


***FINAL***

**SUPPLEMENTAL INVESTIGATION REPORT  
GROUNDWATER-TO-INDOOR AIR  
VOC MIGRATION PATHWAY  
MAIN TCE PLUME, OU5  
*FORMER LOWRY AFB, DENVER, COLORADO***

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## **1.0 INTRODUCTION**

As part of the remediation of base-wide groundwater (Operable Unit 5 [OU5]) at the former Lowry Air Force Base (Lowry), a program to sample residential indoor air, outdoor air, slab air, soil gas, and groundwater was implemented in 2007. The program, a follow-on to two previous investigations related to indoor air, was designed to assess whether or not observed decreases in dissolved volatile organic compound (VOC) concentrations in groundwater have resulted in comparable decreases in VOC concentrations in soil gas, slab air, and indoor air concentrations. The study area that is the focus of this investigation area overlays the Main Trichloroethene (TCE) plume and is bounded by 12th and 14th Avenues on the south and the north, and by Ulster and Valentia Streets on the west and east (see Figure 1).

This Indoor Air Investigation Report was prepared by Lowry Assumption, LLC (LAC) based on work performed by MACTEC Development Corporation (MACTEC) in March 2007.

### **1.1 SITE BACKGROUND**

The environmental program at Lowry began in 1983 with the Air Force Installation Restoration Program. Contamination in the groundwater, primarily from TCE, was identified in three distinct plumes (Main TCE, Headquarters Area and Fire Training Zone plumes). The largest, the Main TCE Plume, extends from source areas within the former base approximately three miles to the north, passing under the study area, a residential area north of the base. The Headquarters and Fire Training Zone plumes are limited in areal extent and do not underlie any residential properties. Compared with average monitoring data collected prior to 2001, TCE concentrations in groundwater within the study area at the time of the 2007 indoor air study had dropped 26 to 68%. This decrease results from the combination of interim remedial actions, active remediation, and natural degradation processes. An off-base injection of potassium permanganate was performed in late 2007 that included the study area. Based on January 2008 groundwater data from samples collected in the study area, there have been additional TCE concentration reductions of 20 to 92% in the study area since March 2007 when this indoor air study was performed.

The groundwater-to-indoor air migration pathway was studied as part of the U.S. Air Force (Air Force) OU5 investigation because of the potential risks from volatilization of VOCs dissolved in groundwater and the potential migration of these VOCs into overlying structures. During two previous Air Force investigations conducted in 1997 and 2001, the groundwater-to-shallow soil gas pathway was investigated using a combination of groundwater, indoor air, slab/subfloor gas, soil gas, and outdoor air samples (Versar, Inc., 2001 and 2003). The 2007 study focused on the very same sample locations in an effort to quantify the changes in TCE concentrations as the concentrations in groundwater have decreased.

#### **Chronology of Indoor Air Studies and Remediation**

<b>Date</b>	<b>Activity</b>
June – November 1997	Initial pathway evaluation sampling (groundwater, soil gas indoor air) of Heritage Estates and on-base buildings
December 1997 – January 1998	Installation of active slab depressurization system at Heritage Estates
1998	OU5 RI Groundwater to Indoor Air Pathway Evaluation
2002	Phase 3 Groundwater to Indoor Air Contaminant Migration Pathway Investigation
January 2003	Transition Plan for Groundwater Cleanup and Landfill Closure at Lowry

Date	Activity
March 2003	Installation of active subslab system depressurization at residence UA03
2003	Phase 1 Corrective Action Plan (CAP) for groundwater remediation
2003	Treatability studies and Phase 2 CAP
Fall, 2004	First round of potassium permanganate injections – on and off-base
Fall 2006	Second round of potassium permanganate injections – on-base
March 2007	Indoor Air Study (described in this report)
Fall, 2007	Second round of potassium permanganate injections – off-base

The previous investigations indicated that TCE vapor derived from the groundwater was potentially migrating from the water table, through unsaturated soil, into overlying structures. Following indoor air sampling conducted in September 1997 at the Heritage Estates apartments, located over the Main TCE plume and immediately north of 11<sup>th</sup> Avenue, the Air Force installed active subslab depressurization (ASD) systems in all buildings at the complex that overlie the Main TCE Plume (Versar, Inc., 1999). In December 1997, the Air Force began an investigation to delineate areas where the groundwater-to-indoor air pathway was potentially complete (Versar, Inc.2001 – Appendix K). The Phase III groundwater-to-indoor air study (Versar, Inc., 2003) focused on residences overlying the center of the Main TCE Plume between 12<sup>th</sup> and 13<sup>th</sup> Street, an area which was understood to represent the worst-case scenario for transport of VOCs from groundwater-to-indoor air due to the relatively higher groundwater concentrations in the area. In that study, indoor air samples were collected in 13 residences at two-month intervals over a period of one year between March, 2000 and February, 2001. In addition, subslab soil gas or crawlspace air, outdoor air, and groundwater samples were collected. The data were used to assess health risks, regardless of confounding influences from indoor or outdoor sources or background. The groundwater exposure point concentration of  $1.4 \times 10^{-5}$  exceeded the target risk level of  $1 \times 10^{-5}$  in one residence (1235 Uinta). The Air Force installed an ASD system in that residence; it began operating in March 2003.

Active remediation of the OU5 groundwater plumes with chemical oxidant (e.g., potassium permanganate) was started in 2004, following treatability studies and the development of the Corrective Action Plan (CAP) (LAC, 2006). TCE was identified as the main contaminant in the Lowry plumes; however, a full suite of VOCs is being evaluated in the groundwater monitoring programs. Two rounds of treatment have been completed on and off-base since injections began in the fall of 2004. For the entire period of investigation and treatment of the Main TCE plume, which began as early as 1983, there has been an average decrease in TCE concentrations in groundwater of approximately 86 to 94% for wells completed in the alluvium (LAC, 2008). These percentages are based on using the initial versus the latest measured concentrations (as of July 2007) and the minimum versus maximum concentrations detected in the wells, respectively.

This indoor air study was designed to assess whether or not observed decreases in dissolved VOC concentrations in groundwater have resulted in comparable decreases in VOC concentrations in soil gas, subslab gas, and indoor air. The sampling program for this study was implemented in March 2007.

## 1.2 OPERABLE UNIT 5 (BASEWIDE GROUNDWATER) STATUS

A large amount of groundwater data have been collected in and around the Main TCE Plume under various investigation, remediation, and monitoring programs. Since the remediation of OU5 was privatized, LAC has collected groundwater data semi-annually from June 2003 through July 2008. Through December 2006, a semi-annual groundwater monitoring network of up to 70 wells was used for long-term monitoring and remediation performance monitoring of the three TCE groundwater plumes (LAC, 2004). In 2007, the semi-annual monitoring network was revised for the Main TCE Plume to create a Closure/Performance GMP network (LAC, 2007b) in order to support the eventual regulatory closure of the Main TCE Plume.

Monitoring wells within the study area used during this program are shown in Figure 1. Some of these wells have been sampled during previous semi-annual monitoring programs and have been analyzed for VOCs by Method 8260, and data from these wells were used to develop the target analyte list used for the indoor air studies.

For the most part, TCE concentrations in the Lowry plumes have decreased since monitoring began as described in the various OU5 documents, particularly in the alluvium. The available data show that mass transfer from the source areas to the downgradient dissolved-phase plumes has been limited. These concentration reductions are likely the result of a combination of all remedial efforts to date as well as natural attenuation processes.

## **2.0 2007 INDOOR AIR ASSESSMENT**

In accordance with the Supplemental Investigation, Groundwater-to-Indoor Air VOC Migration Pathway Sampling and Analysis Plan (LAC, 2007a), the nature and pathway of groundwater-derived VOC concentrations in indoor air were assessed through a combination of groundwater, soil gas, subslab gas, indoor air and outdoor air sampling. All sampling occurred during March 2007.

### **2.1 CHEMICALS OF CONCERN**

Ten constituents of concern (COCs) were the target analytes in this investigation and previous indoor air studies (Table 1). These analytes include all the VOCs that were historically detected in groundwater samples immediately upgradient of the indoor air study area and potential degradation products of those compounds.

**Table 1. Target Analytes**

Vinyl Chloride
1,1-Dichloroethene (1,1-DCE)
Trichloroethene (TCE)
Tetrachloroethene (PCE)
cis-1,2-Dichloroethene (cis-1,2-DCE)
trans-1,2-Dichloroethene (trans-1,2-DCE)
1,1-Dichloroethane (1,1-DCA)
1,2-Dichloroethane (1,2-DCA)
1,1,1-Trichloroethane (1,1,1-TCA)
1,1,2-Trichloroethane (1,1,2-TCA)

### **2.2 BACKGROUND CONSIDERATIONS**

VOCs are found in a large number of consumer products and these external sources can easily confound evaluation of the groundwater-to-indoor air pathway. The sampling program was designed to minimize background concentrations of the constituents in the indoor air of residences. Residents were requested to limit uses of VOC-containing substances during the sampling. Outdoor air, soil gas and subslab samples were collected coincidentally with indoor air in order to evaluate the potential source of any detections and the associated pathway.

### **3.0 TESTING PROCEDURES**

All air sampling was conducted using SUMMA canisters as described below and the samples were analyzed using EPA Method TO-15 in accordance with Colorado Department of Public Health and Environment (CDPHE) guidance as detailed below.

#### **3.1 RESIDENTIAL SAMPLING LOCATIONS**

The residential sampling program was based upon the evaluation of data from two previous vapor migration studies (Versar, Inc. 2001 and 2003). During these two studies, indoor air and subslab gas samples were collected in a total of 14 residences overlying the Main TCE plume with full or partial basements. Attempts were made to resample all 14 homes; however, permission to sample was received from only nine of these residences for the March 2007 study. The sampling at each residence included: two indoor air samples (one in the basement and one on the first floor), and one subslab sample. Where possible, the subslab samples were collected from the same locations where samples were collected in the previous studies. For each day that any indoor air samples were collected, an outdoor air sample was also collected at one of the residences.

##### *Contacting Candidate Residences*

The records of the Denver Assessor's office were examined to determine the current owner for each property. A letter requesting participation in the study was sent to each owner with a postage paid post card; if the owner did not respond, a second letter was hand delivered. For any owners that did not respond, attempts were then made to speak with the owner personally. A third letter was mailed to residents that did not respond to any of the previous contacts. Permission was obtained to collect samples at nine of the residences.

##### *Interviews at Residences*

Prior to indoor air sampling, the residents were interviewed, a questionnaire was filled out, and a home inspection was conducted to identify if obvious sources or activities were present that could produce COCs which might affect indoor air samples. No obvious sources or activities were noted in the nine residences. The inspection also looked for potential conduits for vapor intrusion (i.e., dry wells, sumps, foundation cracks). Heating, ventilation, and air conditioning (HVAC) systems affecting the movement of air through the house, including the presence of direct vents to the basement (e.g., air supply for furnace, windows, other openings). Finally, each house was checked for an existing radon mitigation system. The home at 1314 Ulster had an active radon mitigation system, and 1235 Uinta Street had a system that was not operating at the time of the study. The questionnaires completed for each home are presented in Appendix A.

##### *Indoor/Outdoor Air Sample Collection*

Two indoor air samples were collected at each residence using a canister that was placed two to five feet above the floor in the basement and on the first floor. Canisters were placed as far away as possible from HVAC system vents and windows. Residents were asked to close their windows and doors during the entire sampling period. Canisters for outdoor samples were placed outside the residence at least five feet away from the structure and four to six feet above the ground surface.

Indoor and outdoor air samples were collected using six-liter SUMMA<sup>®</sup>-passivated stainless steel canisters. Air samples were collected in the canisters as composite subatmospheric samples over a nominal 24-hour time period in each residence. Each complete sampling system was certified for acceptable blank levels of COIs prior to shipment by the laboratory. Each canister was evacuated to a

nominal 29 to 30 inches of mercury (in. Hg) at the laboratory and shipped to the field. The canister vacuum was noted and recorded in the field at the beginning and end of each sampling event. Field data sheets are included in Appendix B. Analytical results for the indoor/outdoor air samples are included in Appendix C (Table C.1).

#### *Subslab Air Sample Collection*

After the indoor air samples were collected, subslab air samples were collected in eight of the nine residences. One basement was finished with wall-to-wall carpeting, so no subslab sample was collected. To the extent possible, subslab air samples were collected at the same locations where the previous samples were collected. If the previous sample location could be identified, it was used for the sampling. In two of the basements, a new hole was drilled in the concrete slab. New tubing was used for each sample. Once the hole was open, the tubing was inserted through the hole and the annular space around the tubing was sealed with a bentonite paste. Approximately one-half liter of air was purged from beneath the foundation slab. Following the purge, a sample was collected for analysis. After sampling, the holes were filled with bentonite and sealed with concrete caulk.

Subslab air samples were collected in the canisters as composite subatmospheric samples over a nominal 30-minute time period in each residence. A duplicate subslab sample was collected each day that samples were collected. Each complete sampling system was certified for acceptable blank levels of COIs prior to shipment by the laboratory. Each canister was evacuated to a nominal 29 to 30 in. Hg at the laboratory and shipped to the field. The vacuum was noted and recorded in the field at the beginning and end of each sampling event. Field data sheets are included in Appendix B. Analytical results for the subslab samples are included in Appendix C (Table C.2).

### 3.2 SOIL GAS SAMPLING LOCATIONS

Figure 1 presents the approximate locations for 15 soil gas sampling locations. A soil gas sample point was located near each of the alluvial groundwater monitoring wells and at additional points on Uinta Street and in the alley between Uinta Street and Ulster Streets.

Using direct push methods, a continuous core was collected to a depth of ten feet below ground surface (ft bgs) to identify a permeable zone for sampling at a depth representative of the bottom of a basement slab. After the soil gas sampling location was cored, a small diameter sampling tube (1/4 inch) with a gas sampling probe tip was installed at each location to a depth of seven to ten ft bgs. The probe tip was placed in the middle of approximately one foot of sand pack. One foot of granular bentonite was placed above the sand pack, followed by hydrated bentonite to within approximately one foot of the surface. Silica sand was placed above the hydrated bentonite to the surface. A gas-tight fitting was installed at the top of the sampling tube, and a flush-mount surface completion was installed for each location.

#### *Soil Gas Sample Collection*

Soil gas samples were collected from 14 of the 15 locations shown in Figure 1. No sample was obtained from location SGCA07, because of water in the monitoring point. Based on the completion depth of the soil gas probe, the water in the monitoring point was not groundwater.

For each soil gas sample, new tubing was connected to a sample pump and approximately one liter of air was purged from the soil gas monitoring point. Following the purge, a sample was collected for analysis using a six-liter SUMMA<sup>®</sup>-passivated stainless steel canister. Each sampling system consisted of a canister and a dedicated flow controller. The analytical laboratory preset the dedicated flow controller/critical orifice for each sample canister to a nominal 100 to 200 (ml/min) flow rate. For each soil gas sample collected, a leak test was performed by placing a paper towel saturated with isopropanol

(IPA) around the surface completion of the monitoring point; IPA was included in the analyte list for each sample.

Soil gas samples were collected in the canisters as composite subatmospheric samples over a nominal 30-minute time period. A duplicate soil gas sample was collected each day that samples were collected. Each complete sampling system was certified for acceptable blank levels of COIs prior to shipment by the laboratory (i.e., less than 0.2 ppbv). Each canister was evacuated to a nominal 29 to 30 in. Hg at the laboratory and shipped to the field. The vacuum was noted and recorded in the field at the beginning and end of each sampling event. Field data sheets are included in Appendix B. Analytical results for the soil gas samples are included in Appendix C (Table C.3).

### 3.3 GROUNDWATER SAMPLING

Figure 1 presents the locations of 13 groundwater sampling locations. Monitoring well MWCA12 and MWCA13 were new wells installed in 2007. Monitoring well MWCA13 was installed to replace monitoring well MWOB20.

#### *Groundwater Sample Collection*

Groundwater samples were collected from these wells using the sampling procedures defined in the *Revised Final Groundwater Monitoring Program Work Plan Former Lowry Air Force Base* (MACTEC, 2004), and one duplicate sample was collected during each day of sampling. Analytical results for the groundwater samples are included in Appendix C (Table C.4).

## **4.0 ANALYTICAL PROCEDURES**

### **4.1 INDOOR/OUTDOOR AIR SAMPLES**

All air samples, (indoor, outdoor subslab and soil gas) were analyzed using a modified Method TO-15 (USEPA, 1999a) and the contract laboratory standard operating procedures (SOPs). Specific analytical procedures are described below.

The laboratory reporting limits are initially established for an undiluted laboratory standard. When a sub-atmospheric integrated sample is collected, the canister does not fill completely. A diluent gas is added to pressurize the canisters for analysis. Consequently, sample reporting limits can vary for each sample, depending on sample volume and sample matrix effects (Table 2). The sample reporting limit for TCE meets the most stringent screening level of 0.016 micrograms per cubic meter (ug/m<sup>3</sup>) established in the CDPHE 2004 guidance for TCE in indoor air and all are below the risk based Regional Screening Levels (USEPA, 2008b).

**Table 2. Sample Reporting Limits for Air Samples**

<b>Volatile Organic Compound</b>	<b>Sample Reporting Limits (µg/m<sup>3</sup>)</b>	<b>Screening Level* Target Risk</b>	<b>Screening Level* Hazard Index</b>
Vinyl Chloride	0.030 – 0.042	0.16	100
1,1-Dichloroethene (1,1-DCE)	0.030 – 0.042		210
Trichloroethene (TCE)	0.012 – 0.017	1.6**	
Tetrachloroethene (PCE)	0.030 – 0.042	0.41	280
Cis-1,2-Dichloroethene (cis-1,2-DCE)	0.030 – 0.042		
trans-1,2-Dichloroethene (trans-1,2-DCE)	0.030 – 0.042		63
1,1-Dichloroethane (1,1-DCA)	0.030 – 0.042	1.5	
1,2-Dichloroethane (1,2-DCA)	0.030 – 0.042	0.094	
1,1,1-Trichloroethane (1,1,1-TCA)	0.030 – 0.042		5200
1,1,2-Trichloroethane (1,1,2-TCA)	0.030 – 0.042	0.15	

Source: USEPA Regions 9, 6, and 3 Regional Screening Levels for Chemical Contaminants at Superfund Sites  
[http://www.epa.gov/reg3hwmd/risk/human/rb-concentration\\_table/Generic\\_Tables/xls/resair\\_sl\\_table\\_run\\_12SEP2008.xls](http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/xls/resair_sl_table_run_12SEP2008.xls)

\*\*CDPHE, 2004, Proposed level at which cleanup would be required.

### **4.2 SOIL GAS/SUBSLAB AIR SAMPLES**

Actual sample reporting limits were defined for each sample based on the volume of diluent and sample matrix effects, as described above. The actual reporting limits are shown on the results table and full data are provided in Appendix C. The laboratory inadvertently analyzed the subslab samples for isopropanol, and those data are reported with the COCs.

### 4.3 GROUNDWATER SAMPLES

Groundwater samples were analyzed using Method 8260B as defined in the *Revised Final Groundwater Monitoring Program Work Plan Former Lowry Air Force Base* (MACTEC, 2004).

### 4.4 SAMPLING SYSTEM CLEANING AND CERTIFICATION

Each air sample collection system (i.e., sample canister and flow controller) was certified for cleanliness by the contract laboratory prior to use. The analytical laboratory performed system cleaning and certification evaluations of the systems prior to use. The sampling systems were used to sample ultrapure air (or nitrogen) through the flow controller and into the canister. The collected sample was analyzed by the laboratory for the COCs. If the concentration of each COC in the sample was less than acceptance criteria noted above, the system was laboratory-certified as clean.

## **5.0 QUALITY ASSURANCE AND QUALITY CONTROL**

Laboratory quality assurance/quality control (QA/QC) samples consisted of: instrument blanks, method blanks, cleaning/certification samples, laboratory standards, laboratory control samples (LCS), surrogates, laboratory blank spikes, and laboratory duplicates. Laboratory QA/QC control samples were analyzed at a frequency consistent with the approved laboratory SOPs. In addition, field duplicate samples of each type were collected.

### **5.1 PRECISION**

Precision was evaluated through analyses of laboratory duplicate samples and field duplicate samples. Laboratory duplicates are two aliquots obtained from the same sample that are analyzed to determine matrix-specific precision. Field duplicates were collected in separate canisters.

Precision was calculated in terms of relative percent difference (RPD) for both the laboratory and field duplicate samples. The RPD is expressed as a percentage of the absolute value of the difference of the two results divided by the average of the two results. RPD was calculated for samples with concentrations at least five times the sample reporting limit. The RPD criterion for laboratory and field samples established for the Sampling and Analysis Plan (SAP) was 25%. With one exception, this criterion was met for all indoor air, outdoor air, subslab, soil gas, and groundwater samples, and for the laboratory duplicates. The single exception was a duplicate soil gas sample. For subslab sample SS135001 the initial concentration for TCE was  $14 \mu\text{g}/\text{m}^3$ , and the duplicate sample concentration was  $6.4 \mu\text{g}/\text{m}^3$ . Because of the small absolute value, the difference of  $7.6 \mu\text{g}/\text{m}^3$  resulted in a large percentage difference, but represents a small difference.

### **5.2 ACCURACY**

Accuracy was evaluated through the analyses of LCS and by spiking the air samples with surrogate compounds. LCS analyses are spikes on a blank matrix to assess accuracy independent of matrix effects. For the air samples, certified standards were used for the LCS. The criterion for acceptable recovery for this program was 70 to 130%, and was met for all analyses.

### **5.3 REPRESENTATIVENESS**

Indoor and outdoor air samples were collected over a 24-hour time period and were contained in six-liter stainless steel canisters. Subslab and soil gas samples were also collected in six-liter stainless steel canisters. The samples were collected in accordance with standard industry practices and the approved work plan and are therefore considered to be representative of the media sampled.

### **5.4 COMPLETENESS**

Qualitative completeness was assessed by reviewing the tasks that contribute to the sampling event, such as chain-of-custody procedures, sample documentation, and adherence to the SAP. Quantitative completeness is defined as the ratio of the number of the acceptable sample results obtained to the total number of sample results collected. The laboratory QC parameters that were evaluated include: holding times, initial calibrations, continuing calibrations, surrogate recoveries, LCS recoveries and laboratory duplicate RPDs. With three exceptions, all of the planned samples were collected and the results were acceptable for use. The three exceptions were the planned soil gas monitoring point SGCA05, soil gas sample from monitoring point SGCA07, and a subslab sample in one residence. Permission to install SGCA05 was not obtained from the land owner. The soil gas sample from monitoring point SGCA07 could not be collected, because of water in the monitoring point. One subslab sample was not collected,

because the basement floor in the residence was covered with wall-to-wall carpeting that was glued to the concrete. No sampling location could be installed without damaging the carpeting and the owner declined to allow removal of the carpeting. Adequate data were collected in the study to evaluate the groundwater to indoor air pathway for the uses of this study.

## 5.5 COMPARABILITY

To ensure data comparability, the contract laboratory used standard test methods; standard calculation procedures and reporting formats, standard measures of accuracy and precision, and reported results in units of  $\mu\text{g}/\text{m}^3$  at actual temperature and pressure for the sample location. Meteorological data including barometric pressure, temperature, and other weather observations were obtained for each day samples are collected. Data were collected in accordance with the approved work plan and laboratory analysis followed approved protocols, resulting in comparable data.

## 5.6 DATA VALIDATION

MACTEC performed a validation of the laboratory's analytical results. Using the analytical and QC summaries provided by the laboratory, the analytical data generated during the sampling program were reviewed for completeness and compliance with method QC criteria. An additional raw data review and calculation checks were performed to assess data defensibility for one sample from each medium. MACTEC evaluated the analytical data quality based on the guidance provided in Method TO-15, the laboratory SOPs and, where Organic Data Review (USEPA, 1999b). No additional data qualifiers were required for the data. All data were deemed to be acceptable for use.

## 6.0 RESULTS

Summaries of laboratory data for all samples are provided in this section and in Appendix C.

### 6.1 GROUNDWATER DATA

Eight of the ten target analytes were detected in groundwater samples during the study (Table 3); 1,2-DCA and 1,1,1-TCA were not detected. The laboratory reports for the groundwater data are provided in Appendix C Table C.4. Table C.5 presents a summary of historical TCE concentration data for the monitoring wells included in this study. TCE concentrations ranged from 3.3 to 41 micrograms per liter (ug/L) in alluvial wells and 46 to 270 ug/L in Denver Formation wells (Figure 2).

**Table 3. Groundwater Results (ug/L)**

Sample No.	Aquifer	Vinyl Chloride		1,1-Dichloroethene		Trans-1,2,-Dichloroethene		1,1-Dichloroethane		Cis-1,2,-Dichloroethene		Trichloroethene		1,1,2-Trichloroethane		Tetrachloroethene	
		1	Flag	0.3	Flag	1	Flag	1	Flag	0.36	Flag	8.1	Flag	1	Flag	1	Flag
MW0B22	A	1	U	0.3	J	1	U	1	U	0.36	J	8.1		1	U	1	U
IM-9	A	1	U	0.19	J	1	U	1	U	1	U	3.3		1	U	1	U
B-1	A	1	U	0.66	J	1	U	1	U	1		24		1	U	0.75	J
IM-7A	A	1	U	0.7	J	1	U	0.22	J	1.1		31		1	U	1.1	
MW0B21	DEN	1	U	0.64	J	1	U	0.3	J	1.5		46	D	1	U	1.1	
IM-10	A	1	U	0.38	J	1	U	0.23	J	0.97	J	26		1	U	0.67	J
MW0B04	A	1	U	0.39	J	1	U	0.35	J	1.6		41	D	1	U	0.97	J
MW0B04D	DEN	1	U	1.4		0.2	J	0.73	J	3.7		120	D	0.31	J	2.6	
MWCA13	A	1	U	0.41	J	1	U	0.21	J	1		27		1	U	0.92	J
MWCA13 DUP	A	1	U	0.52	J	1	U	0.24	J	1.1		26		1	U	0.96	J
IM-11	A	1	U	0.26	J	1	U	0.23	J	0.86	J	23		1	U	0.63	J
IM-11 DUP	A	1	U	0.32	J	1	U	0.21	J	0.85	J	24		1	U	0.68	J
MWCA12	A	1	U	0.27	J	1	U	0.19	J	0.63	J	21		1	U	0.52	J
IM-12D	DEN	0.17	J	1.9		0.2	J	0.43	J	1.6		90		1	U	1.1	
IM-7D	DEN	10	U	6.9	J	10	U	2.2	J	11		270		10	U	6.7	J

Samples collected 3/12/07 and 3/13/07

Dup - duplicate sample

U - compound was not detected, reported value is the laboratory reporting limit

J - Estimated concentration, compound detected between the method detection limit and the reporting limit.

D - sample was diluted for quantitation

Aquifer: Alluvial=A; Denver Formation = DEN

Historical groundwater data are available for four monitoring wells within the study area from 1998 and 2001, when the earlier studies were performed. These data can be used to observe the long term trends in TCE concentrations in the aquifer. In wells monitored the longest within the indoor air study area, there was a reduction in the average TCE groundwater concentrations of 44% with a range of 24 to 68% between the earlier indoor air studies (data from 1996-2001) and the 2007 study (data from 2006-2007) (Table 4, Figure 3).

**Table 4. Historical TCE Groundwater Sampling Data (ug/L)**

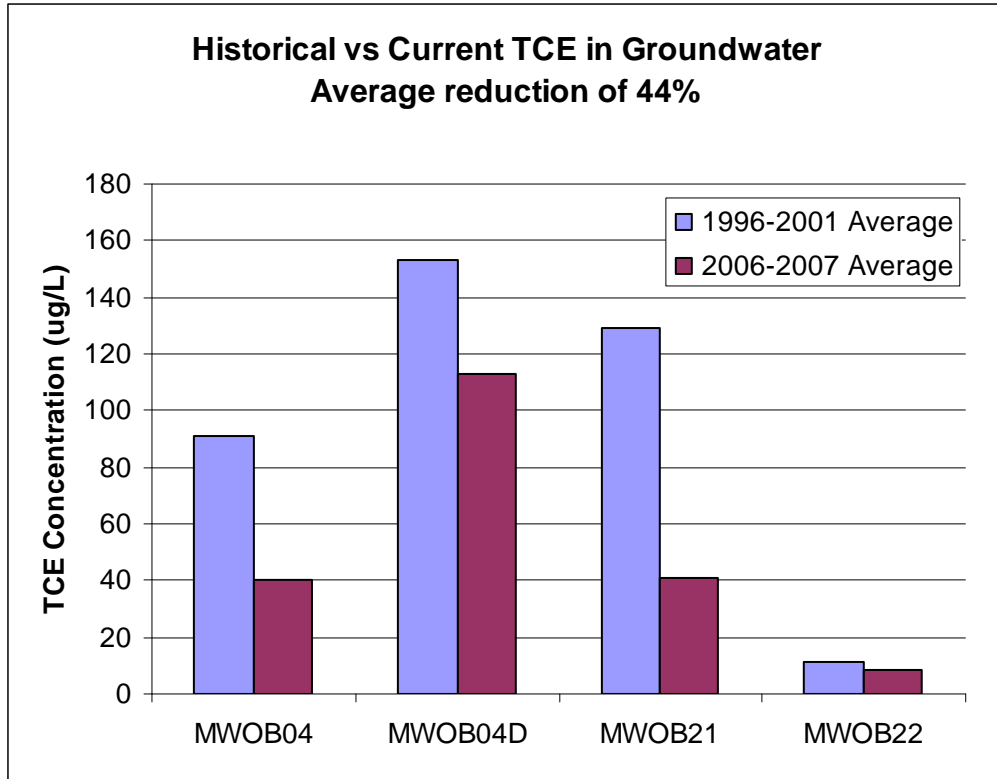
Sample Date	MWOB04	MWOB04D	MWOB21	MWOB22	
10/23/1996	110	150			
12/11/1996	64	150			
7/8/1998			130	13	
8/25/1998			140		
11/4/1998			99		
12/16/1998			130		
12/15/1999	98	160		9.5	
1/24/2000			100		
4/3/2000			160		
6/21/2000			170		
9/14/2000			150		
11/9/2000		170	124		
12/21/2000			75		
2/7/2001			140		
2/27/2001		150			
5/16/2001		160			
8/21/2001		130			
<b>Historical Minimum Concentration</b>	<b>64</b>	<b>130</b>	<b>75</b>	<b>9.5</b>	
<b>Historical Maximum Concentration</b>	<b>110</b>	<b>170</b>	<b>170</b>	<b>13</b>	
<b>Historical Average Concentration</b>	<b>91</b>	<b>153</b>	<b>129</b>	<b>11</b>	
8/23/2006	37	110			
12/4/2006	41	110	36	8.9	
3/12/2007	41	120	46	8.1	
<b>Current Minimum Concentration</b>	<b>37</b>	<b>110</b>	<b>36</b>	<b>8.1</b>	
<b>Current Maximum Concentration</b>	<b>41</b>	<b>120</b>	<b>46</b>	<b>8.9</b>	
<b>Current Average Concentration</b>	<b>40</b>	<b>113</b>	<b>41</b>	<b>8.5</b>	
					<b>AVERAGE**</b>
<b>Ratio: Current/Historical*</b>	<b>0.44</b>	<b>0.74</b>	<b>0.32</b>	<b>0.76</b>	<b>0.56</b>
<b>% Reduction</b>	<b>56%</b>	<b>26%</b>	<b>68%</b>	<b>24%</b>	<b>44%</b>

Note: Blank indicates that well was not sampled

\*Ratio calculated as Historical average /current average

\*\* Average of Ratio for Current/ Historical

Figure 3 – Change in TCE Concentrations In Groundwater



## 6.2 SOIL GAS DATA

Soil gas samples were collected at fourteen locations during the study. No sample was obtained from SGCA07 because there was water in the hole, likely from a nearby utility. Six of the ten target analytes were detected in the soil gas samples (Table 5). TCE and PCE were detected in each sample with the exception of SGCA08 as described below. Isolated detections of 1,1-DCE, 1,1-DCA, cis-1,2-DCE, and 1,1,1-TCA occurred in the samples and 1,1,1-TCA was detected in SGCA18, although the compound was not detected in groundwater. TCE concentrations in the soil gas ranged from 5.8 – 3100 ug/m<sup>3</sup> with the highest concentrations present at the south end of the study area (Figure 4).

**Table 5. Soil Gas Sampling Data Summary (ug/m<sup>3</sup>)**

Sample No.	Isopropanol	1,1-DCE	1,1-DCA	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
SGCA06	<b>680</b>	<b>31</b>	21U	21U	21U	<b>3,100</b>	<b>390</b>
SGCA08	<b>540,000</b>	5,200U	5,200U	5,200U	5,200U	5,200U	5,200U
SGCA09	<b>16</b>	0.88U	0.88U	0.88U	0.88U	<b>110</b>	<b>18</b>
SGCA10R*	<b>1,900</b>	17U	17U	17U	17U	<b>150</b>	<b>68</b>
SGCA11	4.2U	4.2U	4.2U	4.2U	4.2U	<b>400</b>	<b>73</b>
SGCA12	2.9U	2.9U	2.9U	2.9U	2.9U	<b>470</b>	<b>47</b>
SGCA13	2.9U	2.9U	2.9U	2.9U	2.9U	<b>120</b>	<b>32</b>
SGCA14	<b>42</b>	4.1U	4.1U	4.1U	4.1U	<b>530</b>	<b>120</b>
SGCA15	<b>44</b>	2.3U	2.3U	2.3U	2.3U	<b>220</b>	<b>31</b>
SGCA15DUP	<b>46</b>	2.2U	2.2U	2.2U	<b>2.5</b>	<b>330</b>	<b>47</b>
SGCA16	<b>440</b>	<b>37</b>	8.5U	<b>15</b>	8.5U	<b>1,500</b>	<b>120</b>
SGCA17	<b>430</b>	11U	11U	11U	11U	<b>1,300</b>	<b>180</b>
SGCA18	<b>37</b>	<b>45</b>	<b>7.2</b>	<b>14</b>	<b>9.8</b>	<b>2,600</b>	<b>310</b>
SGCA19	<b>210</b>	1.4U	1.4U	1.4U	1.4U	<b>5.8</b>	<b>2.5</b>
SGCA20	<b>11</b>	0.83U	0.83U	0.83U	0.83U	<b>7.6</b>	<b>62</b>
SGCA20DUP	<b>8.6</b>	0.83U	0.83U	0.83U	0.83U	<b>7.5</b>	<b>62</b>

Note: Blank cell indicates compound not detected – full results are in Appendix C

U - not detected above laboratory reporting limit

\* - Data from lab reported under SGCA10R – location was resampled because of possible leak.

The elevated concentration of isopropanol in SGCA08, and to a lesser extent SGCA06, 10R, 16, 17, and 19, indicates a potential short-circuit between the soil gas monitoring point and the atmosphere. The isopropanol concentration in SGCA08 was too high to obtain quantitative concentrations for any other constituent. Concentrations measured at the other five locations may be biased low. For the remaining wells, the concentrations of isopropanol are considered to represent background. Isopropanol was detected in the subslab samples in seven of the nine homes.

Historical TCE soil gas concentrations in the study area were available for a 1998 investigation (Versar, Inc., 2001). Nine of the 1998 sampling locations (Figure 5) were located near the locations of the 2007 sampling. The data from the 1998 investigation and 2007 sampling data for TCE are presented in Appendix C (Table C.6) and are compared below in Table 6.

**Table 6. Soil Gas TCE Comparison Data**

<b>1998 Location</b>	<b>TCE Concentration ug/m<sup>3</sup></b>	<b>2007 Location</b>	<b>TCE Concentration, ug/m<sup>3</sup></b>	<b>Ratio 2007/1998</b>	<b>Percent Reduction (%)</b>
SGOB27	203	SGCA06**	3,100	15	NA
SGOB37	388	SGCA09	110	0.28	82
SGOB16	739	SGCA11	400	0.54	46
SGOB38	1,895	SGCA12	470	0.25	75
SGOB32	15	SGCA14	530	35	NA
SGOB21	4,391	SGCA16**	1,500	0.34	66
SGOB09	2,778	SGCA17**	1,300	0.47	53
SGOB28	8	SGCA19	6	0.74	26
SGOB22	74	SGCA20	8	0.10	90
<b>Average Concentration</b>	<b>1166</b>		<b>825</b>		
	<b>Ratio of Average concentrations 2007/1998</b>		<b>0.70*</b>		
	<b>Average Percent Reduction</b>		<b>30%</b>		

ug/m<sup>3</sup> micrograms per cubic meter

\*Average Ratio based on 1998 Average (1166 ug/m<sup>3</sup>)/2007 average (825 ug/m<sup>3</sup>);

\*\*Isopropanol in sample

Soil gas concentrations at seven of the nine locations decreased between 1998 and 2007 with the percent reduction ranging from 26 to 90% with concentrations increasing at two locations (SGCA06 and SGCA14). Overall, the average concentrations decreased from 1166 to 825 ug/m<sup>3</sup> for adjacent samples between 1998 and 2007. There have been general decreases in alluvial groundwater TCE concentrations in the same timeframe in the alluvial wells as evidenced by the decrease in average groundwater concentrations by 44%. Individual variation in data points may be caused by a number of conditions at the site, and are not explained by direct comparisons at nearby alluvial wells. For example, well B-1, which is just upgradient of SGCA06, had a decrease of TCE in groundwater from a high of 160 ug/L in 2003 to 19 ug/L in January 2008 (well was not sampled in March 2007) while SGCA06 increased 15-fold. In alluvial Well IM-10, immediately upgradient of SGCA14, the TCE concentration increased from 11 ug/l (June 2004) to 26 ug/l (March 2007) or a factor of 2.4, much less than the 35-fold increase in soil gas compared to the adjacent 1998 location.

### 6.3 SUBSLAB DATA

Subslab samples were collected at eight of the nine residences included in this study. Three compounds were detected in the subslab samples: isopropanol, TCE, and PCE. 11 DCE, 11 DCA and cis,1,2 DCE which were detected in groundwater and soil gas samples collected from the study area during 2007, were not detected in any of the subslab samples (Table 7). TCE concentrations in subslab samples ranged from 0.98 to 1400 ug/m<sup>3</sup> (Figure 6). The highest subslab concentrations were present in the central and northern part of the 1200 block of Uinta Street.

**Table 7. Subslab Air Sample Results for Detected Compounds**  
(ug/m<sup>3</sup>)

Address	Sample Date	Isopropanol	Trichloroethene	Tetrachloroethene
1235 Uinta St.	3/6/2007	12	1,100	70
1222 Uinta St.	3/6/2007	0.97	160	13
1222 Dup	3/6/2007	1.5	160	13
1238 Uinta St.	3/6/2007	<85	480	89
1282 Uinta St.	3/6/2007	<14	1,400	85
1329 Uinta St.	3/7/2007	1.0	200	10
1329 Dup	3/7/2007	1.3	170	11
1350 Ulster St.	3/8/2007	3.3	14	1.8
1350 Dup	3/8/2007	22	6.4	1.3
1271 Uinta St.	3/8/2007	14	940	42
1314 Ulster St*.	3/8/2007	2.6	<0.98	<0.98

Dup - duplicate sample

< - Not detected – less than detection limit

\* Subslab system operating

The sample collected from the 1350 Ulster Street had the lowest concentration of both TCE and PCE. The home at 1314 Ulster Street had a radon mitigation system installed, and neither TCE nor PCE was detected in the subslab sample collected at this residence. Results for subslab sampling from the 1998, 2001, and 2007 sampling events are compared in Table 8.

**Table 8. Subslab TCE Concentration Comparison**

Address	TCE Concentration, ug/m <sup>3</sup>			TCE Concentration Ratio 2007/1998	TCE Concentration Ratio 2007/2001	Percent Reduction
	1998	2001	2007			
1235 Uinta St.	-	3,145	1,100	-	0.35	65
1222 Uinta St.	-	111	160	-	1.4	
1238 Uinta St.	-	808	480	-	0.59	41
1282 Uinta St.	-	2,380	1,400	-	0.59	41
1329 Uinta St.	502	-	200	0.40	-	60
1350 Ulster St.	ND	-	14	-	-	
1271 Uinta St.	-	119	940	-	7.9	
1314 Ulster St.*	201	-	<0.98	.005	-	>99
Average	**	1313	613			
				Ratio of Average concentrations 2007/2001	0.47	
				Percent Reduction	53%	

\*Subslab system operating

\*\*No average calculated because of limited data set

Subslab concentrations at five of the eight locations decreased between 1998 and 2007 with the percent reduction ranging from 41 to greater than 99 %. Overall, the average concentration decreased from 1313 to 613 ug/m<sup>3</sup> ( 53%) between the 2001 and 2007 samples (Table 8). The general decreases in soil gas and alluvial groundwater data correlate to the average subslab decrease. In looking at the individual results, concentrations increased at three of the eight locations (1222 Uinta St., 1350 Ulster St. and 1271 Uinta St.). The subslab concentration at 1222 Uinta increased from 111 ug/m<sup>3</sup> in 2001 to 160 ug/m<sup>3</sup> in 2007. The sample is surrounded by soil gas samples SGCA 17, SGCA19 SGCA16 and SGCA20 which all decreased - 53%, 26%, 66% and 90%, respectively. Groundwater concentrations in well IM7A located just southwest decreased from 86 ug/l (9/15/2003) to 25 ug/L (7/6/2007) and nearby well MWOB21 decreased from 140 (8/25/98) to 46 (3/12/07). Soil gas and groundwater TCE concentrations have increased in some samples in the vicinity of 1271 Uinta Street - alluvial Well IM-10 increased from 11 ug/l (6/29/04) to 26 ug/l (3/12/07) and soil gas in SGCA14 adjacent to the well also increased; however, soil gas decreased in SGCA16 which is located just south of the sample. In the vicinity of 1350 Ulster Street, soil gas sample SGCA08 and SGCA10 were not sampled in the earlier studies so information on changes in concentrations is not available. The nearest soil gas samples SGCA09 and SGCA12 had decreases of 82% and 75% respectively and the shallow groundwater well MWOB04 decreased from 98 ug/l in 1999 to 41 during the indoor air study in March 2007.

#### 6.4 INDOOR/OUTDOOR AIR DATA

TCE concentrations in indoor air ranged from 0.096 to 9.7 ug/m<sup>3</sup> (Table 9). One home (1314 Ulster) in the study area had an operating radon mitigation system at the time of the 2007 sampling. Another home, 1235 Uinta, has a system installed but the owner stated that it was not operating at the time of the 2007 sampling. TCE concentrations in the basement samples were higher than the first floor in all but three homes where slight increases were observed. In basement samples, the highest TCE concentrations were observed in 1235, 1238 and 1282 Uinta Street (Figure 7). Comparisons were made where possible between the 2007 and earlier studies, using the first floor or basement where appropriate. TCE concentrations from March 2007 were lower in seven of the nine homes compared to those samples collected in 1998 or 2001 (Table 10) and the overall average declined when comparing homes sampled in 1998 and 2007 and 2001 and 2007. A similar overall decline is seen in the other media in the pathway as described above.

When looking at the individual data, the two increases were observed in the home at 1314 Ulster St. (which has the operating subslab system) and at 1329 Uinta St. The concentrations in both of these homes are low, below the screening level established by CDPHE at which further study or cleanup would be required (CDPHE 2004). The home at 1314 Ulster St. had an increase in indoor air concentrations of 1.5 fold, but had no detection of TCE in the subslab sample. Although no TCE was detected in the subslab, the TCE concentrations in the indoor air samples in this home were approximately in the middle of the range of concentrations for all homes, indicating that indoor air concentrations may be influenced by other factors aside from the groundwater, such as consumer products containing TCE or other background contributions. An increase of 2.9 times was observed in 1329 Uinta St. between 1998 (0.23 ug/m<sup>3</sup>) and 2007 (0.67 ug/m<sup>3</sup>).

The comparison of data from the subslab and basement provide the site-specific attenuation factor (Table 11 and Section 7) which ranges from 0.0036 to 0.011. These values are approximately 1 to 2 orders of magnitude lower than the conservative assumption used in the USEPA's Subsurface Vapor Intrusion Guidance (USEPA, 2002), meaning that there is less intrusion of subslab vapor into these houses than would be conservatively assumed using guidance default values. These attenuation factors are similar to those reported for other sites in the United States with similar soil type descriptions.

As stated above, the concentrations detected in indoor air during the study ranged from 0.097 to 9.7 ug/m<sup>3</sup> these values can be put into perspective by comparison to established background levels and recent regulatory guidance. CDPHE's Policy on an Interim Risk Evaluation and Management Approach for TCE (July 2, 2004) reports that typical TCE levels in homes range from 0.2 to 0.5 ug/m<sup>3</sup> resulting from common household products as well as adhesives and paint removers; a fact supported by the detection of 0.51 ug/m<sup>3</sup> of TCE in the indoor air collected during this study at the home with an operating subslab system (1314 Ulster St.). Data from the Redfields site in Denver (Kurtz and Folkes, 2002) and CDPHE's air toxics sampling show that concentrations in this range have been detected in indoor and outdoor air in the region in areas not associated with groundwater plumes. The Redfields study reports results of 282 samples with a mean of 0.164 ug/m<sup>3</sup> a 95 UCL of 0.224 and maximum of 27 ug/m<sup>3</sup>. CDPHE reports data from an outdoor air station in downtown Denver with a mean of 0.41 and maximum of 3.17 ug/m<sup>3</sup>. In addition, the EPA (2008a) reports a value of 0.8 ug/m<sup>3</sup> as the 95<sup>th</sup> percentile upper confidence level background concentration for indoor air.

A national dialog regarding the cleanup levels for TCE has been ongoing since EPA withdrew the TCE slope factor in 1987 which has resulted in a range of cleanup levels for TCE in indoor air that use a variety of risk assessments at vary 30 to 70-fold (USEPA, 2008c). CDPHE's Policy sets three levels: 0.016 ug/m<sup>3</sup> for screening; 0.8-1.6 ug/m<sup>3</sup> for further study and 1.6 ug/m<sup>3</sup> at which cleanup would be required. Cleanup is currently ongoing in the entire Main TCE plume, thus mitigating exposures by directly reducing concentrations in groundwater. The USEPA reached some resolution on the issue in March 2008 by reaching an agreement in principle with the Department of Defense on cleanup levels to address inhalation exposures. USEPA stated that cleanups should achieve indoor air concentrations of TCE ranging from 1 to 10 ug/m<sup>3</sup> which is the range currently detected in the study area. This level was set based on USEPA's provisional guidance that the agency will adopt the risk assessment prepared by the California EPA.

**Table 9. TCE Concentrations in Air Samples (ug/m<sup>3</sup>)**

Address	Location	Concentration	Attenuation Factor Subslab to Basement	Comment
1235 Uinta St.	B	9.7	0.0088	
	1	8.2		
	O	0.097		
	SS	1,100		
1222 Uinta St.	B	0.35	0.002	
	1	0.18		
	SS	160		
1238 Uinta St.	B	5.6	0.011	
	1	3.7		
	SS	480		
1282 Uinta St.	B	5.1	0.0036	Open to crawlspce
	1	4.4		
	SS	1,400		
1329 Uinta St.	B	0.67	0.003	
	1	0.45		
	O	0.025		
	SS	200		
1305 Uinta St.	B	0.096	No subslab sample	
	1	0.11		
1350 Ulster St.	B	0.12	0.0085	
	1	0.16		
	O	0.021		
	SS	14		
1271 Uinta St.	B	0.98	0.001	Open to crawlspce
	1	0.51		
	SS	940		
1314 Ulster St.	B	0.51	Subslab non- detect	Subslab system operating
	1	0.53		
	SS	<0.98		

B - Basement  
 SS - Subslab  
 1 - First floor  
 O - Outside

**Table 10. Indoor Air TCE Comparison**

		TCE Concentration ug/m <sup>3</sup>				
Address	Location	1998	2001	2007	TCE Concentration Ratio, 2007/1998	TCE Concentration Ratio, 2007/2001
1235 Uinta St.	Basement	-	43	9.7	-	0.23
1222 Uinta St.	First Floor	-	0.58	0.18	-	0.31
1238 Uinta St.	Basement	-	6.6	5.6	-	0.84
1282 Uinta St.	First Floor	-	5.7	4.4	-	0.77
1329 Uinta St.	Basement	0.23	-	0.67	2.9	-
1305 Uinta St.	Basement	1.6	-	0.10	0.059	-
1350 Ulster St.	Basement	0.7	-	0.12	0.18	-
1271 Uinta St.	First Floor	-	0.81	0.51	-	0.63
1314 Ulster St.	Basement	0.34	-	0.51	1.5	-
<b>Average (all samples)</b>		<b>0.72</b>	<b>11.31</b>	<b>2.42</b>		
Comparison to Earlier Sampling						
					2007 average /1998 average	2007 average /2001 average
2007 Average for Homes sampled in 1998				0.35	0.49	
2007 Average for Homes sampled in 2001				4.08		0.36
<b>Overall Average*</b>					<b>0.42</b>	
<b>Overall % Reduction</b>					<b>58%</b>	

## **7.0 PATHWAY EVALUATION**

This Supplemental Groundwater to Indoor Air VOC Migration Pathway Investigation evaluates VOC concentrations in groundwater, soil gas, slab air, indoor air and outdoor air within a study area that has been evaluated in two earlier studies. The intent of the study is to discern whether the observed decreases in groundwater concentrations within the study area have led to concurrent decreases in indoor air concentrations. In the groundwater to indoor air pathway, attenuation is expected as the contaminant passes through different media. For example, in a complete pathway TCE in groundwater may transform to a vapor at the water surface, and then move through the vadose zone, into the space below a house and finally into the building. Through each medium, the contaminant is expected to attenuate due to chemical and physical processes. Data were collected during this study in each of the media listed above in order to evaluate site specific conditions and attenuation factors.

Much data have been gathered throughout the country and collected by the EPA (2008a) regarding the attenuation between indoor air concentrations and the concentrations in other media in the pathway (slab, soil gas and groundwater) observed in sites with different geological and physical settings. These data are often used to support modeling calculations in the vapor to indoor air pathway. As a general check on the data collected at this site, TCE attenuation factors for indoor air to slab, soil gas and groundwater have been calculated and compared to the EPA database, and specifically to other sites with similar underlying sediments identified as “coarse” (Table 11). Depth to groundwater and comparable soil type codes were not available for all data, so finer correlations to the EPA database could not be made.

The attenuation data provided below were calculated for each home where indoor air samples were collected. Samples collected in the basement of each home were used for the calculations. Soil gas sampling locations were selected based on distance to the homes, and calculations for alternate soil gas locations were also evaluated but they are not presented on the table because the attenuation factors were not greatly different than the closest soil gas location. The TCE concentrations in alluvial groundwater for the central part of the study area were averaged because concentrations in the wells upgradient of the homes sampled were within a small range (21 to 31 ug/L).

The EPA data set includes up to 334 results for the “coarse” soil type, using TCE data only, from 10 locations throughout the country, including prior data from this study area. Data for the full EPA data set for TCE are also shown for reference. The data collected in 2007 from the study area north of Lowry matches very well with data from other sites with coarse soil types. The 50th percentile values for groundwater to indoor air from the Lowry and EPA’s coarse soil type match exactly ( $1.2E^{-4}$ ) and the Lowry slab to indoor air ( $3.6E^{-3}$ ) and soil gas to indoor air ( $4.5E^{-3}$ ) are within the same order of magnitude as the EPA data set. In both data sets (EPA Coarse and Lowry) the soil gas and slab to indoor air attenuation factors are similar, since they are collected from similar depth intervals (Figure 8). In reviewing the data, it is apparent that the larger data sets are negatively skewed, so the 50<sup>th</sup> percentiles and the upper and lower quartiles are the best representation of the central tendency.

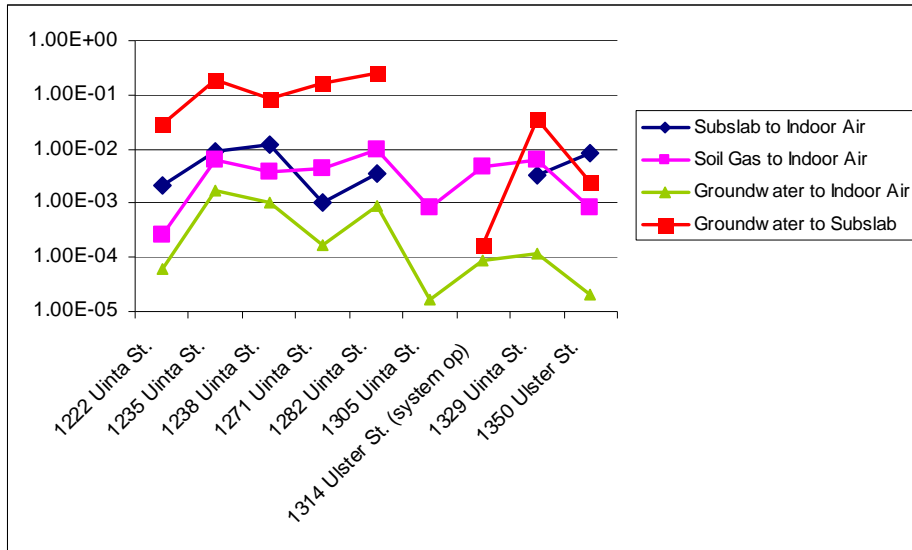
**Table 11  
TCE Attenuation Factors**

Address	Indoor Air - Basement (ug/m3)	SubSlab (ug/m3)	Subslab to Indoor Air Attenuation	CLOSEST SOIL GAS Sample	CLOSEST SOIL GAS (ug/m3)	Soil Gas to Indoor Air Attenuation	Average alluvial groundwater* (ug/L)	Predicted GW vapor concentration (ug/m3) (per EPA database)	Groundwater to Indoor Air	Groundwater to Subslab
1222 Uinta St.	<b>0.35</b>	160	2.19E-03	SGCA17	1300	2.69E-04	25.3	5616.6	6.23E-05	2.85E-02
1235 Uinta St.	<b>9.7</b>	1100	8.82E-03	SGCA16	1500	6.47E-03	25.3	5616.6	1.73E-03	1.96E-01
1238 Uinta St.	<b>5.6</b>	480	1.17E-02	SGCA16	1500	3.73E-03	25.3	5616.6	9.97E-04	8.55E-02
1271 Uinta St.	<b>0.98</b>	940	1.04E-03	SGCA15	220	4.45E-03	25.3	5616.6	1.74E-04	1.67E-01
1282 Uinta St.	<b>5.1</b>	1400	3.64E-03	SGCA14	530	9.62E-03	25.3	5616.6	9.08E-04	2.49E-01
1305 Uinta St.	<b>0.096</b>	NA		SGCA13	120	8.00E-04	25.3	5616.6	1.71E-05	
1314 Ulster St. (system operating)	<b>0.51</b>	0.98		SGCA9	110	4.64E-03	25.3	5616.6	9.08E-05	1.74E-04
1329 Uinta St.	<b>0.67</b>	200	3.35E-03	SGCA9	110	6.09E-03	25.3	5616.6	1.19E-04	3.56E-02
1350 Ulster St.	<b>0.12</b>	14	8.57E-03	SGCA10	150	8.00E-04	25.3	5616.6	2.14E-05	2.49E-03
<b>Study Area</b>	<b>50th percentile</b>		<b>3.6E-03</b>			<b>4.5E-03</b>			<b>1.2E-04</b>	<b>6.1E-02</b>
	<b>Mean</b>		5.6E-03			4.1E-03			4.6E-04	9.6E-02
<b>2008 EPA All Soil Types TCE data</b>	<b>50th Percentile</b>		<b>8.5E-03</b>			<b>4.8E-03</b>			<b>9.3E-05</b>	NA
	<b>Mean</b>		4.6E-01			1.1E-01			1.2E-03	NA
	<b>75th Percentile</b>		1.0E-01			4.2E-02			4.3E-04	NA
	<b>25th Percentile</b>		2.2E-03			5.9E-04			1.9E-05	NA
<b>2008 EPA Course Soil TCE data</b>	<b>50th Percentile</b>		<b>6.8E-03</b>			<b>9.7E-04</b>			<b>1.2E-04</b>	NA
	<b>Mean</b>		2.4E-01			7.1E-03			5.1E-04	NA
	<b>75th Percentile</b>		8.8E-02			3.9E-03			5.1E-04	NA
	<b>25th Percentile</b>		2.0E-03			3.0E-04			2.2E-05	NA

\*TCE gw average for atten factor - alluvial, wells in central study area; closest to and upgradient of vapor samples

B-1	24
IM-7A	31
MWCA13	27
IM-10	26
IM-11	23
MWCA12	21
AVERAGE:	25.3

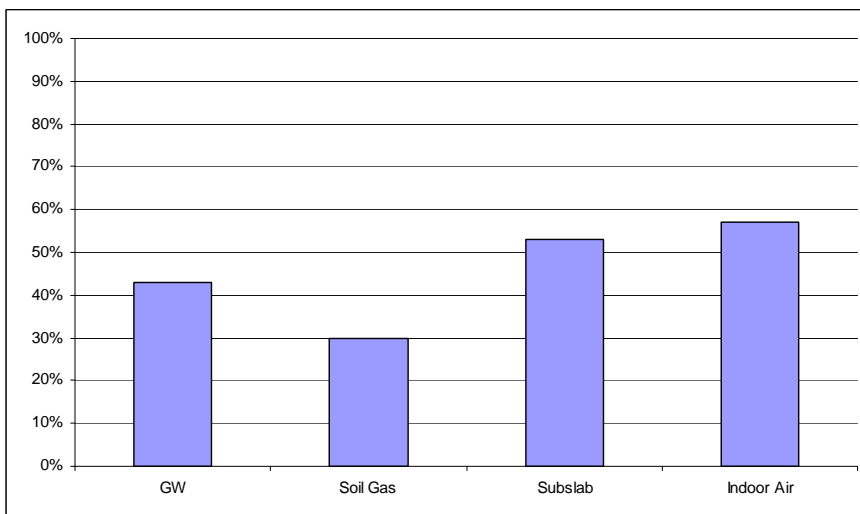
Figure 8 - Attenuation Factors



**Indoor Air Study Concentration Evaluation**

The concentration data presented above illustrate that groundwater concentrations have generally decreased in the study area as have soil gas, subslab and indoor air concentrations (Figure 9). These are based on averages of the data; which provide an overall view of the data. Results for each medium are discussed in the preceding sections, including the range of decreases/increases, relationship of changes in the data for each medium to each other, and calculation of averages. In the study area, a reduction in average groundwater concentrations of approximately 44% has been observed with reductions in the average concentrations of soil gas (30%), subslab air (53%), and indoor air (58%) when comparing the 2007 data to the earlier studies performed in 1998 and 2001.

Figure 9 - Average Percent Reduction in TCE Concentration by Media; 1998 - 2007

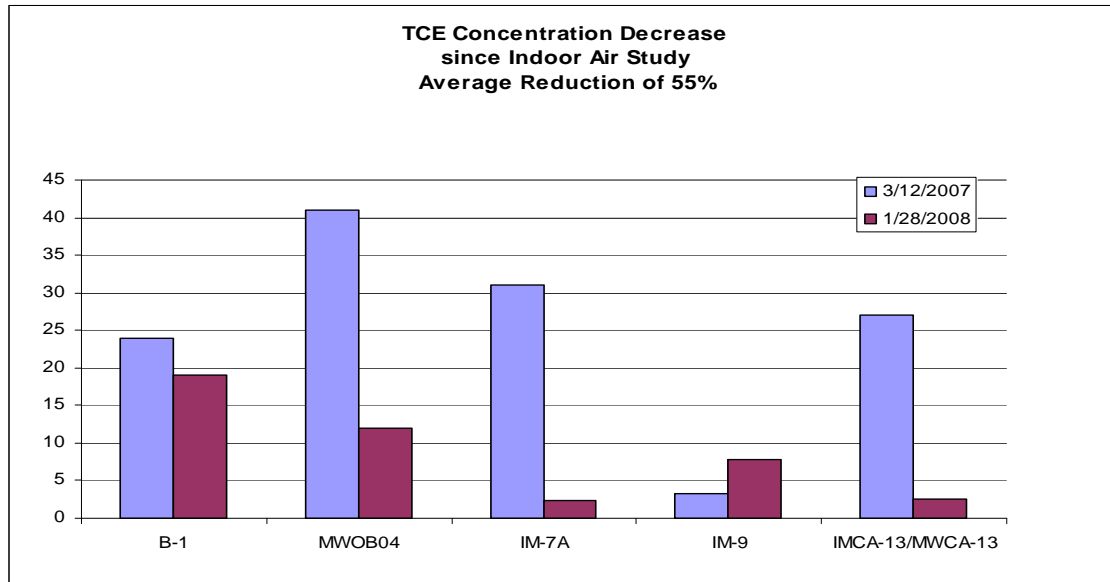


Although there is uncertainty in the averages generated by the limited size of the data set, these data allow generalized predictions to be made for the TCE concentrations in indoor air based on groundwater concentration decreases as remediation progresses. In this study area, additional groundwater treatment was performed in the fall of 2007, after this indoor air study was performed. In November 2007, injections were done at 299 locations in the off-base portion of the Main TCE Plume; 99,000 pounds of potassium permanganate were injected. Groundwater data collected in January 2008 indicate that there were additional reductions of 21 to 92 percent in the TCE concentrations of the individual wells (Table 12) within the study area following the injection (Figure 10). As a whole, the average TCE concentration in the alluvial wells in the study area was 25 ug/L in March 2007 and 9 ug/L in January 2008. As in earlier calculations, the averages were used to calculate a ratio and the percent reduction for the study area between March 2007 and January 2008 was 65%.

**Table 12. TCE Concentrations in Groundwater - Indoor Air Study Area, 2007 and 2008**

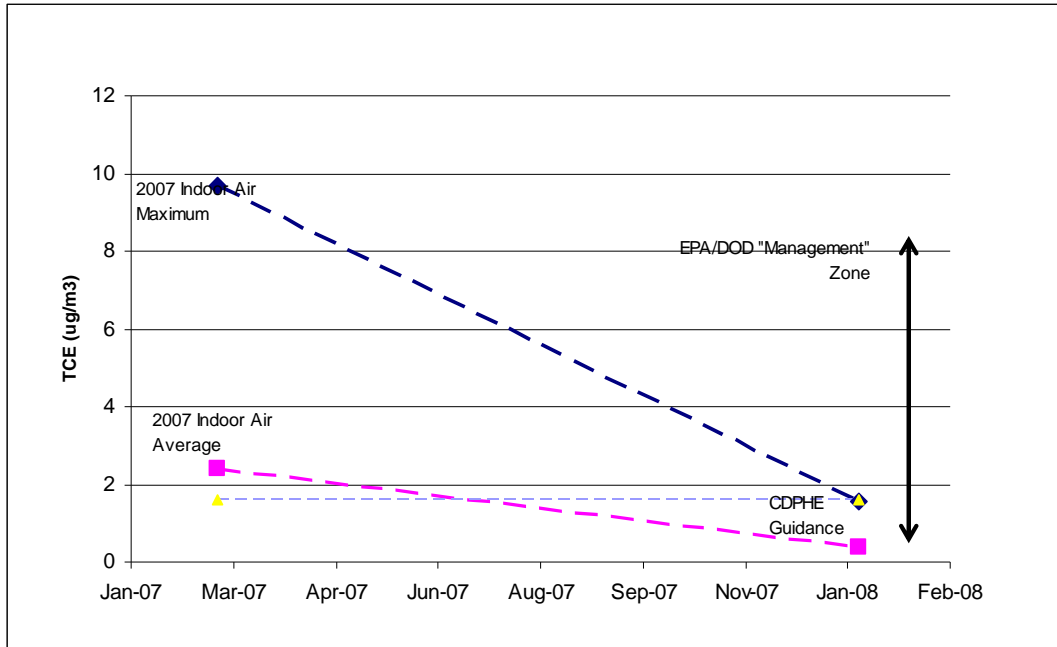
	TCE (ug/L)		TCE Concentration Ratio, 2007/2001	Percent Reduction
	Date			
Well	3/12/2007	1/28/2008		
B-1	24	19	0.79	21
MWOB04	41	12	0.29	71
IM-7A	31	2.4	0.08	92
IM-9	3.3	7.8	2.36	
IMCA-13/MWCA-13	27	<5	0.09	91
Avg Alluvial Concentration in Study Area	25	9		
Ratio (2008/2007)	0.35			
Percent Reduction	65			

Figure 10 TCE Concentration Reduction in Groundwater 2007-2008



Based on the data collected in the 2007 study, an average **44% decrease** of TCE in groundwater and an average **57% decrease** in indoor air concentrations were observed. Using the same ratio from the 2007 data and an additional **decrease of 65%** in the TCE concentration in groundwater that was observed in the January 2008 samples, a further decrease of the indoor air concentrations of **84%** could be expected. To predict the range of indoor air concentrations that could be expected in the study area in January 2008, LAC used the average and the maximum indoor air TCE concentrations detected during the 2007 study and applying the ratio calculated using the 2007 data (Figure 11). The mean indoor air concentration of 2.4 ug/m<sup>3</sup> detected during the 2007 study is expected to have decreased to a concentration of 0.4 ug/m<sup>3</sup> and the maximum indoor air concentration detected in March 2007 of 9.7 ug/m<sup>3</sup> is expected to have decreased to 1.6 ug/m<sup>3</sup>, placing the expected range of TCE concentrations in indoor air at or below the CDPHE (2004) mitigation level.

Figure 11 Predicted Indoor Air Concentrations, January 2008



## **8.0 CONCLUSIONS**

This March 2007 indoor air study was done to evaluate the effect of decreases in groundwater concentrations of TCE on indoor air concentrations. The data illustrate general decreases in TCE concentrations in all components that make up the groundwater to indoor air pathway; groundwater, soil gas, slab, and indoor air. Due to the uncertainties associated with the data set, the data cannot definitively prove a direct relationship between decreases in groundwater concentrations and decreases in indoor air. Comparisons to attenuation factors from a national data set (EPA, 2008a) for similar soil types and background levels to those from Lowry demonstrate that the data collected in this study fit within the expected ranges, thus supporting the data set collected at Lowry. Therefore, the data indicate that TCE in indoor air is derived from the groundwater (with acknowledgement that there is contribution from external sources) and that decreases in groundwater concentrations are associated with decreases in indoor air. More importantly, the data show that indoor air concentrations are approaching levels at which no further mitigation would be required, based on both CDPHE and EPA policy.

Reductions in TCE concentrations of 44% were observed from the time period prior to 2001 to the time period 2006-2007, and a decrease in indoor air concentrations of 58% were observed for the same time period. Extrapolating this general relationship, an estimate of indoor air concentrations was made based on groundwater data collected in January 2008, following the injection of potassium permanganate into groundwater within the study area. Between March 2007 and January 2008, groundwater TCE concentrations in the study area fell 65%, to a range of <5 ug/L to 19 ug/L. Based on the site-specific ratio developed in this study, indoor air concentrations would be expected to have fallen an additional 84% and the expected range of TCE concentrations in indoor air would be at or below the CDPHE (2004) mitigation level.

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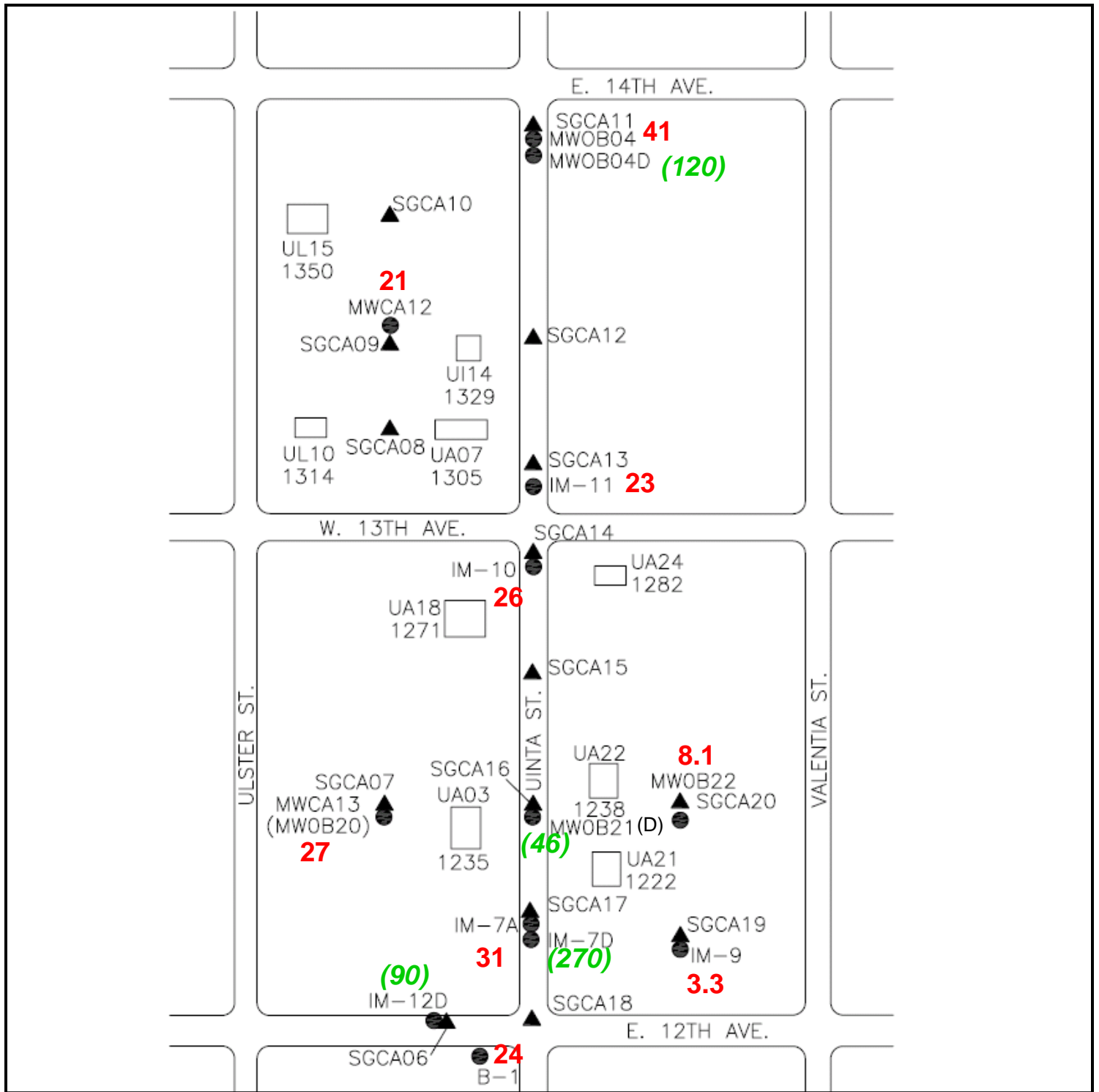
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# FIGURES





D—Well screen in Denver Fm  
 TCE Concentration ug/L

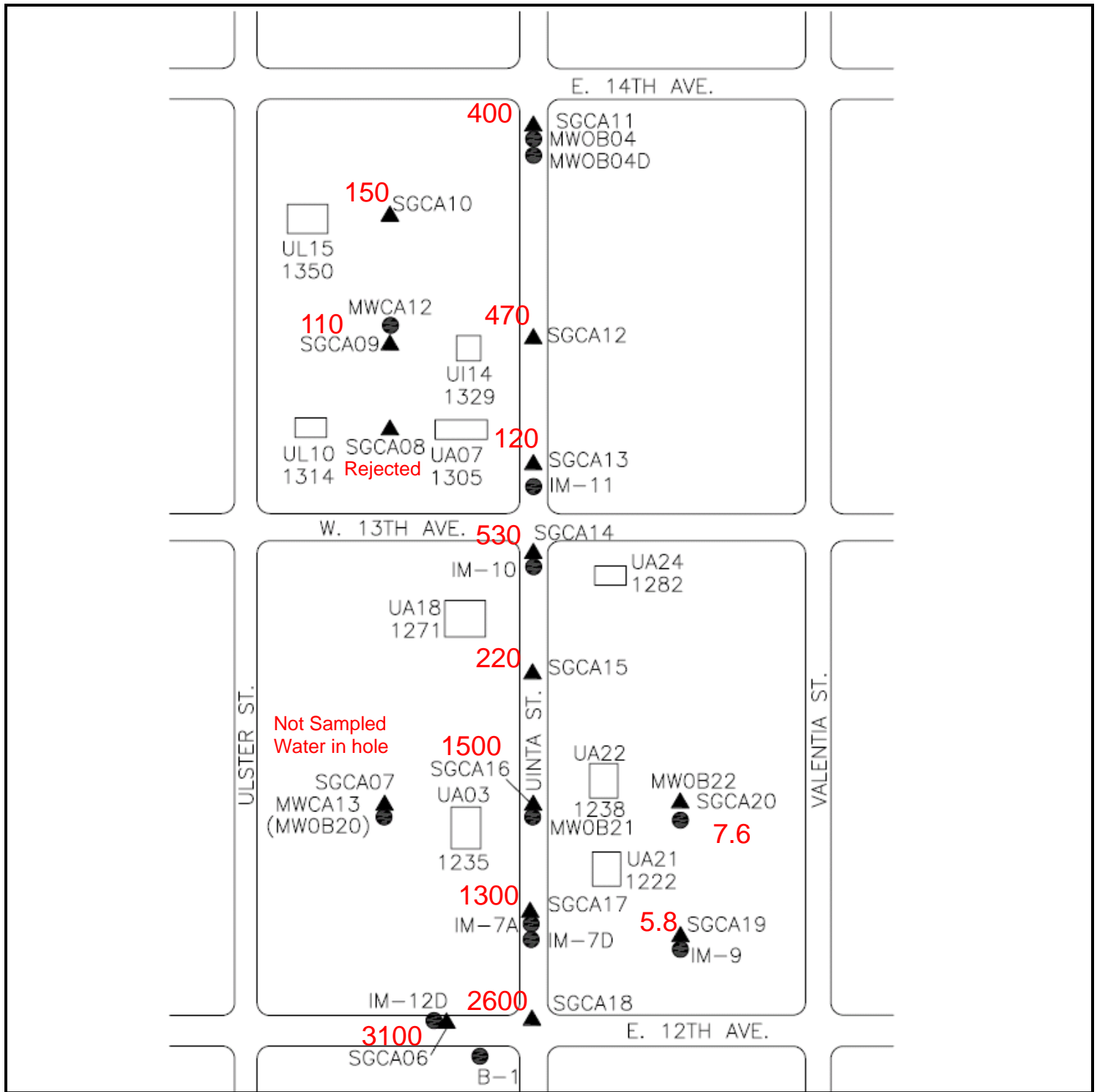
**24** Alluvium  
**(90)** Denver Fm

Legend

- Monitoring Well
- ▲ Soil Gas Sample Location
- UA21 Previous Sample Identifier
- 1222 Street Address

Groundwater to Indoor Air Report  
 Lowry AFB -October 2008

Groundwater Results  
 March 2007  
 Figure 2



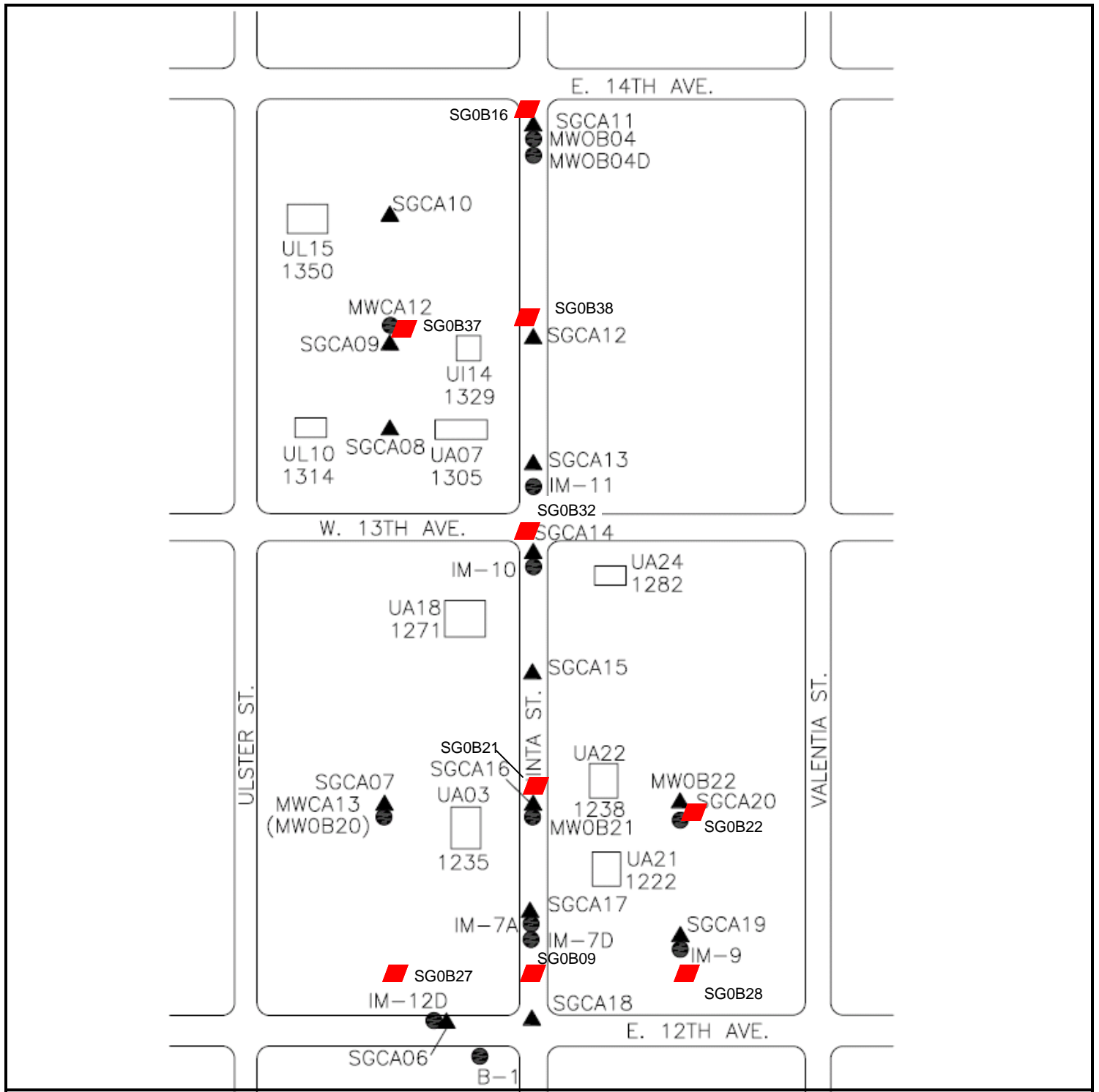
7.6 TCE (ug/M<sup>3</sup>)

Legend

- Monitoring Well
- ▲ Soil Gas Sample Location
- UA21 1222 Previous Sample Identifier Street Address

Groundwater to Indoor Air Report  
Lowry AFB—October 2008

Soil Gas Results  
March 2007  
Figure 4

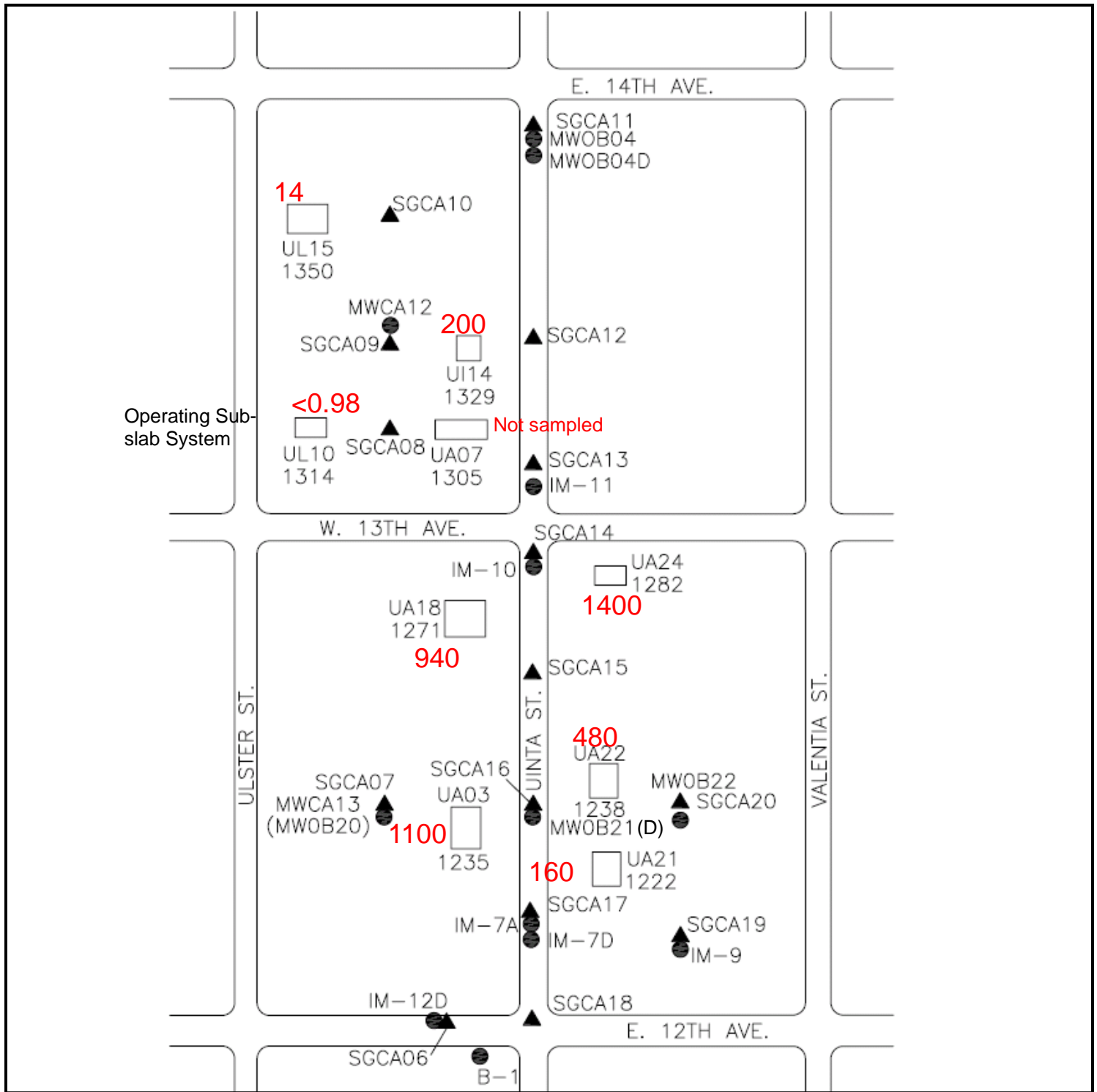


Legend

- Monitoring Well
- ▲ 2007 Soil Gas Sample Location
- UA21 Previous Sample Identifier  
1222 Street Address
- SG0B09 1998 Soil Gas Sample Location

Groundwater to Indoor Air  
Lowry AFB—October 2008

Soil Gas Sampling Locations  
Summer 1998 and March 2007  
Figure 5



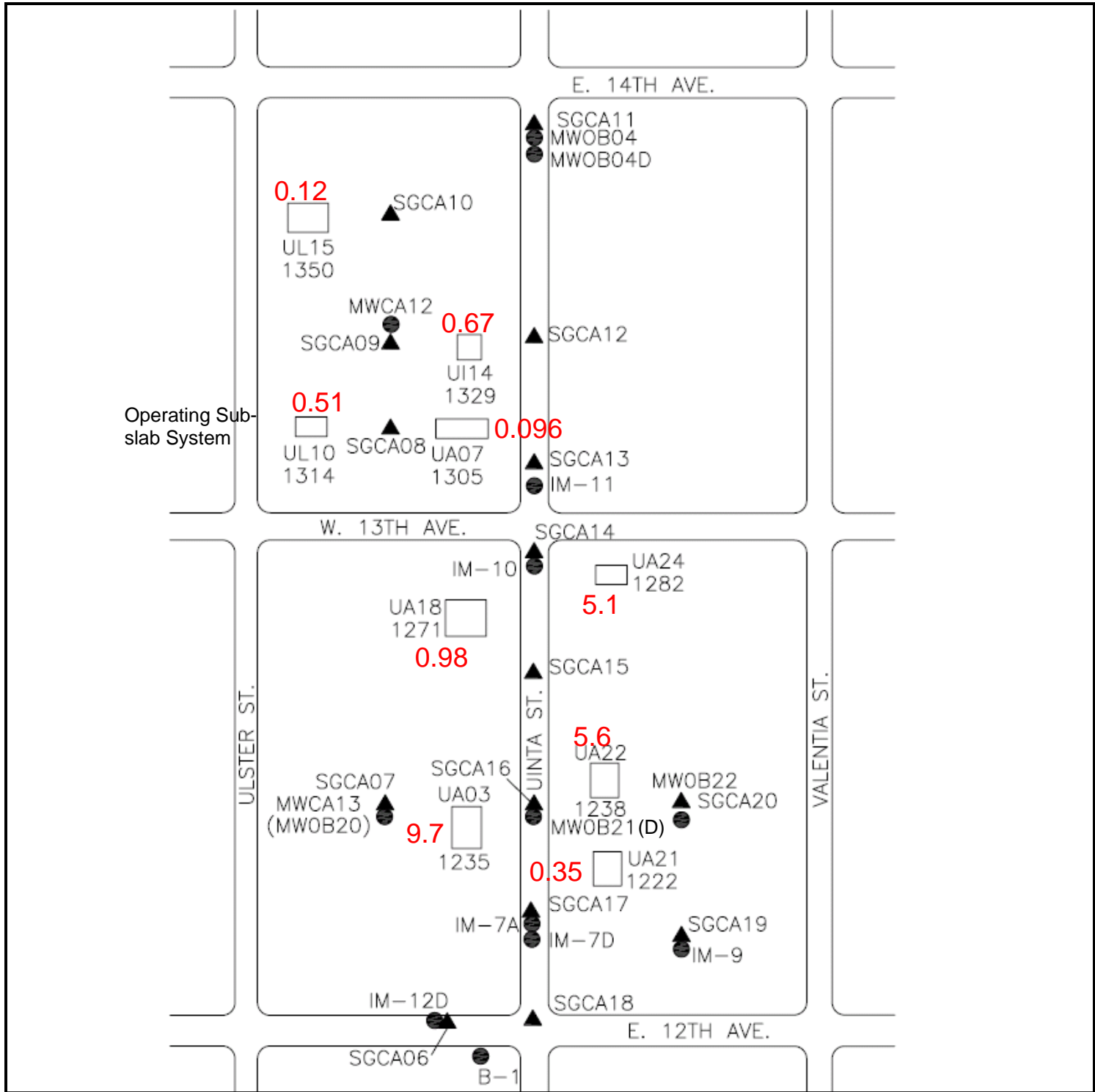
Legend

14 TCE (ug/M<sup>3</sup>)

- Monitoring Well
- ▲ Soil Gas Sample Location
- UA21  
1222 Previous Sample Identifier  
Street Address

Groundwater to Indoor Air Report  
Lowry AFB—October 2008

Subslab Results  
March 2007  
Figure 6



Legend

9.7 TCE (ug/M<sup>3</sup>)

- Monitoring Well
- ▲ Soil Gas Sample Location
- UA21 1222 Previous Sample Identifier Street Address

Groundwater to Indoor Air Report  
Lowry AFB—October 2008

Indoor Air Results—Basement  
March 2007  
Figure 7