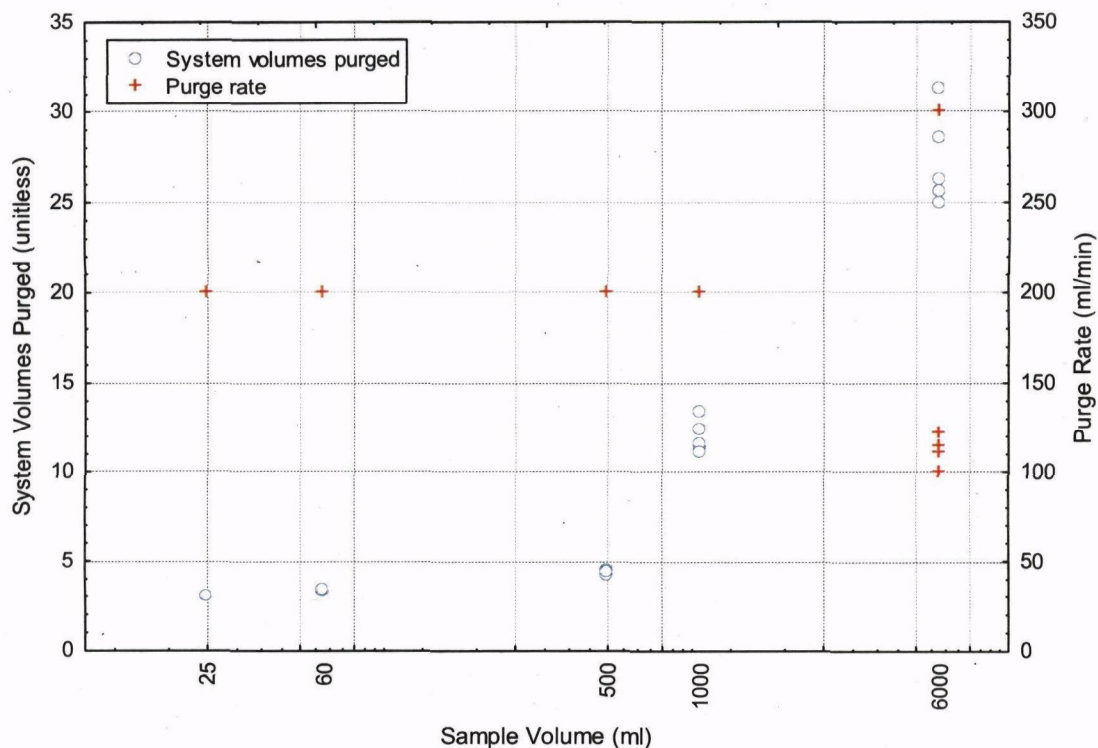


Figure D-1. Sample Volume experimental design. The number of system volumes purged varied directly with sample volume, whereas purge rate was a function of the sampling device

Analysis

Multiple linear regression analysis was performed on the results from the experiments to evaluate the effect of the treatment. When parameters other than the parameter of interest varied in the experimental conditions (e.g., purge volume was also varied in the sample volume experiment), their effects were included in the analysis. Interaction effects (i.e., does the manipulation of one variable have the same effect at all levels of the other variables manipulated?) were not included in the analysis. For the purposes of the analyses presented here, it was assumed the each analytical result could be considered as a randomly collected independent sample.

Effect of Baseline

Prior to conducting analysis of the experiments, baseline conditions in the installed probes were evaluated. Baseline conditions were measured using a purge rate of 200 ml/min, a sample volume of 60 ml, and 3 system volumes purged (i.e., 180 to 228 ml) prior to any of the other experiment. Baseline concentrations varied from 93 $\mu\text{g}/\text{m}^3$ to 2,400 $\mu\text{g}/\text{m}^3$ (Figure D-2).

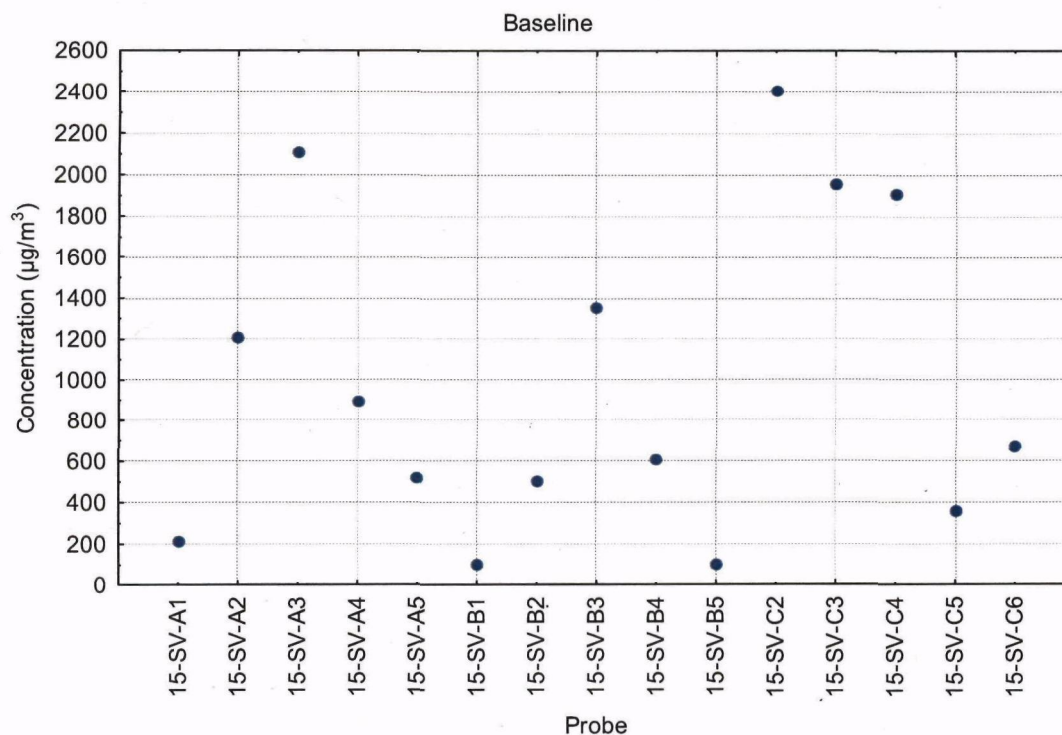


Figure D-2. Plot of baseline concentrations by probe.

To account for the differences in baseline concentrations between the wells in the analyses, baseline concentrations were added as a covariate in all of the analyses. In addition to differences among wells in baseline concentrations, baseline conditions may also have a significant effect on the variation in the response of measured TCE concentrations, with increasing variation in the response at higher baseline concentrations. This effect is seen below in the data from the purge volume experiment (Figure D-3).

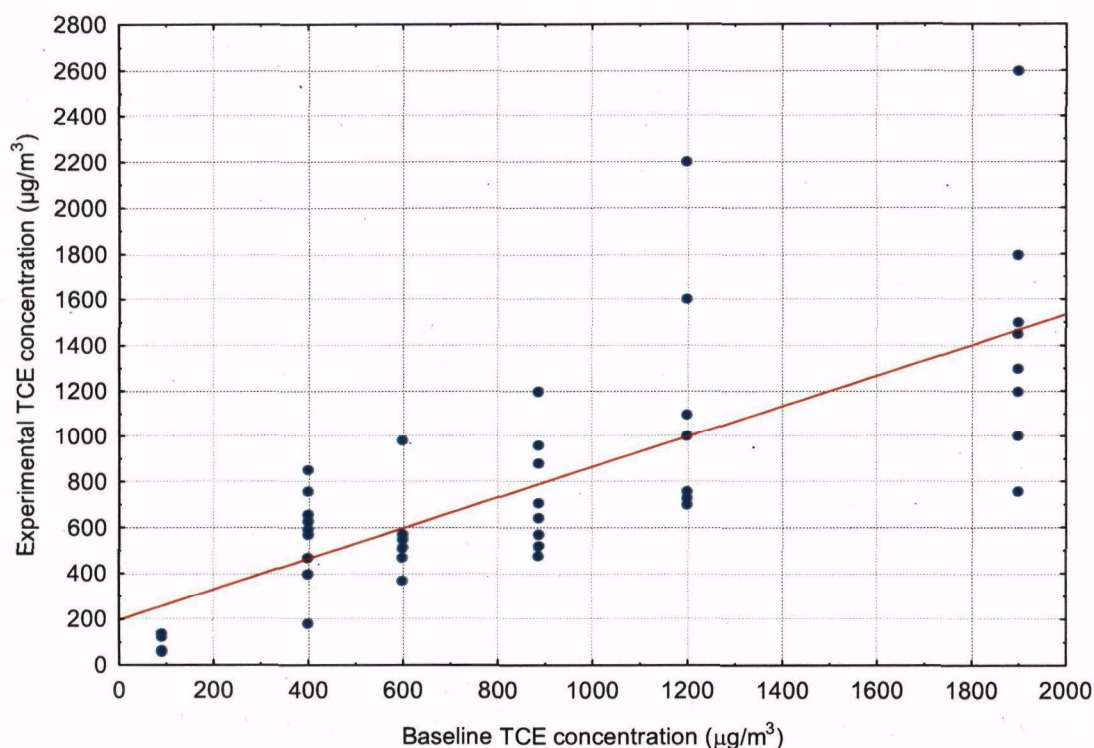


Figure D-3. Effect of baseline concentration on the variance in experimentally measured TCE concentrations from the purge volume experiment. Measured concentrations show a significant correlation with baseline ($r = 0.74$). Similarly, the variance in the result increases with increasing baseline concentrations

To correct for the effect of increasing variance, all data were natural logarithm (i.e., \ln) transformed prior to analysis.

As noted above, the system volumes for each well were also slightly different. This may affect both the baseline concentrations and the concentrations measured during each of the experiments. To account for the potential effect of the difference in system volumes among the wells, system volume was used as a covariate in the analyses.

Purge Rate

In this experiment, the variable of interest was purge rate. While sample volume was held constant, there was some variation in the number of system volumes purged. Therefore, the independent variables used in the regression analysis were: 1) purge rate, 2) system volumes purged, 3) baseline concentration, and 4) system volume. This resulted in a highly significant multiple linear regression with the following parameters $F_{4,22} = 626.99$, $p < 0.0001$, adjusted $r^2 = 0.99$, where:

Adjusted r^2 = the proportion of variation explained by the independent variables in a multiple linear regression. Includes an adjustment for the number of variables in the regression.

F = the ratio of Mean Square for the effect of interest to Mean Square for the error term.

p = the probability of the observed result happening by chance. By convention, a p value of less than 0.05 is used to indicate that the observed effect is significant (e.g., due to the experimental manipulations).

The resulting equation is:

$$\ln(\text{TCE in } \mu\text{g/m}^3) = -4.85 + 0.14 \cdot \ln(\text{purge rate in ml/min}) - 0.044 \cdot \ln(\text{system volumes purged}) + 1.00 \cdot \ln(\text{system volume in ml}) + 0.99 \cdot \ln(\text{baseline TCE in } \mu\text{g/m}^3)$$

These results are presented in Table D-1.

Table D-1

	Parameter Estimate	Standard Error of Parameter Estimate	<i>t</i> (22)	<i>p</i>
Intercept	-4.85	2.12	-2.29	0.03
LN(purge rate)	0.14	0.021	6.89	0.000001
LN(system volumes purged)	-0.044	0.11	-0.41	0.7
LN(Baseline TCE)	0.99	0.020	49.11	<0.000001
LN(system volume)	1.00	0.49	2.03	0.06

Notes:

p - the probability of the observed result happening by chance. By convention, a *p* value of less than 0.05 is used to indicate that the observed effect is significant (e.g., due to the experimental manipulations).

t - the value calculated from the *t* distribution given a sample size and standard deviation.

To directly illustrate the effect of purge rate on the measured TCE concentrations, the regression above was performed without purge rate, and the residuals were calculated. These residuals were then regressed on the purge rate. After accounting for the effect of the other variables, purge rate accounted for approximately 50 percent of the variance observed in the data (Figure D-4).

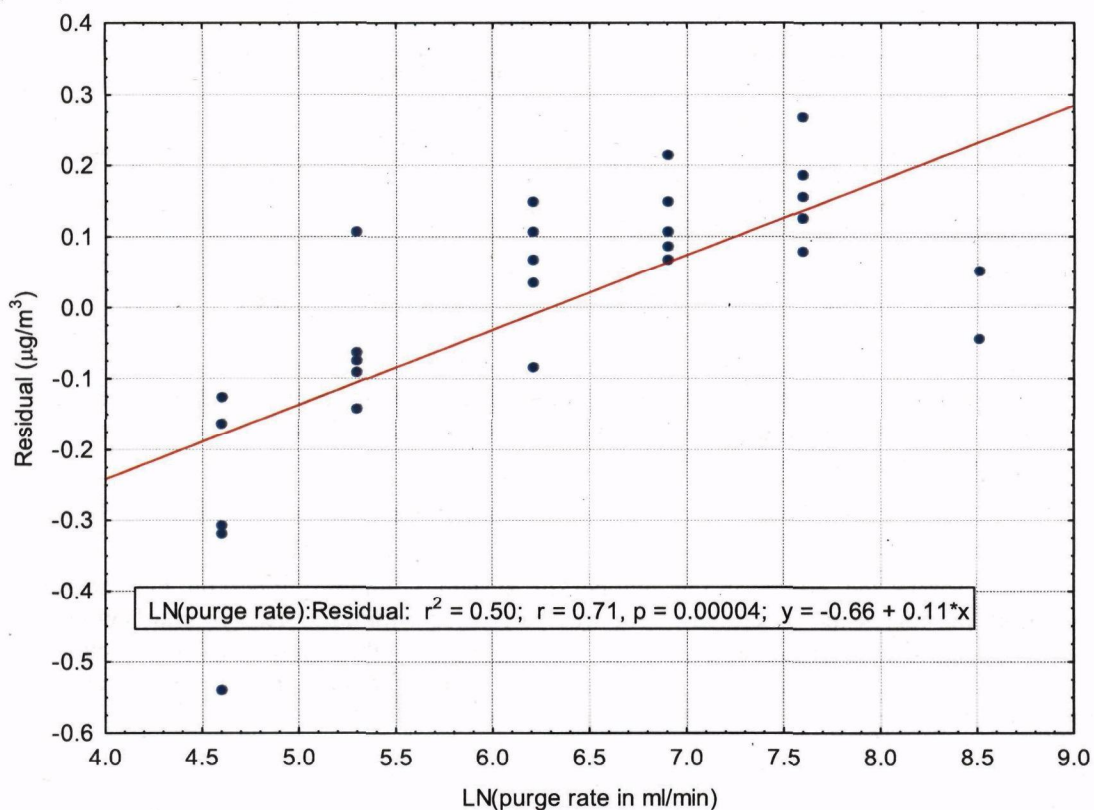


Figure D-4. Effect of purge rate on measured soil gas concentrations, after accounting for the effects of baseline conditions, system volumes purged, and system volume

The two measurements at far right in Figure D-4 were collected using a different number of system volumes purged than the other samples.

Purge Volume

In this experiment, only system volumes purged was varied. Therefore, the independent variables used in the regression analysis were: 1) system volumes purged, 2) baseline concentration, and 3) system volume. These parameters resulted in a highly significant multiple linear regression ($F_{3,34}=163.46$, $p < 0.0001$, adjusted $r^2 = 0.93$). The resulting equation is:

$$\ln(\text{TCE in } \mu\text{g/m}^3) = -6.71 + 0.29 \cdot \ln(\text{system volumes purged}) + 0.95 \cdot \ln(\text{baseline TCE in } \mu\text{g/m}^3) + 1.53 \cdot \ln(\text{system volume in ml})$$

These results are presented in the Table D-2.

Table D-2

	Parameter Estimate	Standard Error of Parameter Estimate	<i>t</i> (34)	<i>p</i>
Intercept	-6.71	3.55	-1.89	0.07
LN(system volumes purged)	0.29	0.049	5.96	0.000001
LN(Baseline TCE)	0.95	0.051	18.56	<0.000001
LN(system volume)	1.53	0.80	1.91	0.06

Notes:

p - the probability of the observed result happening by chance. By convention, a *p* value of less than 0.05 is used to indicate that the observed effect is significant (e.g., due to the experimental manipulations).

t - the value calculated from the *t* distribution given a sample size and standard deviation.

To directly illustrate the effect of the number of system volumes purged on the measured TCE concentration, the regression described above was performed without system volumes purged, and the residuals were calculated. These residuals were then regressed on the number of system volumes purged (Figure D-5). After accounting for the effect of the other variables, purge volume accounted for approximately 50 percent of the variance observed in the data.

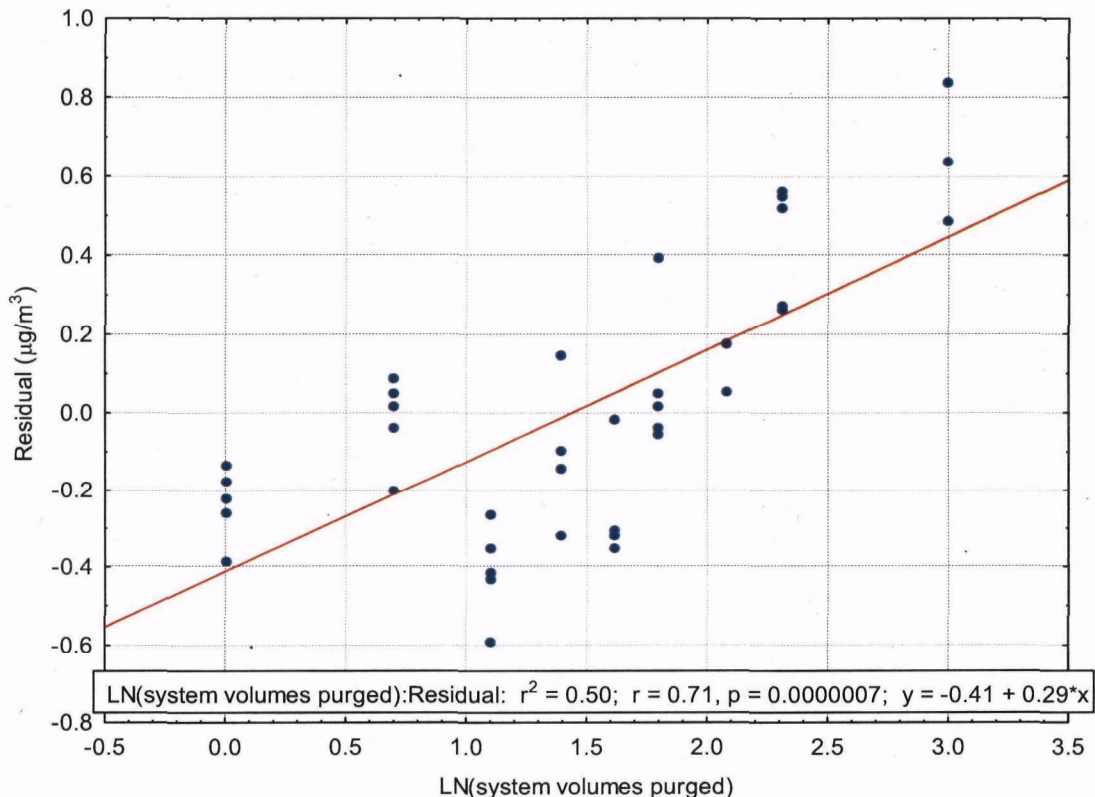


Figure D-5. Effect of the number of system volumes purged on measured soil gas concentrations, after accounting for the effect of baseline conditions and system volume.

Sample Volume

In this experiment, the variable of interest is sample volume. However, the number of system volumes purged necessarily increased with increasing sample volume. Purge rate was held constant, with the exception of the final sample. Sample volume and system volumes purged are not independent variables; i.e., they covary. Purge rate is also not independent. Therefore, these data cannot be evaluated using the multiple regression approach used for the previous two experiments.

To analyze the results of this experiment, we treated sample volume as an indicator of the combined experimental conditions, and as a categorical, rather than continuous, variable. To analyze these data an analysis of covariance (ANCOVA) was used, with the baseline concentrations (ln-transformed) treated as a continuous covariate for the reasons stated above. System volume was examined and was not determined to have a significant effect in the analyses and was, therefore, not included as a covariate.

The ANCOVA indicated that the experimental manipulations had a significant effect on the TCE concentrations measured, after adjusting for the effect of baseline concentrations (Table D-3).

Table D-3

Effect	Sum of Squares	d.f.	Mean Square	F	<i>p</i>
Intercept	0.0275	1	0.0275	0.351	0.56
Sample Volume	2.63	4	0.658	8.42	0.0004
Baseline	19.47	1	19.47	249.0	<0.0001
Error	1.48	19	0.078		

Notes:

df. - degrees of freedom. The total degrees of freedom are equal to the sample size minus one. In regression and ANOVA, the total degrees of freedom are partitioned among the factors, treatment, and error terms.

F - the ratio of Mean Square for the effect of interest to Mean Square for the error term.

p - the probability of the observed result happening by chance. By convention, a *p* value of less than 0.05 is used to indicate that the observed effect is significant (e.g., due to the experimental manipulations).

To determine which treatments are significantly different, the Newman-Kuels multiple range test was used. This test indicated that the TCE concentrations measured in the 25 ml, 60 ml, and 6,000 ml sample volumes were not significantly different from each other. In contrast, the 500 ml and 1,000 ml sample volumes were similar to each other, but were significantly different from the other treatments (Figure D-).

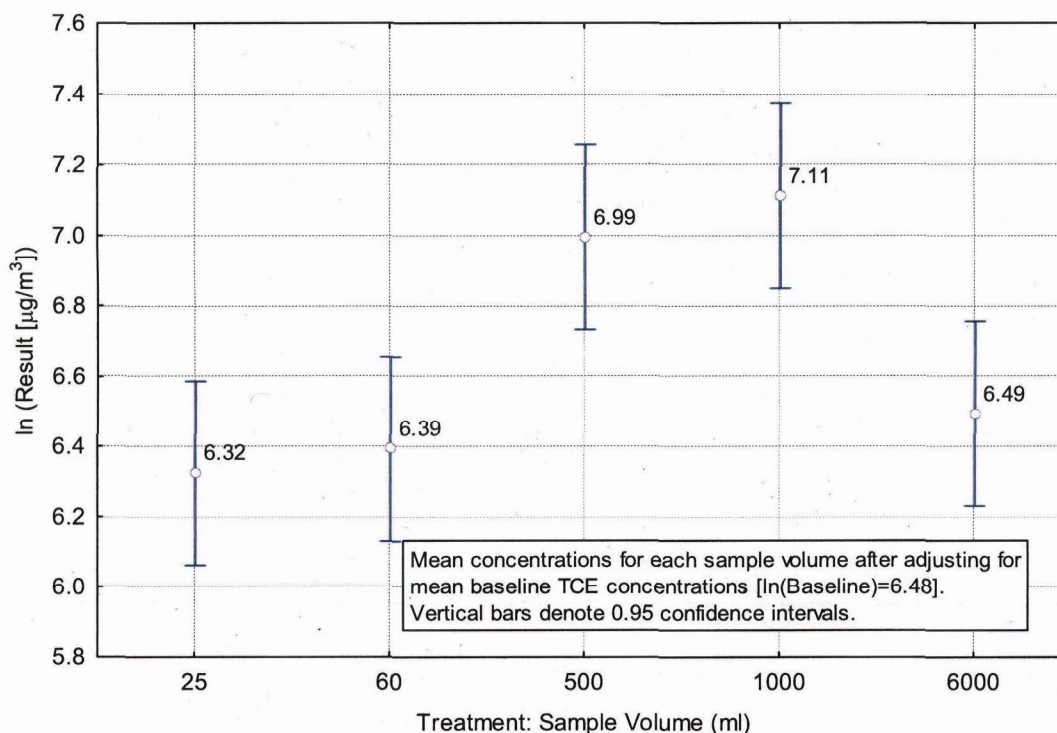


Figure D-7. Graphical representation of the results of the Newman-Kuels multiple range test for the Sample Volume experiment. Samples whose confidence intervals overlap the mean of another sample are not significantly different

Due to the relatively short time period that the samples were stored, it is believed that the differences in measured TCE concentrations observed here is not due to the type of sample container used to collect the samples.

Conclusions

These results indicate that purge rate and purge volume are likely to have a significant effect on measured soil gas concentrations. Sample volume also has an effect on measured soil gas concentrations; however, this effect cannot be separated from the effect of the number of system volumes purged.

The experimental design used focused on varying only a single variable in each of the three experiments. Therefore, the effect of interactions between the variables of interest could not be determined as the experimental design was not fully factorial; i.e., samples were not collected for every combination of purge rate, purge volume, and sample volume.

Temporal Control Point

The data collected from soil vapor well 15-SV-A3, the temporal control point, were analyzed to determine if there were significant temporal trends in the data using the nonparametric Mann-Kendall trend test. This test determines whether there is a monotonic (i.e., single-direction) trend in the data over time (e.g., is the concentration increasing or decreasing over time) and does not examine periodicity in the data. The results of the analysis indicate that, at the 95% confidence level, there was no significant trend over time in the data ($N=14$, Mann-Kendall $S = 0.71$, $p = 0.5$). The data are shown in Figure D-7, below.

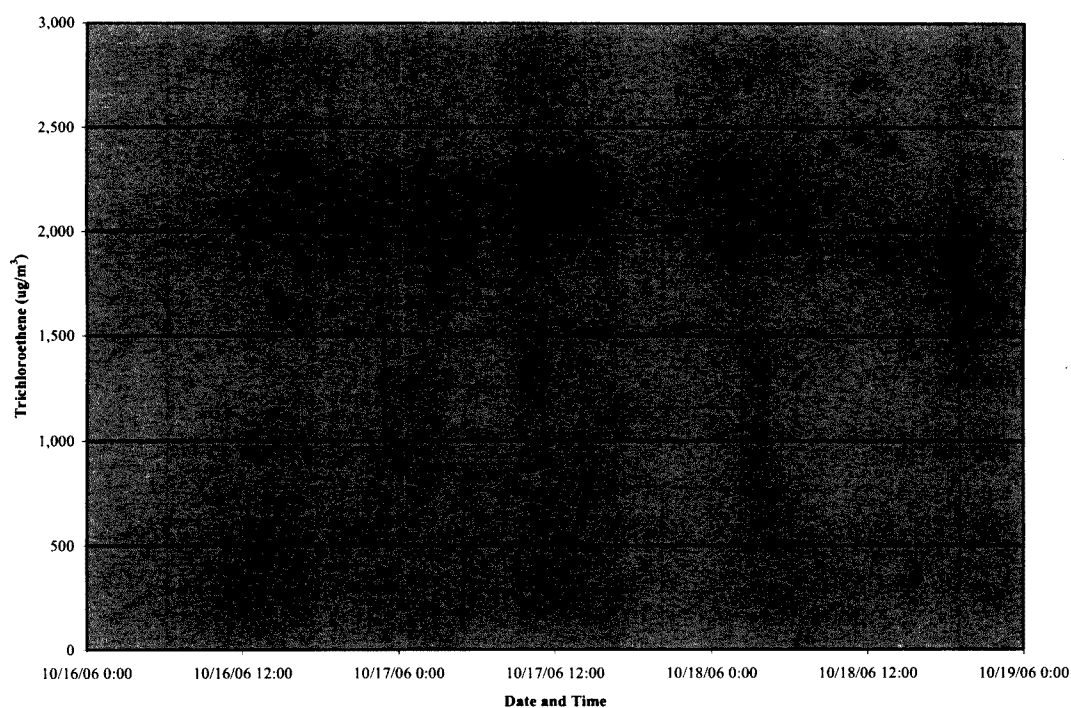


Figure D-7. Temporal control point data

Equilibration Time Analysis

To determine if there was an effect of the amount of time that a soil vapor well was allowed to equilibrate after installation, 13 wells were sampled approximately 1 hour (41 to 85 minutes; mean 59 minutes) after installation and again four days later using the same purge rate, purge volume, and sample volume. The data were analyzed using a matched-pairs *t*-test which showed that waiting four days did not have a significant effect on the mean concentration ($df = 12$, $t = -1.13$, $p = 0.3$). The results are shown in Figure D-8, below.

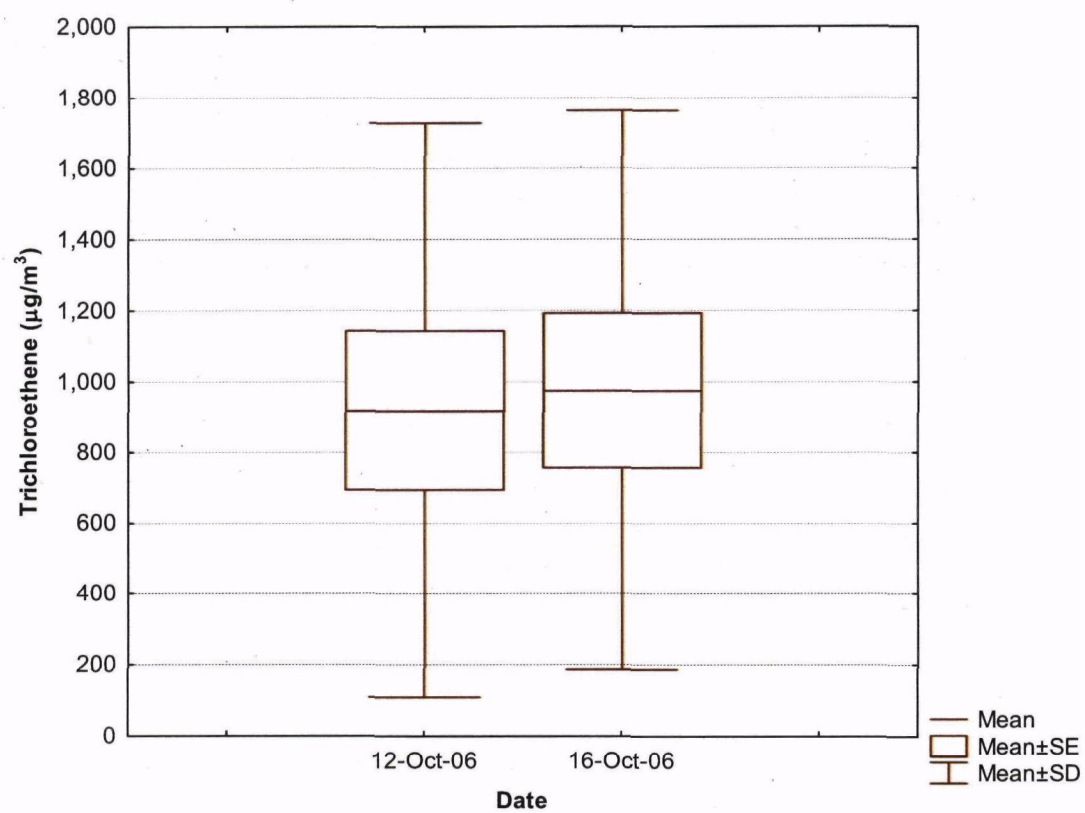


Figure D-8. Results of matched-pairs *t*-test analysis.

Appendix E
Active Soil Gas Sampling Method

1.0 INTRODUCTION

Active soil gas investigations are useful to obtain vapor phase data at sites potentially affected by volatile organic compounds (VOCs), including chlorinated and aromatic hydrocarbons. Active soil gas investigations may also be used to investigate sites potentially affected by methane and hydrogen sulfide, and to measure fixed and biogenic gasses (e.g., oxygen, carbon dioxide, or carbon monoxide). Among other things, the data can be used to identify the source and determine the spatial distribution of VOC contamination at a site, or to estimate indoor air concentrations for risk assessment purposes.

For site characterization, it is encouraged that both soil gas and soil matrix sampling be completed. Typically, soil gas data are more representative of actual site conditions in coarse-grained soil formations while soil matrix data are more representative of actual site conditions in fine-grained soil formations. For evaluating the risk associated with vapor intrusion to indoor air, soil gas data are the preferred contaminant data set, where practicable. Flux chamber and passive sampling methods are not discussed in this guidance. Any sites where such sampling methods are necessary will be addressed separately.

2.0 SUPPLEMENTAL RECOMMENDATIONS

The following sections are included in an effort to ensure that consistent methodologies are applied during soil gas investigations to produce reliable and defensible data of high quality. All sampling probe installation, sampling, and analytical procedures, whether or not discussed below, are subject to review and approval by the United States Environmental Protection USEPA (USEPA).

- 2.1 Project Management
- 2.2 Soil Gas Sampling Probe Installation
- 2.3 Purge Volume Test
- 2.4 Leak Test
- 2.5 Purge/Sample Flow Rate
- 2.6 Soil Gas Sampling

2.1 Project Management

2.1.1 Workplan: An appropriate workplan should be prepared and submitted to USEPA and/or responsible oversight agency [Agency] for review and approval at least 30 days prior to its implementation. Any variations or deviations from this guidance should be specified in the workplan. The soil gas workplan can either be incorporated as part of a comprehensive site investigation workplan or as a stand-alone document, depending on site-specific circumstances.

2.1.2 Field Activities

A. The USEPA/Agency should be notified 10 working days prior to implementation of field activities. All necessary permits and utility clearance(s) should be obtained prior to conducting any investigations described in this guidance.

B. All engineering or geologic work (e.g., logging continuous soil cores, soil description) should be performed or supervised by a Registered Professional in the State under which the work is completed. In addition, where applicable, all work performed should be under the direction and supervision of a project coordinator experienced in soil gas investigations.

C. Evaluation of raw data by USEPA/Agency staff may occur either in the field or in the office.

1. Hard copies of the complete raw laboratory data, including handwritten data and field notes, should be provided to the USEPA/Agency staff upon request.

2. Adjustments or modifications to the sampling program may be required by USEPA/Agency staff to accommodate changes mandated by evaluation of the data set or unforeseen site conditions.

D. Investigation derived wastes (IDW) should be managed as hazardous waste until proven otherwise or until specifically approved by the USEPA/Agency as being non-hazardous waste. IDW should be handled and disposed in accordance with federal, state and local requirements.

E. Field Variations

1. To expedite the completion of field activities and avoid potential project delays, contingencies should be proposed and included in the project workplan (e.g., soil matrix samples will also be collected if clayey soils [as defined in the Unified Soil Classification System (USCS)] are encountered during the proposed soil gas investigation; provisions for step-out sampling activities, etc.).

2. The USEPA/Agency field staff should be informed of any problems, unforeseen site conditions, or deviations from the approved workplan. When it becomes necessary to implement modifications to the approved workplan, the USEPA/Agency should be notified and a verbal approval should be obtained before implementing changes.

F. Soil Matrix Sampling Requirements: Companion soil matrix sampling may be conducted concurrently with a soil gas investigation except where extremely coarse-grained soils (as defined in USCS) are encountered or when specifically excluded by the USEPA/Agency.

2.1.3 Soil Gas Investigation Reports: A soil gas investigation report including a discussion of field operations, deviations from the approved workplan, data inconsistencies, and other significant operational details should be prepared. The report may either be a stand-alone document in a format recommended by the USEPA/Agency or be included within a site-specific assessment report. At a minimum, the report should contain the following:

A. Site plan map and probe location map at an appropriate scale as specified in the workplan (e.g., scale: one inch = 25 to 50 feet);

B. Final soil gas iso-concentration maps for contaminants of concern at the same scale as the site plan map;

C. Summary tables for analytical data in units consistent with the method;

D. Legible copies of field and laboratory notes or logs;

E. All analytical results and Quality Assurance/Quality Control (QA/QC) information including tables and explanations of procedures, results, corrective actions and effect on the data, in the format specified by the USEPA/Agency; and

F. Upon request, all raw data including chromatograms and calibration data should be submitted to the USEPA/Agency.

2.2 Soil Gas Sampling Probe Installation

2.2.1 Lithology: Site soil or lithologic information should be used to select appropriate locations and depths for soil gas probes. If on-site lithologic information is not available prior to conducting the soil gas investigation, at least one (1) continuously cored boring to the proposed greatest depth of the soil gas investigation should be installed at the first sampling location, unless specifically waived or deferred by USEPA/Agency. Depending on site conditions, additional continuously cored borings may be necessary. For site assessment purposes, sampling depths should target lithologic zones permeable to gas. For vapor intrusion assessments, sampling depths may be chosen based upon proximity to receptor rather than lithology.

A. Lithologic logs should be prepared for all borings (e.g., continuously cored borings, soil matrix sampling, geotechnical sampling, etc.). Note: This does not apply to direct-push soil gas probe installations that are not logged.

B. Information gathered from the continuously cored borings may include soil physical parameters, geotechnical data, and contaminant data.

C. If low-flow or no-flow conditions (e.g., fine-grained soil, clay, soil with vacuum readings that exceed approximately 10 inches of mercury or 136 inches of water) are encountered, soil matrix sampling using EPA Method 5035A should be conducted in these specific areas.

D. If the bottom five (5) feet of a continuously cored boring is composed of clay or soil with a vacuum exceeding approximately 10 inches of mercury or 136 inches of water, the continuously cored boring should be extended an additional five (5) feet to identify potential permeable zones. If the extended boring is also composed entirely of clay, the boring may be terminated. Special consideration should always be given to advancing borings and ensuring that a contaminant pathway is not being created through a low permeability zone.

2.2.2 Sample Spacing: There is no single rule regarding ideal sample spacing since each site investigation entails a unique set of considerations and objectives. In general, a sampling grid is an effective approach to objectively assess an overall area. Sample spacing within the grid should consider the overall project objectives, and include consideration of scale, site-specific features, and available investigative information during the preparation of the workplan. A scaled site plan depicting potential or known areas of concern (e.g., existing or former sumps, trenches, drains, sewer lines, clarifiers, septic systems, piping, underground storage tanks [USTs], chemical or waste management units) should be provided in the project workplan. The sampling grid is then projected over the

site plan such that each area of concern or interest is captured within the investigative scope. A background location where no contamination is expected is an important feature to include in all investigations.

Generally speaking, for characterization of known contamination areas and definitions of plume margins, a minimum sample spacing of 25 feet on center is applicable. For overall site coverage, a larger spacing of 50 feet may be more appropriate. For large sites in a general reconnaissance mode of investigation, increased sample spacing may be proposed based on site-specific conditions, with USEPA/Agency approval. To optimize detection and delineation of VOCs, the grid spacing should be modified to include biased (i.e. locations intended to detect areas of known or suspected contamination) sampling locations.

For vapor intrusion assessments, sample spacing will depend upon the size of the receptor (i.e. footprint of the building), location of the source relative to the receptor, and access to the receptor. At a minimum, enough points should be collected near or around the structure to get a representative value of the contaminant concentrations near the footprint of the building.

2.2.3 Sample Depth: Sample depths should be chosen to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface; and to ensure that representative samples are collected. Consideration should be given to the types of chemicals of concern, the lithology encountered, the depth to underlying groundwater, and the depth/location of the contaminant source.

A. At each sample location, soil gas probes are to be installed at a minimum of one sample depth. Five (5) feet below ground surface (bgs) is a common depth, but site specific considerations must always be considered, including shallower or deeper depths as appropriate.

B. In addition, samples should be collected near lithologic interfaces or based on field instrument readings (e.g., Flame Ionization Detector [FID], Photo Ionization Detector [PID]) from soil cuttings and/or cores to determine the location of maximum analyte concentrations at the top or bottom of the interface, depending upon the analyte.

C. Multi-depth sampling is appropriate for any of the following conditions:

1. To determine the source of the contamination vertically in the vadose zone.
2. To determine the vertical attenuation of the soil gas concentrations in the vadose zone
3. To determine the presence and zone of bioattenuation.

D. If no lithologic change or contamination is observed, default sampling depths may be selected for multi-depth sampling. For example, soil gas samples may be collected at 5, 15, 25, 40 feet bgs, etc., until either the groundwater is encountered or VOCs are not detected, whichever comes first.

2.2.4 Sampling Conveyance Tubing: Sample tubing should be of a small diameter (1/8 to 1/4 inch) to minimize "dead volume" and made of rigid wall material (e.g., nylon, Teflon, polyethylene, copper or stainless steel) which will not react or interact with site

contaminants. For example, metal tubing should not be used for collection of hydrogen sulfide samples. If copper tubing is used, the copper must first be adequately cleaned to remove oil residue that might be present from the manufacturing process.

A. Clean, dry tubing should be utilized at all times. If moisture, water, or an unknown material is present in the probe prior to insertion, the tubing should be decontaminated or replaced. All tubing should be flushed immediately prior to installation to ensure any vapors picked up during storage and transport are removed.

B. After use at each location:

1. Non-reusable (e.g., nylon or Teflon) sampling tubes should be discarded; or
2. Reusable sampling tubes should be properly decontaminated between locations.

C. At least once each day, equipment blanks should be collected by pulling clean air or nitrogen through the sampling probe and sample train. Positive detections > 20% of the minimum sample analyte concentrations in an equipment blank will form the basis for corrective action, including but not limited to replacement of tubing and/or sampling train components.

D. A drawing of the proposed probe tip design and construction should be included in the project workplan.

2.2.5 Soil Gas Probe Emplacement Methods

A. Permanent or Semi-permanent Soil Gas Probe Methods:

Permanent or semi-permanent soil gas probes may be installed, using a variety of drilling methods. Note that the mud rotary drilling method is not acceptable for soil gas probe emplacement. Other drilling methods such as air rotary and rotosonic can adversely affect soil gas data during and after drilling and will require extensive equilibration times. Therefore, they are not recommended when other methods can reach the target depths. Other soil gas probe designs and construction (e.g., soil gas wells or nested wells) may be appropriate and should be discussed with USEPA/Agency staff prior to emplacement.

When additional sampling is not anticipated per consultation with the USEPA/Agency, such probes may be properly removed or decommissioned after completion of the soil gas investigation. Unless logistically complicated, it is recommended for all installed probes, whether temporary or permanent, that the locations be recorded with descriptive and/or physical measurements using a measuring tape (or equivalent) to the nearest foot, or Global Positioning Satellite (GPS) coordinates, accurate to within 0.5 feet.

1. The probe tip should be emplaced midway within the sand pack. Typical sand pack thicknesses are 1 foot, but smaller or larger sand packs may be appropriate depending upon the purpose. The sand pack should be appropriately sized (e.g., average particle diameter equal to or greater in size than the adjacent formation) and installed to minimize disruption of airflow to the sampling tip. See Figure 1 for more information.

2. At least one (1) foot of dry granular bentonite should be emplaced on top of each sand pack to preclude the infiltration of hydrated bentonite grout. The borehole should be grouted to the surface with hydrated bentonite grout. With respect to deep probe construction with

multiple probe depths, the borehole should be grouted between probes. One (1) foot of dry granular bentonite should be emplaced between the filter pack and the grout at each probe location. See Figure 2 for more information.

3. The use of a down hole probe support may be required for deep probe construction (e.g., 40 feet bgs for direct push probes).

- a. Such probe support may be constructed from a one-inch diameter bentonite/cement grouted PVC pipe or other solid rod, or equivalent, allowing probes to be positioned at measured intervals.

- b. The support should be properly sealed or solid (internally or externally) to avoid possible cross-contamination or ambient air intrusion.

- c. The probes should be properly attached to the exterior of the support prior to placement down hole.

- d. Alternative probe support designs should be described in the project workplan. If probe support will not be used for deep probes, justification should be included in the project workplan.

4. Tubing should be properly marked at the surface to identify the probe location and depth.

5. As-built diagrams for probes or wells should be submitted with the soil gas investigation report detailing the well identification and corresponding probe depths. A typical probe construction diagram may be submitted for probes with common design and installation.

6. Unless soil gas probes are removed or decommissioned, probes should be properly secured, capped and completed to prevent infiltration of water or ambient air into the subsurface and to prevent accidental damage or vandalism. For surface completions, the following components may be installed:

- a. Gas-tight valve or fitting for capping the sampling tube;
- b. Utility vault or meter box with ventilation holes and lock;
- c. Surface seal; and
- d. Guard posts.

B. Temporary Soil Gas Probe Emplacement Method: In general, the drive rod is driven to a predetermined depth and then pulled back to expose the inlets of the soil gas probe. After sample collection, both the drive rod and tubing are removed.

1. During installation of the probe, hydrated bentonite should be used to seal around the drive rod at ground surface to prevent ambient air intrusion from occurring.

2. The inner soil gas pathway from probe tip to the surface should be continuously sealed (e.g., a sampling tube attached to a screw adapter fitted with an o-ring and connected to the probe tip) to prevent infiltration.

2.2.6 Equilibration Time: During probe emplacement, subsurface conditions may be disturbed. To allow for subsurface conditions to equilibrate, the following equilibration times are recommended:

A. For probes installed by hand methods or direct-push methods where sampling is done through the drive rod, the equilibration time may be highly variable and dependent upon a variety of factors including, but not limited to, probe rod diameter, depth of probe, soil lithology (i.e. tight soils which can result in frictional heating), and soil permeability. A time-series test is recommended to assess the equilibration time when practical (i.e. on-site mobile laboratory). When a time-series test is not practical, an equilibration time of at least 60 minutes is recommended.

B. For probes installed with direct push or hand methods where the drive rod does not remain in the ground (semi-permanent or permanent method), purging of the sand pack is warranted. If the sand pack volume is purged, no equilibration time should be required. If the sand pack is not purged, an equilibration time of at least 60 minutes is recommended unless a time-series test is conducted that shows the soil gas concentrations remain steady.

C. For probes installed with hollow stem drilling methods, purge volume test, leak test, and soil gas sampling should not be conducted for at least 48 hours (depending on site lithologic or drilling conditions) after the soil gas probe installation unless a time-series test is conducted that shows the soil gas concentrations remain steady.

D. Probe installation time should be recorded in the field log book.

E. When an investigation continues over the course of multiple days, and time-series test data are not available, at least one existing probe should be resampled after a 24 hour period in order to assess whether site-specific equilibration times should be increased beyond the default recommendations above.

2.2.7 Decontamination: After each use, drive rods and other reusable components should be properly decontaminated to prevent cross contamination. The proposed decontamination process should be addressed in the site-specific work plan.

2.3 Purge Volume Test

To ensure stagnant or ambient air is removed from the sampling system and near the probe tip after emplacement, a purge volume versus contaminant concentration test may be useful to assure collected soil vapor samples are representative of subsurface conditions. The purge volume test is conducted by collecting and analyzing a sample for target compounds after the removal of appropriate purge volumes. Various soil gas guidance documents recommend purging a probe sequentially after one through seven dead volumes, and plotting the analytic result to obtain an optimum number of purge volume to be applied to all successive probes.

The following considerations apply when determining the need for a purge volume test:

- Sample volume relative to the "dead-space" volume of the sampling probe. For probes with small dead-space volume (<150 ml), a 6-liter sample (i.e. SUMMA) corresponds to approximately 40 dead-space volumes. In this extreme case, a purge volume test is unlikely to yield useful data since the large sample volume overwhelms any measurable effect on modifying the small dead space volume purge.
- Therefore, if the sum of the dead space volume and the sample volume is greater than or equal to 7 times the dead space volume; it is recommended that a single dead space purge volume is sufficient to yield a representative result. The basis for this contention is that the sample container, once filled, will effectively average more than six dead space purge volumes, which spans the entire recommended range of purge volumes to be studied.
- In cases where the sum of the dead space volume and the sample volume is less than 7 times the dead space volume, it is recommended that a purge volume test be completed by collecting and analyzing the samples for target compounds after the removal of seven dead volumes as described in the next section to determine the nearest whole number of purge volumes that result in maximum target contaminant concentrations.
- When permanent or semi-permanent probes (tubes) are installed, the dead volume of the sand pack should be included in the total system dead volume if they are to be sampled the same day.

2.3.1 Purge Test Locations: The purge test location should be selected as near as possible to the anticipated or confirmed contaminant source, and in an area where soil gas concentrations are expected to be greatest based on lithology (e.g., coarse-grained sediments). The first purge test location should be selected through the workplan approval process or as a field decision in conjunction with USEPA/Agency staff.

2.3.2 Purge Volume: The purge volume or "dead space volume" can be estimated based on a summation of the internal volume of tubing used, and annular space around the probe tip. Sample containers (e.g., SUMMA™ canisters, syringes, and Tedlar™ bags) are not included in the dead space volume calculation when the sum of the dead space volume and the sample volume is less than 7 times the dead space volume.

The USEPA/Agency recommends step purge tests of one (1), three (3), five (5) and seven (7) purge volumes be conducted as a means to determine the purge volume to be applied at all subsequent sampling points.

A. The appropriate purge volume should be selected based on the highest concentration for the compound(s) of concern detected during the step purge tests. The purge volume should be optimized for the compound(s) of greatest concern.

B. If VOCs are not detected in any of the step purge tests, a default of three (3) purge volumes should be extracted prior to sampling.

C. The step purge tests and purging should be conducted at the same rate soil gas is to be sampled (see Section 2.5).

D. The purge test data (e.g., calculated purge volume, rate and duration of each purge step) should be included in the report to support the purge volume selection. The report should include a simple analysis of system purge volume versus targeted analyte concentration to document that the selected number of system volumes coincides with the highest concentration detected.

E. When an investigation continues over the course of multiple days, the purge test should be completed using the same probe array twice over a 24-hour interval to assess the effect of equilibration time on analytic results.

2.3.3 Additional Purge Volume Test

A. Additional purge volume tests should be performed to ensure appropriate purge volumes are extracted if:

1. Widely variable or different site soils are encountered; or
2. The default purge volume is used and a VOC is newly detected.

B. If a new purge volume is selected after additional step purge tests are conducted, the soil gas investigation should be continued as follows:

1. In areas of the same or similar lithologic conditions:

- a. Re-sample 20 percent of the previously completed probes.

This re-sampling requirement may be reduced or waived in consultation with USEPA/Agency staff, depending on site conditions. If re-sampling indicates higher detections (e.g., more than 50 percent difference in samples detected at greater than or equal to 10 µg/L), all other previous probes should be re-sampled using the new purge volume.

- b. Continue the soil gas investigation with the newly selected purge volume in the remaining areas.

2. In areas of different lithologic conditions: Continue the soil gas investigation with the newly selected purge volume in the remaining areas.

2.4 Leak Test

Leak tests involve introducing a known compound (e.g., the leak check compound is detected and confirmed in the test sample after its application) in the vicinity of a sample collection to ensure there are no leaks around the installed probe and/or the soil-gas sampling train. Leakage during soil gas sampling may dilute samples with ambient air and produce results that underestimate actual site concentrations or contaminate the sample with external contaminants. In all leak test applications, the practitioner must exercise care when handling leak check compounds so as not to introduce contaminants onto reusable

sampling equipment, into a mobile laboratory environment, or onto their persons which may otherwise result in a series of "false positives" as the contaminant is systematically carried from one location to the next.

2.4.1 Leak tests should be conducted at a minimum of 10% of the soil gas probes sampled, at regular intervals over the course of a program. When on-site analysis is used, leaks can be found in real-time and samples can be recollected, as necessary.

2.4.2 Leak Check Compounds: Methods exist using gases (e.g., helium, propane, SF₆, Freon) or liquids (Freon, isopropanol, butane in shaving cream). Both types of tracers have pros and cons.

A. Gaseous tracers can permit quantitative evaluation of the magnitude of a leak given knowledge of the starting concentration and the concentration detected in the sample. However, gaseous tracers do require additional hardware such as tanks, regulators, tubing, a "hood" within which to disperse the gas, etc. Helium offers a nice advantage in that it is readily measured on-site with a field meter, but due to its small molecular size, helium more readily permeates sampling materials than larger molecules typical of VOCs, so it may result in false positives.

B. Volatile liquid tracers offer logistical simplicity and accomplish the primary goal: detecting any leaks in the probe or sample train. Typically, the use of liquid tracers is not quantitative since the concentration at the point of application is typically not known. However, liquid tracers are readily available and easily and quickly supplied at multiple locations (probe, sampling rod, and sampling train) simultaneously using paper towels or clean rags. This method is particularly more suited for sampling through the probe rod since it can be applied at the base and top of the rod.

2.4.3 A leak check compound should be placed at any location where ambient air could enter the sampling system or where cross contamination may occur, immediately before sampling. Locations of potential ambient air intrusion include:

A. Sample system connections;

B. Surface bentonite seals (e.g., around rods and tubing); or

C. Top of the Temporary Soil Gas Probe (see Section 2.2.5.B).

2.4.4 The leak test should include an analysis of the leak check compound. Consideration must be given to interpretation of positive leak check detections. It is important to recognize that a small amount of tracer in a sample does not necessarily indicate a significant leak, and some discretion is advised. For instance, when a quantitative leak check process is used, if the concentration of the tracer in a sample is insignificant (i.e. less than 5 percent of the starting concentration) USEPA/Agency staff may be consulted to assess whether the sample result may be considered valid.

If a leak check compound is detected in the sample that is otherwise considered significant, the following actions should be followed:

- A. The cause of the leak should be evaluated, determined and corrected through confirmation sampling;
- B. If the leak check compound is suspected or detected as a site specific contaminant, a new leak check compound should be used;
- C. If leakage is confirmed and the problem can not be corrected, the soil gas probe should be properly decommissioned;
- D. A replacement probe should be installed at least five (5) feet from the original probe, or consult with USEPA/Agency staff; and
- E. The leak check compound concentration detected in the soil gas sample should be included and discussed in the report.

2.5 Purge/Sample Flow Rate

Sampling and purging flow rates should not enhance compound partitioning (i.e. excessive vacuum reading) during soil gas sampling. Samples should not be collected if field conditions as specified in Section 2.6.4 exist.

2.5.1 The purging or sampling flow rate should be attainable in the lithology adjacent to the soil gas probe.

A. To evaluate lithologic conditions adjacent to the soil gas probe (e.g., where no-flow or low-flow conditions exist), a vacuum gauge or similar device should be used between the soil gas sample tubing and the soil gas extraction devices (e.g., vacuum pump, SUMMA™ canister).

B. Gas tight syringes may also be used to qualitatively determine if a high vacuum soil condition (e.g., suction is felt while the plunger is being withdrawn) is present.

2.5.2 The USEPA/Agency recommends purging or sampling at rates between 100 to 500 milliliters per minute (ml/min) to limit stripping, prevent ambient air from diluting the soil gas samples, and to reduce the variability of purging rates. The low flow purge rate increases the likelihood that representative samples may be collected. At sites with permeable soils (e.g., clean sands), higher purge rates (i.e. on the order of liters per minute) have been shown to yield valid results and may be proposed in the workplan. The purge/sample rate may be modified based on conditions encountered in individual soil gas probes. These modified rates should be documented in the soil gas report.

2.6 Soil Gas Sampling

After the soil gas probe is adequately purged, samples should be collected by appropriate methodologies.

2.6.1 Sample Container: Samples should be collected in gas-tight, opaque/dark containers (e.g., syringes, glass bulbs wrapped in aluminum foil, SUMMA™ canisters), so that light-sensitive or halogenated VOCs (e.g., vinyl chloride) will not degrade.

A. If a syringe is used, it should be leak-checked before each use by closing the exit valve and attempting to force ambient air through the needle.

B. If syringe samples are analyzed within five (5) minutes of collection, aluminum foil wrapping may not be necessary.

C. Discretion is warranted when specifying use of SUMMA™ canisters due to the high canister volumes (i.e. 1 liter, 3-liter, 6-liter, etc.), and its potential effect on masking the determination of the appropriate number of dead purge volumes (see Section 2.3).

D. If a SUMMA™ canister is used, a flow regulator should be placed between the probe and the SUMMA™ canister to ensure the SUMMA™ canister is filled at the flow rate as specified in Section 2.5.2.

E. Tedlar™ bags may be used depending upon the project DQOs. Samples in Tedlar bags should not be stored for more than 24 hours to 48 hours.

2.6.2 Sample Collection

A. Vacuum Pump: When a vacuum pump is used, samples should be collected on the intake side of the vacuum pump to prevent potential contamination from the pump. Vacuum readings or qualitative evidence of a vacuum should be recorded on field data sheets for each sample.

B. Shallow Samples: Care needs to be taken when collecting shallow soil gas samples to avoid sample breakthrough from the surface. Extensive purging or use of large volume sample containers (e.g., SUMMA™ canisters) should be avoided for collection of near-surface samples [e.g., shallower than five (5) feet bgs].

2.6.3 Sample Container Cleanliness and Decontamination

A. Prior to its first use and after each subsequent use at a site, sample containers should be assured clean by the analytical laboratory.

1. Glass syringes or bulbs should be disassembled and properly decontaminated using an appropriate method.

2. SUMMA™ canisters should be properly decontaminated in the laboratory as specified by appropriate EPA analytical methods to reach required detection levels.

3. During sampling activities using reused/recycled sampling containers (e.g., SUMMAs, glass syringes, glass bulbs), at a minimum one (1) decontaminated sample container per 20 samples or per every 12 hours, whichever is more often, should be used as a method blank to verify and evaluate the effectiveness of decontamination procedures.

C. Plastic syringes should be used only once and then properly discarded.

1. An equipment blank should be run for each batch of plastic syringes used on a project, to document syringe conditions prior to use.

2.6.4 Field Conditions: Field conditions, such as rainfall, irrigation, fine grained sediments, or drilling conditions may affect the ability to collect soil gas samples.

A. Wet Conditions: If no-flow or low-flow conditions are caused by wet soils, the soil gas sampling should cease.

B. If low flow conditions are determined to be from a specific lithology, a new probe should be installed at a greater depth or a new lateral location should be selected after evaluation of the site lithologic logs (See Section 2.2.1) or in consultation with USEPA/Agency staff.

C. If moisture or unknown material is observed in the glass bulb or syringe, soil gas sampling should cease until the cause of the problem is determined and corrected.

D. If refusal occurs during drilling, soil gas samples should be collected as follows or in consultation with USEPA/Agency staff.

1. For sample depths less than five feet, collect a soil gas sample following the precautions outlined in Section 2.6.2.B.

2. For sample depths greater than five feet, collect a soil gas sample at the depth of refusal.

3. A replacement probe should be installed within five (5) feet laterally from the original probe decommissioned due to refusal. If refusal still occurs after three attempts, the sampling location may be abandoned.

2.6.5 Chain of Custody Records: A chain of custody form should be completed to maintain the custodial integrity of a sample. Probe installation times and sample collection times should be included in the soil gas report.

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