SITE INVESTIGATION REPORT
Cheyenne PCE Plume Orphan Site
Cheyenne, Wyoming

Prepared by:

EnviroGroup Limited
Centennial, Colorado

Prepared for:

Wyoming Department of Environmental Quality
Cheyenne, Wyoming

March 13, 2012

Project No. WQ-0663

SITE INVESTIGATION REPORT

Cheyenne PCE Plume Orphan Site

Cheyenne, Wyoming

Prepared by:

EnviroGroup Limited
Centennial, Colorado

Prepared for:

Wyoming Department of Environmental Quality
Cheyenne, Wyoming

March 13, 2012

Project No. WQ-0663

Prepared by	Date
Reviewed by	Date
Approved by	Date

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Site History 1
1.1.1 ERM 2002 Phase 1 Investigation for the former Safeway 1
1.1.2 EPA Investigation 2
1.1.3 Former Randall Rite-Way Gas Station Investigation 4
1.2 Geologic and Hydrogeologic Conditions 4
1.3 Orphan PCE Plume Investigation Purpose and Scope 5
1.4 Report Organization 6

2 INVESTIGATION LOCATIONS 7

2.1 Groundwater Sampling Locations 7
2.2 Soil Vapor Sampling Locations 8
2.3 Sub-Slab Vapor Sampling Locations 8
2.4 Structures Selected for Sampling 9
2.4.1 Access Obtained 10
2.5 Indoor and Outdoor Air Sampling Locations 10
2.5.1.1 Residential Buildings 10
2.5.1.2 Commercial Buildings 11
2.6 UST Investigation at the Knights of Columbus 11
2.7 Mt. Sinai Risk Assessment 11

3 INVESTIGATION PROCEDURES 13

3.1 GROUNDWATER INVESTIGATION 13
3.1.1 Measurements at Existing Wells and Sumps 13
3.1.2 Monitoring Well Installation 13
3.1.3 Well Development and Groundwater Sampling 16
3.1.4 Water Table Elevations 19
3.2 SOIL VAPOR INVESTIGATION 19
3.2.1 Soil Vapor Probe Installation 19
3.2.2 Leak Testing 21
3.2.3 Soil Vapor Probe Sampling and Analysis 22
3.3 INDOOR AIR INVESTIGATION 24
3.3.1 Occupant Interview Documentation 24
3.3.2 Indoor Air Sampling and Analysis 25
3.3.3 Sub-Slab Vapor Probe Installation, Sampling, and Analysis 26

3.3.4 Ambient Air Sampling ... 28
3.3.5 Laboratory Procedures for Indoor Air, Outdoor Air, and Sub-Slab Vapor Samples ... 28
3.4 Knights of Columbus UST Investigation Procedures ... 29
3.5 Ecological Risk Assessment Procedures ... 29
3.6 Mt. Sinai Risk Assessment Procedures ... 30
3.7 Decontamination and Management of Investigative Derived Wastes ... 30
4 RESULTS OF INVESTIGATION ... 32
4.1 Water Levels ... 32
4.2 Soil Results ... 32
4.3 Groundwater Results ... 33
4.4 Soil Vapor Results ... 34
4.4.1 PCE ... 34
4.4.2 TCE ... 35
4.4.3 Fixed Base Laboratory Results ... 36
4.4.4 Ambient Air Results Associated with Soil Vapor Sampling ... 37
4.4.5 Results of Resampling ... 37
4.5 Concurrent Indoor Air, Outdoor Air and Sub-Slab Vapor Results ... 37
4.5.1 Indoor Air Analytical Results ... 38
4.5.2 Outdoor Air Analytical Results ... 38
4.5.3 Sub-Slab Vapor Analytical Results ... 38
4.6 Data Validation ... 39
4.6.1 Quality Assurance/Quality Control ... 39
4.6.2 QA/QC for Soil Samples ... 40
4.6.3 QA/QC for Groundwater Samples ... 40
4.6.4 QA/QC for Soil Vapor Samples ... 41
4.6.5 QA/QC for Indoor Air, Outdoor Air and Sub-Slab Vapor Samples ... 43
4.6.6 Summary of Validation Results ... 45
4.7 Knights of Columbus UST Investigation Results ... 47
5 DATA EVALUATION ... 48
5.1 Nature, Extent and Source(s) of COIs in Groundwater and Soil Vapor ... 48
5.1.1 Groundwater Flow Direction ... 48
5.1.2 Chlorinated Solvent Plumes ... 48
5.2 Evidence for Residual Dense Non-Aqueous Phase Liquids ... 52
5.3 Knights of Columbus UST Investigation ... 52
5.4 Vapor Intrusion Evaluation ... 52

5.4.1 Indoor Air Compared to DEQ Screening Levels 53
5.4.2 Sub-slab Vapor Compared to DEQ Screening Levels 54
5.4.3 Multiple Lines of Evidence Evaluation 55
5.4.4 Indoor Air Mitigation System Recommendations 64
5.4.5 Indoor Air Mitigation Systems 65
5.4.6 Post Mitigation Indoor Air Testing Results 66
5.5 Ecological Risk Assessment Results 67
5.6 Mt. Sinai Risk Assessment Results 67
6 CONCLUSIONS 68
6.1 PCE Source Areas 68
6.2 Nature and Extent of Contamination 68
6.3 Vapor Intrusion Impacts 69
6.4 Mitigation System Installations 69
6.5 Mitigation System Effectiveness 70
6.6 Areas Likely to Require Groundwater Remedial Measures 70
7 STUDY LIMITATIONS 72
8 REFERENCES 73

LIST OF TABLES

Table 2.1 Proposed Indoor Air Sampling Locations
Table 2.2 Locations Sampled for Indoor Air
Table 3.2 Reporting Limits for Air Samples
Table 4.1 Water Level Elevations and Well Completion Details
Table 4.2 Boring Log PID Readings
Table 4.3 Soil Sampling Results
Table 4.4 Field Water Quality Parameters
Table 4.5 Groundwater Sampling Results
Table 4.6 Soil Vapor Sampling Results
Table 4.7 Pre-Mitigation Indoor Air and Outdoor Air Sampling Results
Table 4.8 Sub-slab Vapor Sampling Results
Table 5.1 Summary of Building Testing Status
Table 5.2 Summary of Vapor Intrusion Evaluation
Table 5.3 Indoor Air Mitigation Systems Installed
Table 5.4 Post-Mitigation Indoor Air Sampling Results

LIST OF FIGURES

Figure 1.1 Site Location
Figure 1.2 Previous Investigation Locations (URS, 2004)
Figure 2.1 Groundwater Sampling Locations
Figure 2.2 Soil Vapor Sampling Locations
Figure 2.3 Indoor Air Sampling Locations
Figure 5.1 Groundwater Surface Contour Map
Figure 5.2 Groundwater Results for PCE and TCE

Figure 5.3 Soil Vapor Results for PCE and TCE

Figure 5.4 Sub-Slab Vapor and Indoor Results for PCE

Figure 5.5 Soil Vapor and Sub-slab Vapor Results for PCE

Figure 5.6 Correlation Plot of Shallow Soil Vapor vs. Indoor Air PCE Concentrations

Figure 5.7 Correlation Plot of Indoor Air vs. Sub-slab Vapor PCE Concentrations

Figure 5.8 Plot of Proportion of TCE Relative to PCE in Soil Vapor

LIST OF APPENDICES

Appendix A Product Inventories and Occupant Questionnaires

Appendix B1 Field Forms and Boring Logs

Appendix B2 Soil Vapor Sampling Logs

Appendix C1 Soil Laboratory Results (TestAmerica)

Appendix C2 Groundwater Laboratory Results (TestAmerica & PACE)

Appendix C3 Soil Vapor Laboratory Results (Hartman Geosciences Mobile Laboratory)

Appendix C4 Soil Vapor Laboratory Results (Replicate samples at Centek Laboratories)

Appendix C5 Soil Vapor Laboratory Results (H&P Mobile Geochemistry Inc.)

Appendix C6 Indoor Air, Outdoor Air and Sub-slab Vapor Laboratory Results (Air Toxics & TestAmerica)

Appendix D Knights of Columbus Tank Investigation Report

Appendix E Ecological Risk Assessment – Ecological Exclusion Assessment

Appendix F Mt. Sinai Risk Assessment Report, June 2010

Appendix G Vapor Intrusion Mitigation System Installations Technical Memorandum, October 26, 2011

1 INTRODUCTION

This report, prepared by EnviroGroup Limited (EnviroGroup) for the Wyoming Department of Environmental Quality (DEQ), presents the results of environmental investigations and interim vapor intrusion mitigation measures conducted by EnviroGroup at the Cheyenne PCE Plume Orphan Site (the "Site") from August 2009 to November 2011. The Site is an approximate 5 square block area occupied by residential and commercial buildings located in downtown Cheyenne, Wyoming, on the west side of the Capitol Building (Randall Avenue), and north of 24th Street (Figure 1.1). The following sections present background information, the purpose and scope of the investigation, and the report organization.

1.1 Site History

The current investigation plan was developed based on the results of prior investigations conducted by others between 2002 and 2008, including a Phase 1 Environmental Site Assessment for the former Safeway (ERM, 2002), a PCE plume assessment conducted by URS (2004) for the EPA, and the Randall Rite-Way UST closure evaluation (WDEQ, 2008).

1.1.1 ERM 2002 Phase 1 Investigation for the former Safeway

As part of a proposed store expansion, in 2002, Environmental Resources Management (ERM) conducted a Phase 1Environmental Site Assessment (ESA) for the former Safeway at 2512 Pioneer Avenue (located at the intersection of Pioneer Avenue and 26th Street), and eight adjacent residences, in the area to be covered by the expansion, located at 2502, 2514, and 2522 Thomes Avenue; 508, 510 and 512 W. 25th Street; 514 and 516 W. 25th Street; and 509, 513, 515 and 517 W. 26th Street, in Cheyenne.

This assessment indicated the following potential sources of environmental concern.

- An auto repair shop was formerly located in an outbuilding at 2502 pioneer Avenue, prior to construction of the Safeway store, from at least 1923 to 1931.
- An auto repair shop was operated from the outbuilding at 2502 Thomes Avenue from approximately 1931 to 1938, and a printing shop was operated at the same

location from approximately 1939 to 1964. Staining on the floorboards indicates that petroleum and solvent impacted soils may be present in the vicinity of this outbuilding.

- An outbuilding, formerly located north of the residences at 508, 510, and 512 W. 25th Street, containing a planing mill with electrical motor maintenance from at least 1923 to 1931.
- Prior to 1960, two gasoline stations were located near the intersection of 27th Street and Thomes Avenue.

Following the Phase I ESA, several more investigations have occurred as summarized below.

1.1.2 EPA Investigation

URS conducted a Phase II ESA for the former Safeway in 2002. This investigation indicated that tetrachloroethylene (PCE) and subsidiary quantities of the breakdown product trichloroethylene (TCE) were present in groundwater. To evaluate the nature and extent of this groundwater contamination and the potential for vapor intrusion (VI) into homes, URS, under contract to the United States Environmental Protection Agency (EPA), conducted a Site Inspection investigation in the area surrounding the Safeway from September 2003 to March 2004. A summary of the sampling locations for that investigation is shown in Figure 1.2.

1.1.2.1 Groundwater

The URS investigation indicated that the PCE groundwater plume (concentration of PCE above the maximum contaminant level [MCL] of 5 micrograms per Liter [µg/L]) extended approximately five blocks north-south and three blocks east-west, and passed under a mixed residential and commercial area in downtown Cheyenne (URS, 2004). Of the 22 groundwater samples collected from temporary wells installed in the area surrounding the store, most had non-detectable levels of PCE (< 5 µg/L). However, all wells on the perimeter of the Safeway property had elevated levels of PCE; the highest PCE concentrations were found along the eastern boundary of the Safeway property and extended at least one block to the south.

Follow up sampling of a few additional temporary groundwater wells in January 2004 indicated no detectable levels of PCE in groundwater to the north of 28th Street. However, elevated levels of PCE (up to 450 µg/L) were found in wells MW-2 and MW-3 on the former Randall Rite-Way property and high levels (52 µg/L) were noted in the vicinity of the Knights of Columbus building located at 507 West 28th Street. Lower levels (8 to 25 µg/L) were consistently detected near Oneil Avenue between 27th and 24th Streets. Minor amounts (less than 6 µg/L) of TCE and cis-1,2-DCE were also detected in several wells.

Based on these data, URS (2004) identified four potential sources contributing to the groundwater PCE plume, including the:

- presently operating dry cleaner at 501 Randall Avenue;
- inactive dry cleaner at what is now the Knights of Columbus (507 W. 28th Street);
- Leaking Above/Underground Storage Tank (LAUST) site located near a former gasoline station at 314 Randall Avenue, just south of 27th Street; and
- an unknown source on the north side of the former Safeway property on 26th Street between Thomes and Pioneer Avenues.

1.1.2.2 Soil Vapor

Soil gas sampling at seven to eight foot depths conducted by URS in conjunction with the groundwater sampling indicated essentially non-detectable levels (< 2 part per billion by volume [ppbV]) of PCE north of 28th Street and along Bent Avenue. Very high levels of PCE (1900 to 2600 ppbV) were found near the active dry cleaners just east of Oneil Avenue on 28th Street and near the intersection of 27th and Thomes Avenue. One elevated result (27 ppbV) was found near the former Randall Rite-Way, near the intersection of 27th Street and Randall Avenue, while concentrations in the remainder of the area north of Randall Avenue were essentially non-detectable. Very high (greater than 8000 ppbV) PCE concentrations were found in soil gas on the north side of the Safeway property on 26th Street.

1.1.2.3 Vapor Intrusion

Twenty-four hour indoor air sampling in conjunction with grab sub-slab soil gas sampling was conducted by URS at six locations (2804 and 2718 Oneil Ave., 2619 and 2426 Thomes Ave., 505 W. 27th St., and 422 W. 26th St.) in January of 2004. PCE was detected in sub-slab vapor in all locations except 2804 Oneil Avenue. Concentrations ranged from 39 to 1500 ppbV (at 2619 Thomes Avenue). Low levels of TCE (less than 10% of the PCE concentration) were found in three sub-slab locations. Indoor air PCE levels were below detection (1.4 ppbV) in all locations except 2426 Thomes Avenue (1.6 ppbV) and 2619 Thomes Avenue (4.9 ppbV). No TCE was detected in the indoor air (at 1.4 ppbV). These indoor air PCE levels were below the ATSDR screening levels in effect at the time, although the EPA 2002 Vapor Intrusion Guidance Screening Level for residential indoor air was 1.2 ppbV for a 10^{-5} risk level. No further action was proposed at that time.

1.1.3 Former Randall Rite-Way Gas Station Investigation

From 2003 to 2007, Delta conducted an investigation at the Site of the former Randall Rite-Way retail petroleum facility at 314 Randall Avenue (now 315 W. 27th Street) to evaluate potential leakage from three former gasoline underground storage tanks (USTs). These tanks were believed to have been removed sometime between 1987 and 2003, when the station was razed and before the headquarters building for the Wyoming Association of Municipalities was constructed on the Site in 2005. Delta installed six groundwater monitoring wells (MW-1 to MW-6) to total depths of 20 feet below grade between 2003 and 2006. Water levels, measured in 2008, were from nine to 11 feet below ground surface (bgs) with an inferred groundwater flow direction to the south. Sampling of these wells between 2003 and 2007 indicated non-detectable levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbons (TPH) in all wells except MW-1, located beneath the former station. No analysis was conducted for chlorinated solvents. DEQ issued a closure letter for the Site on December 27, 2007 (WDEQ, 2008).

1.2 Geologic and Hydrogeologic Conditions

The Site is located in an area underlain at depth by the Tertiary Ogallala and Arikaree Formations which form the regional drinking water aquifers. The land surface at the Site

slopes about two to three feet from west to east and, more generally, slopes to the southeast in the Site vicinity. The uppermost unconfined aquifer in the site area is composed of unconsolidated braided alluvial deposits, varying from sand and gravel to silt and clay over short lateral and vertical distances. Sand and gravel lenses can create local differential flow paths. Local perched water tables may be present due to the relatively impermeable silt and clay layers.

URS (2004) reported groundwater at depths of approximately eight to 13 feet bgs, although a discontinuous layer of silty to sandy clay at depths of nine to 13 feet appeared to cause some perched water layers, with an easterly flow direction shown on their map, although the report indicates a south southwesterly flow direction. Similarly, WDEQ (2008) reported groundwater at depths of approximately nine to 11 feet, but with more of a southerly flow direction in the vicinity of 27th Street and Randall Avenue.

1.3 Orphan PCE Plume Investigation Purpose and Scope

Under the Orphan Site Remediation Program, in the Fall of 2009, DEQ contracted with EnviroGroup to:

- evaluate the nature and extent of the PCE and TCE in groundwater and soil vapor previously identified by the EPA in 2004 (URS, 2004);
- evaluate the potential for VI at the Site due to the presence of chlorinated solvents in the subsurface; and
- evaluate whether VI controls were warranted for Site buildings based on the DEQ Screening Levels.

The initial investigation scope of work, described in the Sampling and Analysis Plan (SAP), was approved by the DEQ on October 9, 2009. The first phase of the investigation was implemented from October 2009 to December 2009. Based on these sample results, DEQ identified an area (Figure 2.3) where soil vapor PCE concentrations were above 810 micrograms per cubic meter ($\mu g/m^3$). This area was considered to represent the "worst case" for the potential for VI and DEQ selected residential and commercial structures for indoor air testing in and around this area to confirm the extent of VI impacts, if any. Due to the presence of PCE in soil vapor above 810 $\mu g/m^3$ along

the western edge of the worst case area, under a Task Order Amendment approved May 13, 2010, a second phase of the investigation was implemented from July 2010 to August 2010 to evaluate the nature and extent of PCE in soil vapor along this edge. The second phase resulted in an expansion of the indoor air testing area to include 34 additional residences in 2011 (the Expanded Testing Area) and indicated the need to evaluate the nature and extent of PCE in soil vapor along the southern and western edge of the previously evaluated areas; this third phase of the investigation was implemented in July 2011 under a Task Order Amendment approved January 18, 2011. A small follow-up soil vapor investigation was conducted in the southernmost portion of the area in September 2011 to verify an anomalous TCE soil vapor result obtained in the third phase of the investigation.

1.4 Report Organization

The following sections of this report discuss the areas of evaluation (Section 2); investigation procedures (Section 3); the investigation results and data validation (Section 4); evaluation of the results (Section 5); conclusions (Section 6); and the study limitations (Section 7). References are listed in Section 8.

2 INVESTIGATION LOCATIONS

The orphan PCE plume evaluation included:

- installation and sampling of 18 permanent and three temporary groundwater monitoring wells,
- sampling of two existing monitoring wells, two private wells, and four sumps,
- measurement of water levels in the 18 new permanent wells described above and in the two existing monitoring wells,
- installation and sampling of 83 shallow soil vapor probes,
- installation and sampling of 31 sub-slab vapor probes,
- collection of 147 pre-mitigation and 21 post-mitigation indoor air samples, and
- collection of 20 outdoor air samples.

The locations of groundwater, soil vapor, and indoor air (and sub-slab vapor) samples collected during this evaluation are shown on Figure 2.1, 2.2, 2.3 respectively. The rationale for various sampling locations is described below.

2.1 Groundwater Sampling Locations

Groundwater sampling locations were selected to further characterize the nature and extent of constituents of interest (COIs) in groundwater, including potential identification of source areas. The COIs are all VOCs, included in the analyte list of the procedures followed, that will tend to partition into the soil vapor phase when present in soil above the water table or dissolved in shallow groundwater (EPA, 2002). Sample locations were selected to evaluate:

- the potential source near the active dry cleaner at 501 Randall Avenue;
- the potential source near the former dry cleaner in the present Knights of Columbus building at 507 West 28th Street;

- the potential source near the former Randal Rite-Way at 315 W. 27th Street;
- the potential sources near the former Safeway at 2512 Pioneer Avenue;
- sewer lines as preferential pathways; and
- the boundaries of the groundwater PCE plume.

2.2 Soil Vapor Sampling Locations

Soil vapor sampling locations[1] were selected to evaluate the nature and extent of dissolved plumes (previously indicated by groundwater data) and potential source areas. COI concentrations in soil vapor (and particularly the spatial pattern) can indicate source areas in the vadose zone and, more generally, the path of a dissolved plume, although vadose zone soil conditions can independently affect and complicate the spatial pattern of soil vapors above a dissolved plume. The locations were generally arranged in a grid-like pattern with approximate half block spacing in the areas of the Site previously identified as having PCE in soil vapor by URS (2004), excluding the area to the west of the former Safeway (the 2500 block of Thomes Avenue) where the homes were to be demolished for an expansion of the Safeway. Later phases of the soil vapor investigation expanded the initial testing area to the south and west towards Reed Avenue and 23rd Street.

2.3 Sub-Slab Vapor Sampling Locations

Sub-slab vapors are generated in the same manner as soil vapors outside the buildings, but their distribution and migration can be controlled to some degree by the buildings, and in some cases they can impact indoor air quality by a process known as VI. Therefore, sub-slab vapor sampling locations were selected to help evaluate the potential for VI in each commercial Site building where access was granted. A few residential structures also permitted sub-slab vapor sampling.

Sub-slab vapor samples were located near indoor air sample locations for comparison and evaluation purposes, when access for sub-slab sampling was given. While these collocated samples should be under and above the same slab to be comparable, there is

[1] Soil vapor sampling in this report refers to outdoor locations, while sub-slab vapor sampling refers to indoor (i.e., under slab) locations (see next section).

generally no reason to collect indoor air and sub-slab vapor samples in exactly the same location. The pathway that vapors may follow from the sub-slab region to indoor air is unlikely to be directly through the slab at the point of sampling, but through cracks or other openings in the floor that are generally remote from sampling locations (per standard sampling protocols, e.g., ITRC 2007).

2.4 Structures Selected for Sampling

Based on the soil vapor sample results EnviroGroup obtained in 2009 (EnviroGroup 2010a, b), DEQ initially selected residential and commercial structures for testing within the "worst case" area (Figure 2.3) as shown on Table 2.1 and described below:

- The owners of all residential structures (a total of 32) within the worst case area were offered pre-emptive mitigation and indoor air testing. In addition, the Wyoming County Commissioners Association building located at 409 W. 24th St. is now considered a residential building due to the presence of an occupied apartment in the basement. The owner of this building was offered indoor air testing, although they were not offered a pre-emptive mitigation system since the building was originally classified as commercial. Thus a total of 33 residential buildings were offered indoor air sampling in the "worst case" area.

- The owners of the 31 commercial buildings, not including the Wyoming County Commissioners Association building, were offered indoor air and sub-slab vapor testing to determine the need for further action, including mitigation, if necessary.

In addition, the DEQ initially selected another 19 homes peripheral to the "worst-case" area (i.e., verification locations) where, if access was granted, indoor air testing would be conducted to confirm the extent of VI impacts, if any.

DEQ and EnviroGroup personnel attempted to obtain access to these 52 residential (the 32 offered mitigation, one previously identified as commercial, and the 19 peripheral homes) and 31 commercial buildings for indoor air, and indoor air and sub-slab vapor sampling, respectively. Following the acquisition of additional soil vapor results to the southwest of the "worst-case" area, DEQ and EnviroGroup personnel attempted to obtain access to 34 additional residential structures in the expanded testing area for indoor air sampling in 2011. The Expanded Test Area is also shown on Figure 2.3.

Post-mitigation indoor air testing was conducted at selected buildings as described in Section 5.2.

2.4.1 Access Obtained

After the property owner contact information for the selected buildings was obtained from the County Assessor's office, a DEQ approved letter requesting participation in the indoor air study was sent to each property owner with a postage paid return post card. If the owner did not respond, a second letter was mailed. If a response was not received, DEQ personnel attempted to speak with the owner in person or by phone.

2.5 Indoor and Outdoor Air Sampling Locations

Indoor air samples were collected in 55 residential and 30 commercial buildings out of the 117 proposed for sampling to evaluate the potential for VI impacts, if any, due to the presence of COI in groundwater at the Site (Figure 2.3). The samples provided good spatial coverage across the area, with only a few locations in the center of the Site not sampled due to access limitations.

Ambient (outdoor) air samples were collected to provide information on potential background levels of COI due to ambient air. During indoor air and sub-slab vapor sampling, 20 ambient air samples were approximately concurrently collected, three to five feet above ground surface, in the vicinity of indoor air and sub-slab vapor samples.

2.5.1.1 Residential Buildings

Residential locations sampled are shown on Figure 2.3 and are as follows:

- Of the 32 homeowners (plus the Wyoming County Commissioners apartment) in the "worst case" area offered pre-emptive mitigation systems, 18 chose to have indoor air testing prior to indoor air mitigation system installation (53%); eight chose to waive air testing and install a system (25%); two refused both; and five did not respond.

- Of the 19 residential verification locations, fourteen were tested; one is vacant; and one refused testing (for a 74% acceptance rate). There was no response from three property owners.

- Of the 34 homeowners in the expanded testing area offered air testing, 23 were tested between January and November 2011 (a 68% acceptance rate). One location refused testing and there was no response from ten properties.

2.5.1.2 Commercial Buildings

Permission was obtained to collect indoor air (and in some cases sub-slab vapor) samples at 30 of the 31 candidate commercial buildings (as shown on Figure 2.3) yielding a testing rate of 97%. However it should be noted that:

- Two of the smaller commercial buildings combined into one business (417 and 419 Randall Avenue) with a single indoor air sampling location;
- One property has long been vacant (2714 Oneil Avenue) and therefore was not sampled;
- Eighteen commercial buildings had at least one sub-slab vapor sample collected; and
- One building (315 W. 27th Street) already has a passive radon mitigation system.

2.6 UST Investigation at the Knights of Columbus

An investigation was conducted by EnviroGroup at a former dry cleaner's UST, located in the southeast alley behind the present Knights of Columbus building at 507 W. 28th Street. Six soil samples from six boreholes surrounding the UST and two air samples were collected for analysis. One air sample was collected from the standpipe of the UST and one from the rooftop kitchen exhaust (the kitchen was the former location of the dry cleaning machines). A camera was also lowered into the tank standpipe to determine if the tank had been filled with inert material. Appendix D contains the full report.

2.7 Mt. Sinai Risk Assessment

The Mt. Sinai Synagogue (Mt. Sinai), at 416 W. 26th Street, was the subject of a risk assessment, conducted by Dr. Stephen Foster of TerraMentis for EnviroGroup, which focused on dermal, ingestion and inhalation exposures to site-related contaminants in bath water. The bath water is composed of a mixture of contaminated (i.e., the

concentration of PCE is above the MCL of 5 µg/L) groundwater and tap (i.e., city drinking) water. One groundwater and one bath water, and four indoor air samples were collected in support of the risk assessment. Appendix F contains the full risk assessment.

3 INVESTIGATION PROCEDURES

This section of the report summarizes the groundwater, soil vapor, indoor air, sub-slab vapor, and ambient air sampling procedures followed during the sampling program; detailed field procedures are described in the SAP. Field and laboratory procedures were consistent with the procedures recommended in DEQ VRP Fact Sheets and Chapter 11, Part G – Well Construction and Abandonment (WDEQ, 1984).

The DEQ selected two principal compounds of concern (COCs), PCE and TCE, as the target analytes for soil vapor and indoor air analyses since they are the dominant VOCs historically detected in groundwater and soil vapor samples in the area (URS, 2004; EnviroGroup, 2010a, b). However, the full list of compounds, for each test method, was analyzed in all groundwater samples and selected soil vapor samples in order to evaluate the degradation of PCE and the presence of other potential contaminants in groundwater.

3.1 GROUNDWATER INVESTIGATION

Procedures followed during the groundwater investigation, including monitoring well installation, well development, and groundwater sampling, are described below.

3.1.1 Measurements at Existing Wells and Sumps

Water levels were measured and samples collected at two existing monitoring wells (MW-4 installed by Delta as part of the UST investigation for the former Randall Rite-Way, and Capitol MW-1) in conjunction with measurement and sampling of the newly installed wells (discussed in Section 3.1.2 below) on November 30, 2009 and in early December, respectively. The two private wells at 2915 Thomes Avenue, and 415 W. 24th Street and sumps located at Mt. Sinai (416 W. 26th Street), 523 W. 27th Street, and at the Herschler Building (122 W. 25th Street) were sampled at various times in conjunction with the sampling of the new wells, as described below.

3.1.2 Monitoring Well Installation

Between November 13, 2009 and November 18, 2009, 12 boreholes were advanced by Site Services, Inc. under the oversight of EnviroGroup personnel, to an approximate depth of 14 to 35 feet bgs using a direct-push rig (i.e. Geoprobe®) for the purpose of soil

sample collection and monitor well installation. Site Services, Inc. installed an additional three shallow (13.5 to 15 ft bgs) wells in the western portion and three shallow (17 to 19 ft. bgs) wells in the southern portion of the previously evaluated area in July 2010 and September 2011, respectively. Soil cores were collected using an acetate sleeve from each borehole from ground surface to the total depth of each borehole and soil lithologies were continuously logged by an experienced geologist. A miniRAE 2000 organic vapor analyzer (photo-ionization detector (PID)) was used as a field screening tool to measure organic vapor concentrations within each five foot interval at each borehole. Each one foot interval of recovered core was split immediately after removing the sleeve and a PID reading was taken at one location immediately above the freshly split surface. If staining was noted, additional PID readings were taken at these locations.

In July 2011, during the third phase of soil vapor probe installation, three temporary wells (TW-67, TW-74, and TW-76) were installed with a Geoprobe to approximately 10 to 17 ft. bgs to allow retrieval of groundwater grab samples on the southern and western margin of the previously evaluated area. No soil cores or soil samples were collected for these temporary wells.

Soil samples were collected from soil cuttings from each borehole in 2009 and 2010 with a freshly gloved hand based on visual observation and elevated PID measurements (Table 4.2) for analysis as follows:

- November 16 and 17, 2009: Five soil samples from wells EMW-04 (18-19.0'), EMW-05 (19.0-20.0'), EMW-06 (1.0-2.0'), EMW-08 (16.0-17.5'), EMW-08 (17.5-18.5'), and EMW-08[2] (16.0-17.5') which was collected as a laboratory quality assurance/quality control (QA/QC) sample.

- July 21 and 22, 2010: Three soil samples from wells EMW-13 and EMW-14 for analysis.

- The soil samples were packed tightly (to minimize head space) into clean 4 ounce glass jars with Teflon lids (laboratory-supplied), labeled, logged onto chain of custody documents, and stored on ice for submittal to TestAmerica-Denver for

[2] Soil samples were also selected from EMW-08 to evaluate the significance of a single elevated PID reading at 18 foot depth, since this borehole was beyond the known plume boundary.

VOC analysis using USEPA Method 8260B. The remaining soil core and samples not submitted to the laboratory were placed into 55 gallon drums and stored in a fenced enclosure in the DEQ parking lot for the Herschler Building in November 2009, and in a fenced enclosure behind the former Safeway in July 2010 and September 2011, pending analytical results and eventual disposal by DEQ at the Arvada Treatment Center in Colorado.

3.1.2.1 Well Installation

Immediately upon completion of borehole advancement, all 18 boreholes were completed as monitoring wells. Fifteen boreholes were completed as shallow monitoring wells to evaluate current PCE concentrations near the water table. Because PCE is denser than water, it tends to sink and accumulate at the top of low permeability horizon below the water table. Thus, three boreholes were completed as deeper monitoring wells to evaluate the vertical extent of PCE in groundwater and evaluate the potential for higher PCE concentrations at depth.

Monitoring wells were constructed in accordance with applicable DEQ groundwater rules and regulations (WDEQ, 1984). In particular, shallow monitoring wells (EMW-01, EMW-02, EMW-03, EMW-04, EMW-05, EMW-08, EMW-09, EMW-11, EMW-12, EMW-13, EMW-14, EMW-15, EMW-16, EMW-17, and EMW-18) were constructed with 2 inch inner diameter (I.D.), schedule 40 flush joint threaded PVC materials ranging in depth from 13.5 to 25 feet bgs. Well screens were 5 feet in length (except EMW-14, 16, 17, and 18 which have ten foot screens) with a slot size of 0.020 inch. The filter material (10/20 Colorado Silica Sand) was placed in the annulus of each borehole to a level of approximately two feet above the top of the screen interval. Following installation of the filter material, a bentonite seal (bentonite chips) was placed on top of the filter material to a minimum thickness of two feet. Distilled water was added to ensure proper hydration of the bentonite. Additional bentonite chips were placed in the annular space to approximately one-half foot bgs in all wells and hydrated. Deeper monitoring wells (EMW-06D, EMW-07D, and EMW-10D), ranging in depth from 30 to 35 feet, were constructed similar to shallow monitoring wells, except for the use of 10 foot screens. All monitoring wells were completed with an eight inch diameter flush-mount well vault.

Note that wells EMW-04 and EMW-11 were screened 8-15 feet below the water table, over a depth interval of 19.7 to 24.7 feet, and thus may not represent VOC concentrations at the water table (i.e., those responsible for VI). Due to very slow recharge rates, several other wells were screened slightly (a few feet) below the water table (EMW-01, EMW-05, EMW-08, EMW-09, EMW-12) and thus may not accurately represent VOC concentrations at the water table.

Well completion information, including information on MW-4 from the former Randall Rite-Way site, is summarized on Table 4.1. Monitoring well locations are presented on Figure 2.1.

3.1.3 Well Development and Groundwater Sampling

Groundwater samples from new and existing monitoring wells were collected using Low-Flow Purge (LFP) methods. This method relies on the removal of groundwater at a rate similar to the wells rate of recharge (i.e., the groundwater column height during pumping should not vary more than approximately 10 percent from its steady-state condition or by keeping the drawdown at a minimal level (e.g., 0.33 feet); and is documented in the USEPA's Groundwater Sampling Guidelines for Superfund and RCRA Project Managers (Yeskis, D. and Zavala, B, 2002).

Prior to sampling activities, the static water level was measured using an electronic water-sensing probe. A stainless steel submersible pump was placed in the well to a depth determined to be the center of the screened interval. Purge volumes were calculated based on the pump, flow-through cell, and tubing diameters and lengths. Water levels were continuously measured during purging to ensure drawdown did not exceed 0.33 feet. Field water quality parameters (pH, temperature, specific conductance, oxidation-reduction potential, and dissolved oxygen) were measured during purging using a flow-through cell. Once three successive readings of two or more field water quality parameters stabilized, samples were collected directly from the discharge port of the pump prior to passing through the flow cell into laboratory-supplied containers. Groundwater samples were labeled, logged onto chain of custody documents, and stored on ice for submittal to TestAmerica–Denver for VOC analysis using USEPA Method 8260B.

To minimize cross contamination of groundwater samples, the submersible pump and cable were cleaned (decontaminated) between sample locations with a solution of alconox/deionized water (DI) followed by a DI water rinse, and dedicated, disposable polyethylene tubing (not requiring decontamination) was used at each well. Purge water was containerized at each well location and temporarily placed into a 150 gallon polyethylene tank mounted in the back of the field vehicle.

During the initial Site visit on October 8, 2009, groundwater samples were collected from two existing sumps in the Herschler Building (North Sump and South Sump) using a bailer. All newly installed wells were developed prior to groundwater sampling activities as follows:

- November 2009: The 12 newly installed monitoring wells were developed and two existing monitoring wells (MW-4 and Capitol MW-1) were re-developed between November 19, 2009 and November 30, 2009;
- July 2010: The three new shallow monitoring wells installed in July 2010 were developed on August 3, 2010; and
- September 2011: The three new shallow monitoring wells installed on September 13, 2011 were developed on September 20.

Wells were developed utilizing a 3 foot weighted slug, 1.5 inch dedicated, disposable polyethylene bailers, and a GeoSub SS submersible pump. Prior to well development, the static water level was measured using an electronic water-sensing probe to allow calculation of the wetted casing volume (i.e., the volume of groundwater standing in the casing under steady-state conditions). The wetted casing volume was calculated based on the static water level, well diameter (2 inch), and well depth. Following recording of initial water levels from each well, the wells were developed by surging the water column with a slug to flush the fine particles from the sand filter surrounding the well screen. Development continued by purging groundwater containing the suspended particulates from the well casing with a submersible pump. Surging and purging continued until a minimum of ten wetted casing volumes were removed. Purge water was containerized at each well location and temporarily placed into a 150 gallon polyethylene tank mounted in the back of the field vehicle.

Upon completion of monitoring well development activities wells were allowed to rest one to three days to recharge. Thus,

- Groundwater samples were collected from two existing sumps at the Herschler Building (North Sump and South Sump) during the initial Site visit on October 8, 2009.

- Groundwater samples were collected on December 3 and December 4, 2009 from the 12 newly installed monitoring wells (EMW-01 to EMW-12) and two existing monitoring wells (MW-4 and Capitol MW-1). Additionally, groundwater samples were collected on December 3, 2009 from the Mt. Sinai sump and a tap water sample was collected from the private well located at 2915 Thomes Avenue after 5 minutes of purging the tap. Two laboratory prepared trip blanks (TB100809 and TB120409), two duplicate (EMW-06 DUP and EMW-11 DUP) samples, and two replicate (Capitol MW-1 and EMW-09 REP) samples were collected for QA/QC purposes.

- On March 22, 2010, a groundwater sample was collected from two feet below the water surface in the private well located in the backyard at 416 W. 24th Street. A trip blank was also collected.

- On April 15, 2010 a groundwater sample was collected from the sump located at 523 W. 27th Street. A trip blank was also collected.

- On August 5, 2010, groundwater samples were collected from three newly installed wells (EMW-13, EMW-14, and EMW-15). One laboratory prepared trip blank (TB080510) and one duplicate sample (EMW-14 DUP) were collected for QA/QC purposes.

- The grab samples from the three temporary wells installed in July 2011 were sampled within a few hours of installation. One laboratory prepared trip blank (TB071411) was collected for QA/QC purposes.

- On September 21, 2011, groundwater samples were collected from three newly installed wells (EMW-16, EMW-17, and EMW-18). One laboratory prepared trip

blank (TB092111) and one duplicate sample (EMW-16 DUP) were collected for QA/QC purposes.

- Three (excluding QA/QC samples) groundwater samples were collected on September 21, 2011 from three newly installed monitoring wells (EMW-16, 17, and 18). One laboratory prepared trip blank (TB092111) and one duplicate sample (EMW-16 DUP) were collected for QA/QC purposes.

3.1.3.1.1 Investigation Derived Waste

All purge water was transferred into 55 gallon drums and placed in a fenced enclosure in the DEQ parking lot for the Herschler Building in November 2009, and in a fenced enclosure behind the former Safeway in July 2010 and September 2011, pending analytical results and disposal by DEQ at the Arvada Treatment Center of Colorado.

3.1.4 Water Table Elevations

The Northing, Easting, ground surface elevation, and top of casing elevation of all sampled wells in December 2009 were surveyed and referenced to a consistent site datum by an experienced surveyor on January 22, 2010, for wells EMW-13, EMW-14, and EMW-15 on August 28, 2010, and wells EMW-16, EMW-17, and EMW-18 by Western Research and Development on January 24, 2012.

Water level measurement data was used to develop an estimation of the shallow groundwater surface and to assess groundwater flow directions.

3.2 SOIL VAPOR INVESTIGATION

Procedures followed during the soil vapor investigation, including soil vapor point installation, sampling, and analysis using a mobile and fixed-base laboratory, are described below.

3.2.1 Soil Vapor Probe Installation

Between November 18, 2009 and November 20, 2009, 43 permanent soil vapor probes (ESV-1 to ESV-43) were installed at the locations shown on Figure 2.2. The probes were installed at select locations within the PCE soil vapor and groundwater plumes previously identified by EPA in 2004.

Soil vapor probes were installed under the oversight of EnviroGroup personnel, at locations selected by EnviroGroup, at depths of approximately 5 feet bgs using a direct-push rig (i.e. Geoprobe® or equivalent). Upon completion of drilling activities and using freshly-gloved hands, each soil vapor probe assembly was immediately placed into the borehole by drilling personnel. All soil vapor probes, except ESV-41, 42, 43, 60, 61, 62, and 63, were constructed using 0.25 inch I.D. by 6 inch long stainless steel screens connected to 0.25 inch outer diameter (O.D.) Nylaflow® tubing. Screens were placed at the desired sampling depth (typically in the middle of the sampling zone, described below) and the tubing extended up the center of the borehole to approximately 6 inches above ground surface and was fitted with an air-tight valve. Screens were placed in the soil vapor sampling zone (typically one foot in length) at the bottom of the borehole. In the case of ESV-41, 42, 43, 60, 61, 62, and 63, a shortage of stainless steel screens resulted in the use of one inch long Discard-A-Stone plastic air diffusers as the screen.

Each screen was centered within the sampling zone and the annulus surrounding the screen was backfilled with approximately one foot of clean silica sand (i.e., 60 – 120 sieve size) then sealed with bentonite. The granular bentonite seal was installed in nominal 8 inch lifts (with distilled water hydration following each lift) to a height of approximately two feet above the silica sand. The remaining annulus was then backfilled to grade with granular bentonite, installed in two foot lifts (with distilled water hydration between each lift). A five inch diameter flush-mount well vault was concreted around the top of each soil vapor probe to minimize infiltration of water or outdoor air.

Additional permanent soil vapor probes, also shown on Figure 2.2, were installed following the same procedures as described above in 2010 and 2011 as follows:

- Between July 20, 2010 and July 22, 2010: at 20 select locations (ESV-44 to ESV-63) along and beyond the western margin of the PCE plume identified by the first phase of the investigation.

- Between July 12, 2011 and July 14, 2011: at 14 select locations (ESV-65 to ESV-78) along and beyond the southern and western margins of the PCE plume identified by the first and second phases of the investigation.

- Between September 13, 2011 and September 14, 2011: at five select locations (ESV-79 to ESV-83) near the intersection of 23rd Street and Bent Avenue where an anomalous TCE result was found in the previous phase of the investigation.

3.2.2 Leak Testing

During soil vapor sampling activities, a clean, small plastic shroud with two small ports was placed over each soil vapor probe and weighted down. An air-tight seal of foam was placed on the ground surface around the edge of the shroud where it contacted the ground. The soil vapor probe tube, fitted with an air-tight valve, was extended up through the air-tight seal to the exterior side of the shroud.

Each soil vapor tube connected to an air-tight valve, was then connected with a tedlar bag attached to one side of the valve and the glass sampling syringe on the other side of the valve (both outside of the shroud). Prior to purging or sampling activities, helium tracer gas was released via a small diameter tube through a port in the shroud into the enclosure beneath the shroud to a minimum concentration of 22.5% helium (i.e., at least ten times the detection limit of the helium meter). A sample of the air inside the shroud was measured through the second port using a portable helium detector to determine the concentration of helium within the enclosure beneath the shroud. Three purge volumes (calculated based on the volume of probe tubing and screen) were purged at a flow rate of 0.1 liters per minute, through the shroud into a 60 milliliter (mL) calibrated gas-tight syringe and transferred to a tedlar bag. The tedlar bag was then connected to a portable helium detector to measure for the presence of helium gas in the purged vapor. If high concentrations (>10% of the shroud concentration) of helium were observed in the purge vapor, the soil vapor probe seal was checked and/or enhanced to reduce the infiltration of ambient air into the enclosure and another sample collected. If helium concentrations were less than 10% of the shroud concentration, a soil vapor sample was collected for analysis.

Tracer test results measured during both phases of the investigation indicated minimal tracer gas breakthrough (<1% of the shroud concentration), except for point ESV-16 (in the Knights of Columbus parking lot, November 2009) where the purge gas contained approximately 15% of the shroud concentration. This point was resealed several times with no improvement in the apparent ambient air leakage. The elevated helium

concentrations at this location likely indicate communication between ambient air and permeable base/coarse soils below the asphalt, through cracks in the asphalt, rather than leakage along the annulus of the probe, which reflects Site conditions rather than problems with sampling procedures. Based on the observation of minimal tracer gas in the purge gas from the remaining probes during both sampling events, we believe that all other soil vapor probes were properly installed and representative soil vapor samples were collected. Upon completion of sampling activities all soil vapor probes were closed and secured.

3.2.3 Soil Vapor Probe Sampling and Analysis

Soil vapor samples were collected in the field using current state of the art procedures for mobile and fixed-based laboratory methods which are described below.

Sampling and Analysis

To provide information on the nature and extent of PCE and TCE, a mobile laboratory provided by Hartman Environmental Geosciences provided real-time laboratory analysis of PCE and TCE in the soil vapor samples. Duplicate soil vapor samples were also collected from approximately 20% of the soil vapor probes (collected concurrently with mobile lab samples) for fixed-based laboratory VOC analysis to demonstrate comparability of sample results and to screen for the presence of breakdown products (e.g. cis-1,2-dichloroethene and vinyl chloride) and volatile petroleum compounds (e.g., benzene, toluene, ethylbenzene, and xylenes). The soil vapor sampling was conducted in phases as follows:

- November 19, 2009 through November 20, 2009: soil vapor samples including two field duplicate samples (ESV-16DUP and ESV-38DUP) were collected from the first 43 soil vapor probes. Eight samples were collected for fixed-base laboratory analysis.

- July 22, 2010: 22 soil vapor samples, one field duplicate sample (ESV-25DUP), and four duplicate samples for fixed-base laboratory were collected from the 20 new soil vapor probes plus two existing probes installed in November 2009 (ESV-12 and ESV-25).

- July 14, 2011: 16 soil vapor samples, two field duplicate samples, and three duplicates for fixed-based laboratory were collected from the 13 of the 14 new soil vapor probes plus three existing probes installed in July 2010 (ESV-44, ESV-60 and ESV-61). One soil vapor probe (ESV-72) was wet and unable to be sampled at that time.

- September 14, 2011 seven soil vapor samples were collected from the five new soil vapor probes plus two existing probes installed in July 2011 (ESV-72 and ESV-74) and sent to a fixed-based laboratory for VOC analysis by EPA Method TO-15 as no mobile laboratory was utilized for this sampling event.

Each soil vapor probe was not disturbed for at least 24 hours prior to sampling (other than ESV-41, 42, and 43 which were installed several hours prior to sampling on November 20, 2009, and ESV-60, 61, 62, and 63 which were installed several hours prior to sampling on July 22, 2010). The latter probes were added to the first and second phases of the investigation program, respectively, based on mobile lab results from the nearby soil vapor points, which indicated that the boundary of the plume had not been delineated by the existing points. These field decisions, as approved by DEQ, did not allow 24 hours between probe installation and sampling for these seven points because the mobile laboratory was departing the day of installation in each case. These seven soil vapor points with short equilibration times may not be fully representative of subsurface concentrations and the results may be biased low. Two of these probes (ESV-60 and 61) were resampled in July 2011 in order to verify the earlier results.

Soil vapor samples for mobile laboratory analysis were collected at flow rates of less than 0.1 liters per minute using clean, 30 mL glass syringes supplied and certified clean to reporting limits by Dr. Hartman of Hartman Mobile Geosciences. Fixed-base laboratory duplicate soil vapor samples were collected concurrently with mobile lab samples over approximately a 10 minute time period, utilizing dedicated, laboratory-set regulators and 1 liter Summa® (or equivalent) canisters supplied and certified clean (i.e. batch certification) to reporting limit levels by Centek Laboratories, LLC, (Centek), a National Environmental Laboratory Accreditation Conference (NELAC)-certified laboratory in 2009 and 2010 for the first two sampling events and by H&P Mobile Geochemistry, a NELAC-certified laboratory, for the last two sampling events (July 2011 and September 2011).

The mobile laboratory used a gas chromatography-mass spectrometry (GC/MS) and completed soil vapor analysis for PCE and TCE only, using USEPA Method 8021 with nominal reporting limits of 7.0 to 15.0 micrograms per cubic meter ($\mu g/m^3$) and 11.0 to 15.0 $\mu g/m^3$, respectively. Duplicate samples were shipped to Centek or H&P Labs within two days of sampling so that no sample exceeded the 30-day holding time for the TO-15 method. These samples were analyzed for VOCs by USEPA Method TO-15 with minimum reporting limits of 1.6 $\mu g/m^3$ or less. All samples were analyzed within 13 days of collection. Full chain of custody documentation was maintained for all canisters from time of shipping from the laboratory to the time of analysis.

A total of four ambient air samples (1 per day) were collected during the three phases of mobile lab soil vapor sampling to provide information on potential background levels of PCE and TCE due to ambient air. Samples were collected in an upwind location, approximately five feet above ground surface near the location of the mobile laboratory using clean, 30 mL glass syringes, and were analyzed via USEPA Method 8021 by the mobile lab.

3.3 INDOOR AIR INVESTIGATION

Procedures followed for indoor air sampling, sub-slab vapor probe installation and sampling, and ambient air sampling are described below.

3.3.1 Occupant Interview Documentation

Prior to sampling activities, an EnviroGroup representative interviewed a resident (or the building owner) and evaluated building conditions at each sampling location using a DEQ approved questionnaire. This included completing a building inspection form and a floor plan sketch to establish construction details relevant to VI evaluation (such as locations of dry wells, sumps, foundation cracks, type of heating and ventilation system, sources of outdoor air, etc.) and a chemical inventory to identify obvious sources or activities that could produce COCs and potentially affect indoor air samples. To limit the potential for internal sources of VOCs to impact the indoor air during the sampling, residents were requested to limit uses of VOC-containing substances during the sampling period. In addition, each building was inspected for an existing radon mitigation system and the status of that system, if applicable. The completed questionnaire, floor plan sketch, and chemical inventory for each building are provided in Appendix A.

3.3.2 Indoor Air Sampling and Analysis

Indoor air samples were collected from the basement, when present, even if not occupied, in order to provide a measure of worst case VI impacts. In addition, the samples were collected during the winter to most likely represent the worst case indoor air concentrations. Winter indoor air concentrations are typically expected to be approximately 150% of the annual average concentration in a home (Kuehster et al., 2004) due to building factors like stack effects.

For QA/QC purposes, a contemporaneous outdoor air sample was intended to be collected during each day of indoor air and sub-slab vapor sample collection. However, due to the difficulty of scheduling indoor air tests efficiently, the frequency of outdoor air sampling was reduced to weekly in order to be cost effective. The 20 outdoor air samples collected are considered to adequately represent the locations sampled.

As shown in Table 2.2 and described below, indoor air samples were collected from the buildings as follows:

- Two commercial buildings (508 W. 27th Street and 422 W. 26th Street) and one residential structure had an indoor air sample collected from both the crawl space and basement.
- Three air samples were collected from the utility tunnels beneath the former Safeway (2512 Pioneer) in addition to seven indoor air samples on the main floor of the building.
- Eight of the commercial buildings had more than two indoor air samples collected in order to provide adequate spatial coverage.
- One indoor air sample was collected from the basement of 55 residential structures and 12 commercial buildings.
- No indoor air samples were collected from the apartment building located at 400 W. 27th Street. Only two sub-slab samples were collected at this location, as requested by the building owner.

Indoor air sample locations were selected away from vents, windows, and chemical sources, in a centrally-located area, at a height of approximately three feet above the floor to represent the typical breathing zone (e.g., height when sitting). Building occupants were asked to keep windows and doors closed during the entire sampling period.

Residential and commercial indoor air samples were collected over a 24 hour and 8-hour time period, respectively. All samples were collected in dedicated, laboratory-set regulators and 6 Liter (L) Summa® (or equivalent) canisters supplied and individually certified clean to reporting limit levels by Air Toxics Ltd., of Folsom, California (Air Toxics), a NELAC certified laboratory and shipped under chain-of-custody documentation within four days of sampling to Air Toxics Ltd. and analyzed for VOCs by USEPA Method TO-15.

3.3.3 Sub-Slab Vapor Probe Installation, Sampling, and Analysis

Contemporaneous with the indoor air sample collection, sub-slab vapor samples were collected from 17 commercial buildings, one apartment building, a daycare center, and one private residence as shown on Figure 2.3. When possible, and as permitted by the owners, the sub-slab vapor samples were collected in a central location, away from foundation footings and obvious slab perforations, on the lowest floor of the building. Seven of the commercial buildings tested, including the former Safeway, were slab on grade structures. Two or more sub-slab vapor samples were collected in seven of the larger commercial buildings to provide better spatial coverage.

Temporary probes for sub-slab vapor sampling were installed by drilling approximately 1/2 or 3/4 inch outer diameter (OD) holes through the basement or first floor slabs, as applicable, no further than 2 inches into the underlying sub-slab materials. The 1/2 or 3/4 inch OD hole was then over-drilled with a larger 1.5 inch OD hole to a depth of about 1 inch below the slab surface. A new, clean length of 0.190 inch ID x 0.25 inch OD Nylaflow® tubing, fitted with an acrylic screen, was inserted into the hole to the base of slab and sealed in the hole with hydrated bentonite.

Sub-slab vapor samples were collected using current state of the art procedures as follows. Once the probes were installed, a clean, small plastic or stainless steel shroud with two small ports was placed over each sub-slab vapor probe and weighted down. An

air-tight seal of foam was placed on the ground around the edge of the shroud. The sub-slab vapor probe tube extended up through the air-tight seal of foam to the exterior of the shroud and was connected to an air-tight three-way valve. The remaining two ports of this valve were connected to a tedlar bag and a 60 mL calibrated gas-tight syringe.

Prior to purging or sampling activities, helium tracer gas was released via a small diameter tube through a port in the shroud into the enclosure beneath the shroud. A sample of the air inside the shroud was measured through the second port using a portable helium detector to determine the concentration of helium within the enclosure beneath the shroud.

Sub-slab vapor probes were purged (i.e., approximately three probe volumes) at a flow rate of 100 to 200mL per minute, through the shroud into a 60 mL calibrated gas-tight syringe and transferred to the tedlar bag. The tedlar bag was then connected to a portable helium detector to measure for the presence of helium gas in the purged vapor. If high concentrations (>10% of the shroud concentration) of helium were observed in the purge vapor, the sub-slab probe seal was checked and/or enhanced to reduce the infiltration of ambient air into the enclosure and another sample collected. If helium concentrations were less than 10%, a sub-slab vapor sample was collected for analysis. Upon completion of sampling activities, all sub-slab vapor probes were removed and holes filled with bentonite and sealed with concrete.

Sub-slab vapor samples were collected over approximately the same time period as the associated indoor air sample (i.e., 24 hours for the residential building and 8 hours for the commercial buildings) utilizing dedicated, laboratory-set regulators and 6 L Summa® (or equivalent) canisters supplied and individually certified clean to reporting limit levels by Air Toxics.

Samples were shipped to the laboratory within three days of sampling so that no sample exceeded the 30-day holding time for the TO-15 method. Full chain of custody documentation was maintained for all canisters from time of shipping from the laboratory to the time of analysis. Sub-slab vapor collection information is summarized on the sub-slab vapor sample collection logs provided in Appendix B.

3.3.4 Ambient Air Sampling

One outdoor air sample was collected for each week of indoor air sampling, contemporaneous with indoor air sampling, for comparison to the indoor air results. The 20 outdoor air samples were collected immediately outside the buildings (but not closer than 5 feet), on the upwind side, away from any exhaust from the buildings (e.g., exhaust vents) or wind obstructions, at a height of approximately three feet above ground level, and distant from any obvious source of VOCs at the buildings.

Ambient air samples were collected using dedicated, 8-hour or 24-hour laboratory-set regulators (consistent with the indoor air sampling time period for commercial and residential locations, respectively) installed on 6 L Summa® (or equivalent) canisters, equipped with particulate filters, supplied and certified clean (i.e. individual certification) to reporting limit levels by Air Toxics Ltd.. Ambient air samples were shipped under chain-of-custody documentation to Air Toxics Ltd. and analyzed for VOCs by USEPA Method TO-15.

3.3.5 Laboratory Procedures for Indoor Air, Outdoor Air, and Sub-Slab Vapor Samples

All samples (indoor air, outdoor air, and sub-slab vapor) were analyzed using a modified Method TO-15 (USEPA, 1999a), with minimum reporting limits of 0.8 $\mu g/m^3$ for PCE and 0.25 $\mu g/m^3$ for TCE (the two COCs), by Air Toxics Ltd., using internal standard operating procedures (SOPs). Due to a shortage of canisters, two locations had canisters supplied by, and analyses conducted by, TestAmerica, Los Angeles, also a NELAC certified laboratory. Specifics regarding the derivation of laboratory reporting limits are described below.

The laboratory reporting limits (RLs) 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 RLs can vary for each sample, depending on sample volume and sample matrix effects, as shown on Table 3.2.

As shown in Table 3.2., in general, the RLs for PCE and TCE in indoor air were much less than the residential screening levels established by DEQ except in three cases where

the samples were diluted more than usual due to the presence of high concentrations of non-target analytes. In all three cases the RL for TCE was above, and the RL for PCE was below, the residential screening level. In two of these cases the PCE was not detected at a reporting limit below the residential screening level and in the third case, the detected PCE concentration exceeded the screening level. In the latter case it is likely that TCE was also present above the screening level based on the expected relative abundance of TCE and PCE derived from VI, as described in Section 5.4.4.

Table 3.2 Reporting Limits for Air Samples

Volatile Organic Compound	Indoor/Outdoor Air Sample RL (µg/m^3)	DEQ Residential Screening Level (µg/m^3)	DEQ Commercial Screening Level (µg/m^3)
Trichloroethene (TCE)	0.15 to 0.48[a]	0.9	4.2
Tetrachloroethene (PCE)	0.21 to 0.39[b]	8.1	27.2

Notes: a) Three anomalously high RLs of 2.0, 2.5, and 4.6 µg/m^3
b) Three anomalously high RLs of 2.0, 2.6, and 5.8 µg/m^3

3.4 Knights of Columbus UST Investigation Procedures

Six boreholes were installed by Geoprobe or hand-augering to approximately 10 foot depth in the vicinity of the underground storage tank for the former dry cleaners at 507 W. 28th Street (not the Knights of Columbus). The cores were screened with a ppbRAE and selected soil samples were collected from each borehole and submitted for laboratory analysis of VOCs. A vapor sample from the tank standpipe and an air sample from the kitchen stove vent (the former location of the dry cleaning machines) were collected with syringes and analyzed by the on-site mobile laboratory. Additional details are included in the attached Investigation Technical Memorandum (Appendix D)

3.5 Ecological Risk Assessment Procedures

Step 1, the Ecological Exclusion Assessment, of an Ecological Risk Assessment was completed in accordance with DEQ VRP Fact Sheet #14 for the Cheyenne PCE Plume Orphan Site. Based on the results of Step 1, which indicated no wetlands or endangered species were present in the Site vicinity, it was determined that Step 2 was not necessary for this Site. The full report is included as Appendix E.

3.6 Mt. Sinai Risk Assessment Procedures

On March 2, 2010 the DEQ sampled indoor air and bathwater at Mt. Sinai (416 W. 26th Street) as part of the Cheyenne Orphan Site Program Investigation. A groundwater sample was also collected on December 3, 2009 from the Mt. Sinai sump. The purpose of the risk assessment was to provide a summary of estimated risk from exposure to groundwater and indoor air for a special receptor: a woman (attendee) using the Mikvah (or bath) at the synagogue. Potential risks to the attendee were evaluated for ingestion, dermal contact, and inhalation pathways. Dr. Stephen Foster, of TerraMentis Environmental Consulting, Boulder, Colorado completed the risk assessment according to standard EPA methods. The full report is included as Appendix F.

3.7 Decontamination and Management of Investigative Derived Wastes

Minimal amounts of investigative derived wastes (IDW) associated with the installation of monitoring wells and soil vapor probes, well development, and groundwater sampling activities were generated during investigation activities. All IDW was stored on-site, at the locations selected by DEQ.

All drilling equipment was decontaminated between borehole/monitoring well and soil vapor probe locations. Drilling equipment was cleaned using a detergent and potable/distilled/deionized water wash following by a triple-rinse with distilled or deionized water. Decontaminated equipment was then allowed to air dry or appropriately stored for later use.

Drill cuttings/soil cores were assumed to potentially have significant levels of COIs (e.g., PCE and TCE), and were visually inspected for the presence of non-aqueous phase liquids (NAPLs) and field screened with a ppbRAE to measure organic vapor concentrations at each borehole location. Based on field measurements, no soils exhibited NAPL or elevated organic vapor concentrations. Cuttings were placed into 55 gallon drums, properly labeled with a pending label, and stored on-site pending laboratory analytical results.

Decontamination and groundwater purge waters were visually inspected for the presence of NAPL. As no strong odors or sheen were observed, decontamination and

groundwater purge waters were placed into 55 gallon drums, properly labeled with pending labels, and stored on-site pending laboratory analytical results.

All other IDW (e.g., disposable gloves, used LFP tubing, bailers and rope, and the like) was bagged, properly labeled with a pending label, and stored on-site, pending disposal arrangements.

An inventory of each day's IDW was recorded in a bound field book and/or on appropriate field forms. The inventory references the date and area of generation and was provided to DEQ for its use in the proper management of the IDW. DEQ will remain the sole owner of any IDW generated by investigation activities; however, EnviroGroup assisted DEQ with assessing waste transportation and disposal options.

Soil and water placed in drums were characterized by DEQ based upon laboratory analytical results from groundwater samples. Soil and water drums were picked-up, transported, and disposed of by Arvada Treatment Center, of Arvada, Colorado, a Part B permitted hazardous waste treatment, storage, and disposal facility.

4 RESULTS OF INVESTIGATION

The results of the investigation, including data validation, are presented in this section. Complete laboratory data is presented in Appendix C. An evaluation of the data is presented in Section 5.

4.1 Water Levels

The results of water level measurements for the new wells, and existing wells MW-04 and Capitol MW-1, are presented in Table 4.1. Well construction details for the new wells are also provided in this table.

4.2 Soil Results

The organic vapor headspace (PID) readings taken of the soil borings during well installation indicated the presence of elevated organic vapor concentrations in 11 of 18 boreholes. Elevated PID readings were measured in all boreholes except EMW-01, EMW-03, EMW-10, EMW-12, EMW-16, EMW-17, and EMW-18. PID results are summarized on Table 4.2.

Soil analytical results, included in Appendix C, and summarized on Table 4.3 indicated:

- the presence of PCE at 0.08 to 0.19 milligrams per kilogram (mg/kg) in sample EMW-04, EMW-05, and EMW-06, exceeding the PCE Migration to Groundwater Cleanup Level of 0.000052 mg/kg (DEQ Voluntary Remediation Program (VRP) Fact Sheet #12, Soil Cleanup Level Look-Up Table, 2009).
- TCE concentrations were just below the Migration to Groundwater Cleanup criteria in two samples (EMW-04 and EMW-06).
- 1,2-dichloroethane was present at concentrations of 0.011 mg/kg in three samples (EMW-05, EMW-06, and EMW-08 (17.5 to 18.5'), exceeding the Migration to Groundwater Cleanup Level of 0.000044 mg/kg (DEQ VRP Fact Sheet #12, Soil Cleanup Level Look-Up Table, 2009).
- Methylene chloride was present at low levels in the three July 2010 samples, likely due to laboratory blank contamination.

- No PCE or TCE was detected in the soil samples from EMW-08, EMW-13, or EMW-14.
- All other compounds were not detected at the reporting limit (RL).

4.3 Groundwater Results

Field water quality parameters were measured for each well and the Mt. Sinai sump and are presented on Table 4.4. A summary of groundwater analytical results is presented on Table 4.5. Complete laboratory data is presented in Appendix C.

As shown in Table 4.5, groundwater analytical results indicated:

- Concentrations of PCE were above the EPA Primary Drinking Water Standard (EPA MCLs) (EPA, 2003) and DEQ Groundwater Cleanup Levels (DEQ GCLs) (DEQ VRP Fact Sheet #13, 2009) of 5 µg/L in 14 of 29 groundwater samples (includes two sump samples and one private well sample), with concentrations ranging from 11 µg/L to 720 µg/L.
- TCE concentrations exceeding DEQ GCLs were also detected in sample EMW-13 (7.6 µg/L) and the sump sample from 523 W. 27th Street (17 µg/L). Low TCE concentrations, below DEQ GCLs were detected in 9 other monitoring wells, one private well, and in one sump sample.
- All other compounds were reported below DEQ GCLs.
- Low levels of cis-1,2-DCE, a breakdown product of PCE, were detected in two wells and two sumps.
- Low levels (up to 17 µg/L) of chloroform were detected in nearly all wells.
- Traces of xylenes were detected in five wells.
- Acetone and methylene chloride were the only other compounds detected in groundwater.

PCE concentrations in groundwater exceeding DEQ GCLs were observed within the historic groundwater PCE plume boundaries (URS, 2004) and extending further to the

southwest. PCE was not detected to the north of the historic PCE plume boundary (URS, 2004), in groundwater wells EMW-07 and EMW-08 and in the private well at 2915 Thomes Avenue. With the exception of one well (EMW-12) PCE concentrations were generally comparable to or higher than those observed in 2004, particularly in the northwestern and southwestern portion of the Site.

4.4 Soil Vapor Results

The following presents a summary of the PCE and TCE soil vapor sample results obtained from the mobile and fixed-base laboratory analysis, and a comparison of these results to the URS (2004) soil vapor sample results.

4.4.1 PCE

Soil vapor analytical results indicated the presence of PCE above the DEQ screening level of 810 $\mu g/m^3$ in 29 soil vapor probes during the four phases of investigation:

- 18 soil vapor samples and one duplicate sample during the November 2009 sampling event,
- 11 soil vapor samples during the July 2010 sampling event, and
- none during the July or September 2011 sampling events.

PCE was detected below the screening level in all remaining probes (including five non-detects).

This screening level was selected by DEQ based on the $1x10^{-5}$ target indoor air concentration risk level of 8.1 $\mu g/m^3$ from the 2002 EPA OSWER Draft Vapor Intrusion Guidance (EPA, 2002), with an assumed attenuation factor (the ratio of the indoor air concentration to the soil gas concentration) of 0.01. Soil vapor results are summarized in Table 4.6 and PCE and TCE concentrations are shown on Figure 4.2.

Three of the 29 soil vapor probes exceeding the screening level, located just south of the operating dry cleaner at 501 Randall Avenue (i.e., ESV-15, ESV-16, and ESV-41), contained the highest PCE concentrations, ranging from 52,000 $\mu g/m^3$ to 320,000 $\mu g/m^3$. Note that point ESV-16 was the one sample point where the helium shroud data indicated

significant ambient air leakage (approximately 15% of the shroud concentration). On that basis, it is expected that the true soil vapor concentrations in ESV-16 are up to 15% higher than those measured. The remaining 26 locations above the screening level had PCE concentrations ranging from 885 $\mu g/m^3$ to 20,000 $\mu g/m^3$. The majority of locations above the screening level were along the western portion of the soil vapor plume, with the exception of four points surrounding the former Safeway store at 2512 Pioneer Avenue.

4.4.1.1 Comparison to URS (2004) Results

Overall, PCE concentrations detected in the soil vapor were generally higher than those observed by URS in 2004. The highest PCE concentrations were observed within or immediately adjacent to the historic PCE plume boundary identified by EPA in 2004 (URS, 2004); however, soil vapor probe ESV-49, which contained a concentration of 15,000 $\mu g/m^3$, was collected approximately 300 feet west of the 2004 interpreted plume boundary. The extension of the elevated soil vapor concentrations to the west of the previously investigated area is consistent with the finding of groundwater concentrations above the MCL in four new wells (EMW-13, EMW-14, EMW-15, and EMW-17) installed west of ONeil Avenue. Soil vapor concentrations were also above the screening level at the southern extent of the expanded investigation area along 25th Street (ESV-44, ESV-45, ESV-46, and ESV-48), indicating that the southern extent of the soil vapor plume was still not defined. The third phase of soil vapor testing to the south and west of the phase 2 expanded investigation area returned results that were all below screening levels, with the exception of one anomalous result for TCE at ESV-74 at the far south edge of the investigation area.

4.4.2 TCE

Soil vapor analytical results indicate the presence of TCE in 15 soil vapor samples at or above the DEQ screening level of 90 $\mu g/m^3$. This screening level was selected based on an estimated $1x10^{-5}$ risk level target indoor air concentration of 0.9 $\mu g /m^3$ (based on considerations of an EPA compilation of background indoor air concentrations by DEQ) with an assumed attenuation factor of 0.01 for shallow soil vapor to indoor air. Two soil vapor probes (ESV-16 and ESV-41) near the presently operating dry cleaner at 501 Randall Avenue contained TCE concentrations ranging from 22,000 $\mu g/m^3$ to 24,000

μg/m^3. The remaining thirteen soil vapor probes with TCE above the screening level had TCE concentrations ranging from 90 μg/m^3 to 1480 μg/m^3. One of the locations with TCE above the screening level was located at the far southern edge of the test area (ESV-74) and had an anomalous abundance of TCE relative to PCE[3]. This location was resampled in September 2011 and returned fixed-base laboratory results that were below detection for TCE suggesting that the initial mobile lab analysis was in error for this sample. TCE was detected well below the screening level in sixteen additional soil vapor probes and not detected in the remaining soil vapor probes.

4.4.3 Fixed Base Laboratory Results

The fixed-base laboratory duplicate samples generally returned PCE and TCE concentrations somewhat lower than those from the mobile laboratory (Table 4.6). In addition, the fixed-base laboratory duplicate samples indicated the presence of cis-1,2-dichloroethene in a number of samples (ESV-11, ESV-16, ESV-27, ESV-29, ESV-35, ESV-39, and ESV-55); vinyl chloride in ESV-16 and ESV-60; trans-1,2-dichloroethene in ESV-55; and 1,1-dichloroethene in ESV-16. Petroleum hydrocarbons and chloroform were also present at elevated levels in a number of samples from the western portion of the Site (ESV-47, ESV-55, ESV-59, and ESV-60) with the highest levels of BTEX in ESV-59 and the highest levels of chloroform in ESV-55. The high chloroform levels (200 μg/m^3) may indicate a leaking water line. ESV-16 and ESV-47 also had elevated levels of benzene, cyclohexane, hexane, and heptane. The high abundance of cyclohexane, hexane, and heptane, despite their absence in groundwater, can be explained by the very high volatility of these compounds (Henry's Law Constants several orders of magnitude greater than benzene and toluene) which can produce significant soil gas concentrations from levels present below the detection limit in groundwater. The presence of low levels of Freon 11 and 12 in many samples is probably due to the permeation of some ambient air into the shallow soils (due to diffusion and downward pressure gradients during periods of rising barometric pressures).

[3] TCE is normally present at a concentration equal to approximately 10% of the PCE concentration.

4.4.4 Ambient Air Results Associated with Soil Vapor Sampling

PCE and TCE were not detected in ambient air samples collected in conjunction with the soil vapor sampling (i.e. EAA-01, EAA-02, EAA-03, and EAA-04) at mobile laboratory reporting limits of 7 to 11 $\mu g/m^3$ and 15 $\mu g/m^3$, respectively.

4.4.5 Results of Resampling

The two soil vapor points installed in November 2009 that were sampled again in July 2010 (ESV-12 and ESV-25) yielded 45% to 200% higher results than in the November sampling. This is not unexpected as soil temperatures are higher in July and the shallow soils were probably drier leading to increased volatility and transport in the vadose zone. Three soil vapor points installed in November 2009 and July 2010 were sampled again in July 2011 and yielded nearly identical results for two of the three samples. The third sample returned results 30 times higher in July 2011. The short equilibration time for this point (ESV-60) in July 2010 may explain the low initial result.

4.5 Concurrent Indoor Air, Outdoor Air and Sub-Slab Vapor Results

This section presents the results of the investigation, including indoor air, outdoor air and sub-slab vapor results. As summarized in Tables 4.7 and 4.8, a total of:

- 147 pre-mitigation indoor air samples were collected from 52 homes, three apartment buildings, and 30 commercial buildings;
- 36 sub-slab vapor samples were collected from 18 commercial and two residential buildings;
- 20 outdoor air samples were collected from the vicinity of 11 homes and 9 commercial buildings for comparison purposes; and,
- 21 post-mitigation indoor air samples were collected from 16 homes and one commercial building.

4.5.1 Indoor Air Analytical Results

As shown in Table 4.7, PCE was detected in nearly all indoor air samples, with concentrations ranging from below detection (< 0.22 μg/m^3) up to 62 μg/m^3. PCE was not detected in:

- five residential structures (two apartment buildings and three single family homes) in the verification area, and five commercial buildings and one home (2616 Carey Avenue) located in the worst case area; and
- seven of the 23 residential structures tested in the expanded testing area.

TCE concentrations ranged from below detection (< 0.17 μg/m^3) up to 5.6 μg/m^3. Thirty five samples had detections of TCE. Only eleven residential buildings had detections of TCE.

4.5.2 Outdoor Air Analytical Results

PCE was the only COC detected in outdoor air (other than one anomalous result), with concentrations ranging from below detection to 0.73 μg/m^3. The average PCE concentration in these samples was less than the typical reporting limit of 0.3 μg/m^3. In addition, the concentrations detected were much lower than those detected in the indoor air in most of the buildings tested. One anomalous TCE result of 1.3 μg/m^3 was measured for a sample collected at ground level next to 507 W. 28th Street (directly across the street from the active dry cleaner).

4.5.3 Sub-Slab Vapor Analytical Results

As shown in Table 4.8, PCE was the dominant COC present in sub-slab vapor, with concentrations ranging from 0.47 μg/m^3 to 3,700 μg/m^3.

The concentration of TCE detected in the sub-slab vapor ranged from below detection (< 0.17 μg/m^3) to 810 μg/m^3. TCE was not detected in sub-slab vapor in ten buildings. TCE concentrations were typically about 10% or less of the associated PCE concentration, except for the samples at 523 W. 27th Street and 400 W. 27th Street where TCE was approximately 30% of the PCE concentration.

4.6 Data Validation

All soil, groundwater, soil vapor, indoor air, sub-slab vapor, and outdoor air samples were subject to data validation by EnviroGroup. This was performed to verify that they were collected and tested according to EnviroGroup Standard Operating Procedures.

Data validation included the following items (several apply only to sub-slab vapor, indoor and outdoor air):

- Ensuring that sample documentation and holding time requirements were met for all samples;
- Ensuring that chain of custody requirements were met;
- Evaluation of field duplicates;
- Evaluation of pre-test and post-test vacuum;
- Evaluation of the concentration of the tracer gas for all soil vapor and sub-slab samples;
- Ensuring that laboratory control samples and standards were within laboratory specified control ranges for the VOCs analyzed;
- Ensuring the method blank results were non-detect at the reporting limits;
- Ensuring that instrument tuning procedures were documented;
- Ensuring that all surrogate recoveries were within acceptable ranges; and
- Ensuring that the data summary sheets were correct based on an evaluation of the raw data.

4.6.1 Quality Assurance/Quality Control

The quality assurance objective for field and laboratory investigations is to provide defensible analytical data that are accurate, precise, representative, comparable between labs and complete to the degree defined by the project QA/QC Plan, and required for the

performance of monitoring obligations, the evaluation of remedial alternatives, and the design of remedies.

4.6.2 QA/QC for Soil Samples

4.6.2.1 Laboratory QA/QC

Laboratory QA/QC was generally acceptable. Methylene chloride was noted in the method blank for samples analyzed in July 2010. Detectable methylene chloride results in all associated samples (EMW-13, EMW-14, and the soil samples from the Knights of Columbus UST investigation) were flagged by the laboratory to indicate possible lab contamination.

4.6.2.2 Field QA/QC

No field QA/QC samples (e.g., trip blanks of field duplicates) were required for this investigation.

4.6.3 QA/QC for Groundwater Samples

4.6.3.1 Laboratory QA/QC

Laboratory QA/QC analytical results were reviewed during data validation. Results indicated acceptable accuracy and precision in the analyses. In particular, the laboratory duplicates yielded excellent agreement, with relative percent differences (RPDs) of less than 10% for PCE and TCE.

4.6.3.2 Field QA/QC

Field QA/QC samples (i.e. duplicates and trip blanks) were reviewed to assure compliance with the project QA/QC plan. As discussed below, the data obtained were determined usable.

4.6.3.3 Trip Blanks

- Methylene chloride results are biased high in the September 2011 groundwater samples due to presence in the trip blank. Methylene chloride was also detected

in the trip blank in December 2009. The two detected results from the Herschler Building sumps are considered to be biased high.

- Chloroform was detected in the trip blank for the August 2010 samples. Detected results in the associated samples are considered to be biased high.

4.6.3.4 Field Duplicates

Groundwater field duplicates consisted of two sequential samples. Field duplicates are prepared to evaluate sampling technique and laboratory procedures through the analysis of representative samples obtained from a relatively homogenous medium. Four field duplicates and two replicate samples (sent to a second laboratory) were collected during the investigation, yielding a duplicate rate of approximately 14%.

The four field duplicates yielded excellent agreement with RPDs of less than 10%. The two replicate samples had very low concentrations but returned results in good agreement.

4.6.4 QA/QC for Soil Vapor Samples

4.6.4.1 Laboratory QA/QC

Laboratory QA/QC analytical results were reviewed during data validation. Results indicated acceptable accuracy and precision in the analyses from both Centek and H&P laboratories. In particular,

- The H&P laboratory duplicates (LCS and LCSD) yielded excellent agreement, with relative percent differences (RPDs) of less than 10% for PCE and TCE.
- Methylene chloride results are biased high in the September 2011 soil vapor samples analyzed by H&P due to high recovery (above control limits) in the laboratory LCS.
- The Centek laboratory duplicates (LCS and LCSD) yielded good agreement, with relative percent differences (RPDs) of less than 15% for PCE and TCE.

4.6.4.2 Field QA/QC

Field QA/QC samples (i.e. duplicates) and canister vacuums were reviewed to assure compliance with the project QA/QC plan. As discussed below, the data obtained were determined usable.

4.6.4.3 Trip Blanks

Trip blanks were not submitted to the fixed base laboratory for the soil vapor sampling program because the laboratory used certified clean Summa canisters. Trip blanks were not considered to be necessary when such cleaning certification was provided and the expected levels in soil vapor are much higher than those in indoor air.

Field blanks for the mobile laboratory were composed of ambient air samples. No results above the laboratory reporting limits were detected.

4.6.4.4 Field Duplicates

Sequential syringe samples were collected for mobile laboratory field duplicates. Five soil vapor field duplicate samples for mobile laboratory analysis were collected during the investigation, yielding a duplicate rate of approximately 6%. In addition, 15 Summa canister duplicates were collected for analysis at a fixed base laboratory, yielding a duplicate rate of approximately 19%.

Four of the five field duplicates for mobile laboratory analysis yielded good agreement with RPDs of less than 25%. One duplicate pair (ESV-74) yielded highly discrepant results for PCE and TCE, with TCE much more abundant than PCE in the primary sample and both non-detectable in the duplicate. The anomalous results for this sample pair led to follow up soil vapor sampling in this area. The anomalous TCE result was no confirmed.

The results of the fixed base laboratory analyses compared to the mobile laboratory analyses were typically about 50% lower for PCE at the higher concentration end of the range (greater than 200 $\mu g/m^3$). The fixed base laboratory results were generally lower than the mobile laboratory results at the very low concentration end of the range. Since the mobile laboratory is a screening level analysis, this discrepancy for PCE is generally acceptable.

4.6.4.5 Canister Vacuums

For canisters sent to labs located at sea level, the initial post-test lab vacuum reading should be approximately 4” to 6" Hg higher than the final field (Cheyenne) vacuum reading. Where this is not the case, the canister may have leaked during its return to the lab or the gauge may have been hit. This did not occur during the soil vapor sampling program.

4.6.5 QA/QC for Indoor Air, Outdoor Air and Sub-Slab Vapor Samples

4.6.5.1 Laboratory QA/QC

Laboratory QA/QC analytical results were reviewed during data validation. Results indicated acceptable accuracy and precision in the analyses. In particular,

- The five laboratory duplicates for sub-slab vapor yielded excellent agreement, with relative percent differences (RPDs) of less than 10% for PCE and TCE.
- The seven laboratory duplicates for indoor air yielded excellent agreement, with RPDs of less than 5% for PCE and TCE.

4.6.5.2 Field QA/QC

Field QA/QC samples (i.e. duplicates and outdoor air samples) and canister vacuums were reviewed to assure compliance with the project QA/QC plan. As discussed below, the data obtained were determined usable.

4.6.5.3 Trip Blanks

Trip blanks were not submitted for the sub-slab vapor or indoor air sampling program because the laboratory selected used individually certified clean Summa canisters and flow regulators. Trip blanks were not considered to be necessary when such cleaning certification was provided.

4.6.5.4 Field Duplicates

Indoor air field duplicates consisted of two canister samples collected simultaneously and side by side. In the case of sub-slab vapor samples, simultaneous Summa canister samples were collected through a “T” arrangement. Field duplicates are prepared to

evaluate sampling technique and laboratory procedures through the analysis of representative samples obtained from a relatively homogenous medium. Eighteen indoor air and six sub-slab vapor field duplicate samples were collected during the investigation, yielding a duplicate rate of approximately 15%.

The six field duplicates for sub-slab vapor yielded excellent agreement with RPDs of less than 15%, except for the sample pair at 2614 Pioneer Avenue which yielded a 128% RPD for PCE. The results for this sample pair were not much above the reporting limit and larger variability is to be expected at these low concentrations.

Field duplicates for indoor air generally yielded excellent agreement, with RPDs of less than 15%, except for one of the field duplicates where the RPD for PCE was 29%. This is still well within the typical acceptance limits for air sample field duplicates of 50% RPD.

4.6.5.5 Ambient Air

Eight hour or twenty-four hour ambient (outdoor) air samples were to be collected during each day of indoor air sampling, contemporaneous with the indoor air sampling, for comparison to the indoor air results. Due to the extended time frame of indoor air sampling indoor air sampling frequency was reduced to once per week. Summa canisters were unavailable for outdoor air sampling on several occasions when indoor air samples were collected. However, the 20 outdoor air samples collected are considered to be adequate to represent the range of outdoor air VOC concentrations during the indoor air sampling program.

4.6.5.6 Canister Vacuums

Due to atmospheric pressure changes at higher altitudes (loss of 4 inches of mercury for every mile above sea level), initial field vacuums detected in Cheyenne should be greater than approximately 24 inches Hg for canisters received from labs located at sea level where the vacuum is initially established at 30 inches of mercury. All sub-slab and indoor air samples had acceptable initial field vacuums.

For canisters sent to labs located at sea level, the initial post-test lab vacuum reading should be approximately 4” to 6" Hg higher than the final field (Cheyenne) vacuum reading. Where this is not the case, the canister may have leaked during its return to the

lab or the gauge may have been hit. These samples are flagged with a “G” in the database. This happened on three occasions during the sampling program (indoor air samples CHIA000015, CHIA000018, and CHIA00114). Such leakage may have resulted in a low bias or cross contamination in these three results.

Eleven canisters reached atmospheric pressures within the nominal 8-hour or 24-hour testing period (i.e., were at 0" Hg gauge pressure when picked up after 8 or 24 hours). These samples may represent a time-integrated sample over a period shorter than 8 or 24 hours; however, this shorter sample duration is unlikely to have a significant impact on the measured concentration or the long-term average concentration of compounds in the air. The final canister vacuum in indoor air samples collected in five commercial (CHIA00016, CHIA00017, CHIA00077, CHIA00104, and CHIA00105) and four residential (CHIA00018FD, CHIA00066, CHIA00120, and CHIA00135) building samples was equal to 0 inches Hg indicating that the sampling duration may have been less than 8 hours and 24 hours, respectively. Two sub-slab samples (CHSS00021 and CHSS00026) also had final canister vacuums equal to zero inches of Hg. These results are flagged with a “<” in the database.

Note that there was a transposition of the final field vacuums on the chain of custody and the Summa Canister forms for the two sub-slab samples at 2712 Thomes Avenue (CHSS00025 and CHSS00026). Based on laboratory records, the sample with the actual final field vacuum at 0 inches of Hg was CHSS00025; the sample yielding the much lower PCE result. The higher result is considered to be the most representative. These two samples received “C” flags to indicate the transposition on the chain of custody.

In addition, one sample (CHIA00062) had non-detectable results at very high reporting limits (but still below the PCE screening level) due to a large sample dilution by the laboratory. Very high concentrations of a non-target analyte were the reason that the high dilution was necessary.

4.6.6 Summary of Validation Results

Validation resulted in the following qualifications on the data. None of the data was rejected.

4.6.6.1 Soils

No qualifiers were added to the soils data during validation. The laboratory flagged methylene chloride in some samples due to its presence in the method blank.

4.6.6.2 Groundwater

Data qualifiers were added to methylene chloride results for groundwater data for EMW-16, 17, and 18 due to laboratory blank contamination.

4.6.6.3 Soil Vapor

Four soil vapor samples were given a "G" flag to indicate possible sample canister leakage during return to the laboratory. These four samples may have a low bias.

For soil vapor, the results of the fixed base laboratory compared to the mobile laboratory were typically about 50% lower for PCE. Since the mobile laboratory is a screening level analysis, this discrepancy for PCE is generally acceptable. This does suggest that the mobile laboratory results for PCE are biased somewhat high and provide a conservative estimate of VI potential.

4.6.6.4 Indoor Air and Sub-slab Vapor

- Two sub-slab samples were flagged with a "C" due to a chain of custody error. Both samples were from the same building, so no confusion regarding sample locations exists.
- The abbreviated sampling duration for CHSS00026 (final field vacuum at zero) may partially explain the large discrepancy between the two sub-slab results obtained for this building.
- Three indoor air samples were given a "G" flag to indicate possible sample canister leakage during return to the laboratory. These three samples may have a low bias.
- Field duplicates for sub-slab vapor and indoor air all returned results within acceptance limits.

- Eight indoor air samples received a "<" flag to indicate that final field vacuums were equal to zero and that the sampling duration may have been shorter than planned. This should have no serious impact on the results.

4.7 Knights of Columbus UST Investigation Results

As presented in Appendix D, the investigation of the UST at the Knights of Columbus, which remained from the former dry cleaning operation in the building, indicated that:

- only low levels of PCE were present in one of the six soil samples collected within the vicinity of the tank;
- no detectable level of PCE was present in the exhaust from the kitchen (former location of dry cleaning machines)
- no detectable level of PCE was present in the vapor samples collected from the tank standpipe; and
- the tank had been filled with cement.

5 DATA EVALUATION

This section presents an evaluation of 1) the nature, extent and potential sources of COIs in groundwater and soil vapor at the Site, 2) the evidence for the presence or absence of residual dense non-aqueous phase liquids (DNAPL), and 3) the potential for VI impacts due to COIs in soil and groundwater at the Site, based on the results of this investigation (Section 4) and the results of prior investigations (Section 1.1.2).

5.1 Nature, Extent and Source(s) of COIs in Groundwater and Soil Vapor

The following sections discuss the nature, extent and probable sources of the COIs in groundwater and soil vapor, beginning with a discussion of the nature and direction of groundwater flow.

5.1.1 Groundwater Flow Direction

Based on 2009 and 2010 water levels (Table 4.1), the water table is quite shallow across much of the Site and generally appeared to flow in a southeasterly direction in the vicinity of Randall Avenue, becoming more southerly between Oneil and Pioneer Avenues, and southwesterly to the west of Oneil Avenue (see Figure 5.1). Typical depths to water ranged from 6.4 to 10 feet in the majority of the monitoring wells; however, water levels appear to be slightly deeper in the southeastern portion of the Site (EMW-01, EMW-02, EMW-11, and EMW-16).

5.1.2 Chlorinated Solvent Plumes

Similar to the URS (2004) investigation, chlorinated solvents and their breakdown products (chlorinated VOCs) were observed in groundwater (Figure 5.2) and soil vapor (Figure 5.3) during the current investigation at various locations across the Site. As discussed below, based on the results, there are four general areas with high PCE concentrations in groundwater and soil vapor that are generally bounded by wells and soil vapor probes yielding trace to non-detectable levels of PCE: 1) the vicinity of the active dry cleaner (One Hour Cleaners) at 501 Randall Avenue and 28th Street, 2) the vicinity of the former Randall Rite-Way at 315 W. 27th Street, 3) the vicinity of the former Safeway

at 2512 Pioneer Avenue, 4) the vicinity of the intersection of 26th to 27th Streets and Oneil Avenue.

5.1.2.1 Active dry cleaner source at 501 Randall Avenue

There appears to be a source of PCE at the active dry cleaner (One Hour Cleaners) at 501 Randall Avenue (northwest corner of the intersection at Randall Avenue and 28th Street), based on the high soil vapor PCE (320,000 $\mu g/m^3$) and TCE (24,000 $\mu g/m^3$) concentrations at ESV-41 just outside the south side of the building (Figure 5.3) and the high PCE concentrations in groundwater (250 µg/L) just down gradient (EMW-05). High groundwater PCE concentrations are also found approximately one block to the south at EMW-04 and in the sump water at 523 W. 27th Street.

Although only partially supported by the pattern of soil vapor concentrations (Figure 5.3), this source likely contributes to groundwater and soil vapor contamination that generally extends due south and downgradient of this area to approximately 24th Street between Thomes Avenue and Reed Avenue. Groundwater PCE concentrations drop to levels below reporting limits (less than 1 µg/L) within a block to the north and east of this apparent source area. Soil vapor PCE concentrations behave similarly and drop to trace levels less than a block to the north and east. Soil vapor and groundwater PCE concentrations are generally below screening levels and the MCL west of Reed Avenue and south of 24th Avenue in this plume area.

Data from the 2003-2004 study by EPA did not clearly indicate a source from the dry cleaner at 501 Randall Avenue. The EPA data did suggest some PCE contamination in groundwater just to the south of the Knights of Columbus building at 507 W. 28th Street, immediately south of 501 Randall Avenue on the south side of 28th Avenue, consistent with the former operation of a dry cleaner at this location. Residual contamination from this former dry cleaner could also be contributing to the groundwater and soil vapor contamination in this area, although the tank investigation at the Knights of Columbus (Appendix D) did not reveal any elevated PCE concentrations in soils in the vicinity of the former underground storage tank in the alley behind the building.

5.1.2.2 Potential Source near 26th Street and Oneil Avenue

The high soil vapor concentrations along 26th Street between Oneil and Bent Avenues (Figure 5.3) suggest the presence of an additional source area from an unknown historic facility. The high concentration portion of this soil vapor plume extends in a dominantly westerly direction along 26th Street to Bent Avenue (possibly due to the influence of a sewer line). Groundwater PCE concentrations in the area were are fairly low, ranging from 18 to 21 µg/L (Figure 5.2). Groundwater and soil vapor PCE concentrations drop to very low levels near Reed Avenue. This area is also downgradient of the dry cleaner sites near Randall Avenue and 28th Street, as discussed above, and impacts could be related to one or both of those facilities if the shallow well closest to the active dry cleaner (EMW-05) was somewhat cross gradient of the center of the plume or the former dry cleaning operation at the current Knights of Columbus building has residual impacts on groundwater.

Most of the indoor air PCE concentrations on the Site that are above screening levels occur in this vicinity (Figure 5.4). The indoor air PCE concentrations decrease substantially to the east of 514 W. 26th Street, indicating that this represents the eastern edge of the high concentration soil vapor plume.

5.1.2.3 Dispersed source originating near former Safeway

Elevated PCE concentrations were found in shallow groundwater to the south of the former Safeway at EMW-01, EMW-03 and the private well at 416 W. 24th Street (Figure 5.2). Soil vapor PCE concentrations in the present investigation were quite high on the north (ESV-23), east (ESV-27 and 30), and south (ESV-31 and 35) sides of this property (Figure 5.3). The Phase 1 ESA (ERM, 2002) identified several potential historic sources for the PCE found in groundwater and soil vapor in this area, and the EPA investigation in 2003-2004 indicated high PCE concentrations in groundwater on all sides of this property, with the highest concentrations on the northeast and southeast corners (200 to 276 µg/L).

Groundwater data indicate PCE concentrations above the MCL as far south as 23rd Street (EMW-01), with concentrations below the MCL and below detection at EMW-18 at 22nd Street. Similarly, soil vapor data indicate PCE concentrations above screening levels as

far south as 24th Street, between Pioneer and Thomes Avenue, and below detection at 23rd Street.

PCE levels in indoor air were elevated at the former Safeway, but below commercial screening levels. None of the buildings tested in the area surrounding the former Safeway had indoor air PCE concentrations above screening levels and most were within the normal background range, except for the home at 409 W. 24th Street, one block to the south.

5.1.2.4 Deep source near the former Randall Rite-Way

The deep well (EMW-10) adjacent to south side of the former Randall Rite-Way gas station at 314 Randall Avenue (now 315 W. 27th Street just east of the intersection of Pioneer and Randall Avenues) had quite high levels of PCE (350 µg/L) with no associated petroleum hydrocarbons. The shallow monitoring well (MW-4) on the north side of the property, which remains from the 2003 investigation of the three former USTs at this Site, had very low PCE concentrations (1.2 µg/L) when sampled for this investigation. Previous sampling of two other former shallow monitoring wells on the south side of the former gas station by EPA in 2004 (URS, 2004) indicated PCE concentrations of 67 to 450 µg/L. The near absence of PCE on the north side of the former gas station, and the high PCE concentrations on the south side, suggest that the former gas station was the source.

This location is upgradient of the former Safeway property, described below, and cross-gradient from the dry cleaner sites described above; therefore, a separate source is likely responsible for the PCE observed in deep groundwater during this study and in shallow wells by EPA (URS, 2004). The actual source of the PCE is uncertain. It is possible that a PCE spill was associated with the former gasoline station operations, if it had an automobile repair facility. The station closed in 1987. Soil vapor PCE concentrations were generally moderate to low in this area (Figure 5.3), with one sample near the southeast corner of the former Randall Rite-Way property having a concentration slightly above 800 $\mu g/m^3$. None of the homes or building tested in this vicinity had indoor air PCE concentrations above typical background levels.

Downgradient PCE concentrations in shallow groundwater are relatively low (e.g., EMW-12 at 2 µg /L), although the PCE concentration in sump water at the Mount Sinai

Synagogue (11 µg/L) was above the MCL. The extent of PCE in deep groundwater is unknown. Clay layers, typically found at eight to 11 foot depth, may be inhibiting soil vapor concentrations due to the deep groundwater impacts to some degree.

5.2 Evidence for Residual Dense Non-Aqueous Phase Liquids

Groundwater PCE concentrations were well below the level expected if residual DNAPL was present in the areas tested. Soil results from 18 to 20 foot depth from the two wells (EMW-04 and EMW-05) with the highest PCE concentration yielded no evidence of residual DNAPL near these two potential source areas. PCE concentrations in soil vapor were also well below what is predicted if residual DNAPL were present. Therefore, DNAPL, if present, does not appear to be located near the wells and probes sampled during this investigation. Any DNAPL within source areas may be in a residual state (i.e., the soil pores are not saturated with DNAPL) or may have diffused into the matrix of soil and or bedrock over time.

5.3 Knights of Columbus UST Investigation

The investigation of the UST at the Knights of Columbus, which remained from the former dry cleaning operation in the building, concluded that the tank was properly closed and that there was no current evidence of solvent leakage from the tank that was impacting soils or groundwater (Appendix D). This does not eliminate the potential for historic releases of PCE at the facility due to other operations or mechanisms.

5.4 Vapor Intrusion Evaluation

The following sections present an evaluation of the potential for VI impacts in existing Site buildings based on sub-slab vapor (Table 4.8), and indoor air samples (Table 4.7) collected between January 2010 and November 2011. The concentrations of PCE in these media are shown on Figure 5.4.

The purpose of the evaluation was to determine whether the concentrations of COCs detected in the indoor air of the buildings exceeded the DEQ indoor air screening levels and whether multiple lines of evidence indicate the indoor air quality was due to VI or background sources. These lines of evidence include:

- spatial correlation of indoor air results to subsurface (i.e., soil vapor, groundwater) conditions;
- comparison of indoor air, outdoor air, and sub-slab soil vapor data;
- ratio analysis of COCs detected in all environmental media;
- comparison of indoor air concentrations detected to background indoor air levels reported in the literature; and
- the potential for other (e.g., internal) sources.

As discussed below, in general, the evaluation of the VI pathway indicates that the potential for VI exists in the worst case areas based on soil vapor concentrations, although the potential varies between buildings, and that soil gas PCE concentrations greater than approximately 2000 $\mu g/m^3$ have the greatest potential to contribute to VI above residential indoor air screening levels.

5.4.1 Indoor Air Compared to DEQ Screening Levels

Of the 64 commercial and residential buildings located in the "worst case" area and the 19 homes in the verification area selected for testing, a total of 62 buildings were tested. As summarized in Table 4.7, depicted on Figure 5.4, and discussed below, of the 62 buildings tested, only ten buildings in the worst case area (eight residential and two commercial) and two verification homes had a concentration of PCE exceeding the DEQ residential or commercial Indoor Air Screening Level (IASL) for PCE. The concentration of TCE also exceeded its residential IASL in six of these worst case area homes. No commercial buildings had a concentration of TCE greater than the commercial TCE IASL. One additional home, outside the "worst case" area, had a concentration of TCE in the indoor air exceeding the residential TCE IASL; however, the concentration of PCE detected was below the PCE IASL.

Within the "worst case" area, the eight residences where the concentration of PCE was greater than the residential IASL for PCE were located at: 409 W. 24th Street; 514 and 518 W. 26th Street; 2523, 2606, 2610, 2612 and 2622 Oneil Avenue (Figure 5.4). The remaining nine residences in the "worst case" area that were tested had PCE results well

below the residential IASL. The commercial buildings located at 508 and 523 W. 27th Street had indoor air PCE results above the commercial PCE IASL. One commercial building, located at 507 W. 28th Street, had results close to the commercial PCE IASL and was retested in the winter of 2010-2011 with comparable results.

Only two of the fifteen residences tested within the verification area (i.e., peripheral to the worst case area) had indoor air PCE results above the residential PCE screening level (610 W. 26th Street and 613 W. 27th Street). One other home in the verification area (522 W. 25th Street) had an indoor air concentration of TCE in exceedance of the residential TCE IASL; however this home did not have a concentration of PCE greater than the residential PCE IASL (Table 4.7).

Three of the 23 residences tested in the expanded testing area (southwest of the initial testing area discussed above) had indoor air PCE results above the residential PCE screening level (621 W. 25th Street, 2611 Bent Avenue, and 614 W. 26th Street). The indoor air retest at 621 W. 25th Street had PCE results well below the screening level. The remaining 20 homes that were tested had PCE results well below the residential IASL. No home in the expanded testing area had a concentration of TCE greater than the residential TCE IASL.

5.4.2 Sub-slab Vapor Compared to DEQ Screening Levels

As shown on Table 4.8 and summarized below, of the 18 commercial buildings and two residential buildings where sub-slab vapor samples were collected, the following six commercial buildings had a sub-slab soil vapor concentration of PCE above the DEQ Soil Gas Screening Level of 810 $\mu g/m^3$:

- 508 and 523 West 27th Street;
- 501 W. 27th Street;
- 2424 Pioneer Avenue;
- 422 W. 26th Street; and
- 617 W. 26th Street, the Cradles to Crayons Day Care Center, which had the highest concentration of PCE detected in a sub-slab vapor sample (3700 $\mu g/m^3$).

It should be noted that only two of these buildings (508 and 523 West 27th Street) had concentrations of PCE in the indoor air above the commercial PCE IASL; all of the other buildings listed above had a concentration of PCE in the indoor air below both the residential and commercial screening levels. All buildings with sub-slab vapor PCE below the soil gas screening level had indoor air concentrations below the IASL.

5.4.3 Multiple Lines of Evidence Evaluation

As presented below, indoor air concentrations can only be due to VI if the source (contaminated groundwater or soil vapor) is present below or near the building; thus a spatial correlation is conducted first. A comparison of the relative concentrations (ratios) of PCE and TCE in the various media is then conducted to evaluate further if VI is the likely source of the VOCs detected in the indoor air. Following this analysis, the potential for other sources of VOCs is evaluated.

5.4.3.1 Spatial Correlation to Subsurface Concentrations

If VI is a source of VOCs in the indoor air, these VOCs must be present at high enough concentrations in the subsurface to pose a VI concern. This section evaluates the distribution of VOCs detected in the groundwater and soil vapor around and underneath the buildings within this study area.

5.4.3.2 Distribution of VOCs in Groundwater and Soil Vapor

The results of the groundwater and soil vapor samples collected by EnviroGroup from November 2009 through September 2011 indicate that PCE is the dominant VOC present in both of these environmental media in the Study Area[4]. However, as discussed below, the concentration of PCE and TCE detected varied substantially across the Study Area.

<u>Groundwater</u>

Within the vicinity of the buildings studied, the concentration of PCE ranged from 0.47 to 720 µg/L in the shallow groundwater (Figure 5.2). The average PCE concentration in the fifteen new shallow wells installed by EnviroGroup was 97µg/L. PCE was also detected in two of the three deep wells (EMW-06 and EMW-10) at concentrations of 35 to 350

[4] Groundwater Investigation Procedures and Results Technical Memo of December 28, 2010 (EnviroGroup, 2010b); Soil Vapor Investigation Procedures and Results Technical Memo of December 30, 2010 (EnviroGroup, 2010a).

µg/L. High PCE concentrations also were found in the sump sample from 523 W. 27th Street (200 µg/L) and the private well at 416 W. 24th Street (52 µg/L).

TCE was detected in groundwater samples collected from 11 of the 15 EnviroGroup-installed shallow wells in the Study Area with concentrations ranging from 0.22 to 7.6 µg/L (Figure 5.2). It was also detected in the private well at 416 W. 24th Street (1.4 µg/L), the sump at Mt. Sinai (0.3 µg/L), and the sump at 523 W. 27th Street (17 µg/L).

Soil Vapor

The concentration of PCE detected in the soil vapor samples collected near the buildings studied ranged from 16 to 320,000 µg/m^3. TCE concentrations ranged from below detection (< 15 µg/m^3) to 24,000 µg/m^3 and were typically about 10% or less of the associated PCE concentration detected in that sample. It should be noted that:

- The vast majority of the soil vapor locations with PCE concentrations above 10,000 µg/m^3 were located along the western side of the Study Area (Figure 5.3).
- All of the ten buildings within the worst case area where the indoor air concentration of PCE exceeded its IASL were located near soil vapor sample locations with elevated PCE concentrations (generally above 2,000 µg/m^3).
- A number of soil vapor locations along the southwestern edge of the original Study Area had PCE results above 810 µg/m^3, which led to additional soil vapor and indoor air sampling to the southwest (the Expanded Testing Area) in order to fully delineate the area with potential for VI.
- Soil vapor PCE concentrations in the Expanded Testing Area fell below 810 µg/m^3 within approximately one block of the boundary of the worst case area.

Sub-slab Soil Vapor

In general, although sub-slab soil vapor was not collected from many of the buildings tested, the areas with elevated concentrations of PCE and TCE in the shallow (external) soil vapor have elevated levels of PCE and TCE in the sub-slab (internal) soil vapor indicating that the soil vapor is a good screening tool at this Site. A summary of the sub-

slab soil vapor and external soil vapor PCE data is presented on Figures 5.3 and 5.4 and in Tables 4.6 and 4.8. As shown and summarized below:

- The highest sub-slab vapor concentrations of PCE were detected under buildings located at 508 W. 27th Street, 523 W. 27th Street, and 617 W. 26th Street. These buildings are proximal to three of the seven soil vapor locations with the highest PCE concentrations (greater than 10,000 $\mu g/m^3$).

- Two buildings with sub-slab vapor PCE concentrations above 810 $\mu g/m^3$ (422 W. 26th Street and 501 W. 27th Street) are located in areas where soil vapor PCE concentrations appear to show a steep gradient from concentrations below 400 $\mu g/m^3$ to values of 10,000 $\mu g/m^3$ or greater.

The sub-slab soil vapor concentration of PCE detected below the remaining buildings was either:

- comparable to the concentration of PCE in the proximal soil vapor samples and above the Soil Gas Screening Level; or

- low (less than 40 $\mu g/m^3$), indicating that these buildings, which are located outside the 810 $\mu g/m^3$ contour for soil vapor, are likely to be beyond the edge of the area with potential VI concerns at the present time.

In addition, the concentration of PCE detected in the sub-slab samples collected at the commercial building located at 2727 Oneil Avenue are significantly lower (three orders of magnitude) than the concentration of PCE detected in the soil vapor on the north and south sides of this building (Figures 5.3 and 5.5). This suggests that the sub-slab samples at this building may not adequately represent the sub-surface conditions and the potential for VI.

Summary of Spatial Relationship between Groundwater and Soil Vapor Conditions

A general spatial relationship is apparent between shallow groundwater concentrations and nearby soil vapor concentrations of PCE[5]. However, a number of the shallow wells

[5] Water level measurements in August 2010, which included three new wells installed on the western side of the Study Area, indicated a component of groundwater flow to the south-southwest in addition to the previously recognized southeasterly flow. This south-southwesterly flow is most likely responsible for the

are not screened across the water table and thus may not provide a true representation of the groundwater PCE concentration available for VI. A particular example is shallow well EMW-12, near the northeast corner of the former Safeway (Figure 5.2). This well is screened over a five foot interval at a depth of approximately 5 to 10 feet below the water table. While very low PCE concentrations (2 µg/L) were measured in this well, nearby soil vapor points (ESV23 and ESV-27) to the south and west have highly elevated PCE concentrations of 9,580 to 11,800 $\mu g/m^3$ (Figure 5.3), indicating either a shallow groundwater or potentially a vadose zone source of PCE.

5.4.3.3 Comparison of VOCs in Indoor Air to Subsurface Environmental Media

As expected, in general, there is a good spatial correlation between elevated groundwater and soil vapor concentrations and those buildings where the indoor air concentration exceeds the IASLs. However, as discussed below, there are other factors that may restrict or exacerbate migration of vapors into the buildings, or result in other sources being responsible for the VOCs detected in the indoor air.

Comparison of Groundwater to Indoor Air

Although a high PCE concentration (350 µg/L) was detected in deep well EMW-10, groundwater collected from the nearby shallow well MW-4, which is screened across the water table, had trace levels (1.2 µg/L) of PCE detected. Since the concentration of PCE detected in the deep groundwater is not reflected in the indoor air of nearby sampling locations (315 W. 27th Street, 2614 and 2622 Pioneer Avenue, and 2616 and 2622 Carey Avenue), the presence of deep groundwater contamination is not necessarily an indicator of VI potential.

The widespread presence of clay horizons at depths below approximately eight feet may act as a barrier and impede migration of vapors due to groundwater contamination below this depth and soil vapor in shallower horizons. Vapors derived from shallow groundwater contamination (water table depth ranged from 6.4 to 11.2 feet for the

distribution of groundwater and soil vapor contamination further to the south and west than previously documented.

various wells between November 2009 and September 2011) may be significantly attenuated for buildings with foundations above the clay horizon.

Elevated levels of PCE (200 µg/L) and TCE (17 µg/L) were found in the sump water sample from 523 W. 27th Street. Since the sump was not sealed, this water may provide a direct volatilization source for PCE in indoor air in this building. This appears to be supported by the unusually high PCE concentrations in indoor air in this building compared to those in nearby soil vapor (Figure 5.6) and in sub-slab vapor (Figure 5.7). Thus, it is likely that this building is impacted by direct volatilization from the groundwater in the open sump and sealing the sump should mitigate the impacts to indoor air from that source. However, the presence of groundwater with elevated levels of PCE beneath the building also creates the potential for soil vapors to impact the indoor air of this building; this pathway cannot be distinguished from the direct off-gassing of the sump water at this time.

Elevated levels of PCE (52 µg/L) were found in the well water sample from 416 W. 24th Street and may explain the elevated levels of PCE (15 ug/m^3) in indoor air at the nearby (downgradient) home at 409 W. 24th Street, although the indoor air at 416 W. 24th Street did not have elevated levels of PCE.

Comparison of Soil Vapor to Indoor Air

The two buildings with the highest indoor air concentrations of PCE (514 W. 26th Street and 508 W. 27th Street) are proximal to two of the four soil vapor locations with the highest PCE concentrations (other than ESV-16 and ESV-41 located near the active dry cleaner) (Figures 5.3 and 5.4). The building at 523 W. 27th Street had unusually high indoor air PCE concentrations compared to those in nearby soil vapor (Figures 5.6). As discussed above, this may be due in whole or in part to direct volatilization from the open sump in the basement of this building.

As shown on Figure 5.4, most of the other buildings with indoor air PCE concentrations above the IASL are located in the western portion of the Study Area where soil vapor concentrations are consistently above the Soil Gas Screening Level of 810 ug/m^3, and typically above 2,000 ug/m^3. However, although outside this general area of concern in the western portion of the Site, the home located at 409 W. 24th St. had a high indoor air PCE concentration in the basement and the commercial building at 2424 Pioneer Avenue

had an indoor air concentration slightly above typical background levels; the indoor air concentrations detected are consistent with the high soil vapor concentrations measured at nearby soil vapor point ESV-35 and ESV-31 and the high groundwater PCE concentrations found in the private well at 416 W. 24th Street.

In addition, although the concentration of PCE detected in the indoor air of the former Safeway building (2512 Pioneer Avenue) and the building located at 507 W. 28th Street were below the commercial PCE IASL, they were somewhat elevated and atypical of background levels. These buildings are located in the vicinity of high soil vapor PCE concentrations which would suggest a high VI potential (Figure 5.3); thus, the levels detected in indoor air might be from VI. None of the other buildings to the south or east of the former Safeway (Figure 5.4) had indoor air PCE concentrations significantly above background levels, except 409 W. 24t Street and 2424 Pioneer Avenue, as discussed above.

Similarly, in general, the buildings with the lowest indoor air PCE concentrations are located near areas with the lowest levels of PCE detected in soil vapor.

However, as discussed below, the indoor air results obtained in the following four buildings are lower than what would have been predicted from the nearby soil vapor sample results (Figures 5.3 and 5.4):

- Based on the soil vapor concentrations to the south of these locations, the buildings located at 2718 and 2722 Oneil Avenue appear to be just northwest of the upgradient edge of the groundwater plume. Therefore, it is likely that these buildings were not impacted by significant VI because the contaminated groundwater is moving away from them.

- Although elevated levels of PCE (1450 to 17,200 $\mu g/m^3$) were detected in soil vapor samples near the commercial building located at 500 W. 27th St., low concentrations of PCE were detected in the sub-slab samples collected from the adjacent buildings (2710 and 2712 Thomes Avenue). Since sub-slab soil vapor concentrations are more representative of the environmental conditions that could impact indoor air quality via the VI pathway, the low levels of PCE detected in the indoor air of the 500 W. 27th Street building may be representative of the low VI potential for this location. Furthermore, the sub-slab soil vapor results

obtained at these two buildings indicate that the high concentration portion of the shallow groundwater plume does not extend as far east as these two buildings, or apparently to 500 W. 27th Street.

- Although elevated levels of PCE (9580 to 11,800 μg/m^3) were detected in soil vapor samples to the west and southwest of the home located at 321 W. 26th Street and the commercial building located at 320 W. 25th Street, the low indoor air PCE concentrations are consistent with the low concentrations in the soil vapor points to the north (639 μg/m^3 at ESV-22) and northwest (136 μg/m^3 at ESV-18). They are also consistent with the low sub-slab vapor PCE concentrations (40 μg/m^3) at 320 W. 25th Street (although it is a slab-on-grade structure). This suggests that soil vapor concentrations decrease rapidly to the east of Pioneer Avenue on the east side of the former Safeway (see Figure 5.3).

Comparison of Sub-slab Vapor to Indoor Air

Although, as discussed above, the only two commercial buildings (508 and 523 W. 27th Street) with indoor air concentrations of PCE above the commercial PCE IASL also had elevated levels of PCE in the sub-slab soil vapor, four other commercial buildings had sub-slab PCE concentrations above the Soil Gas Screening Level of 810 μg/m^3 but indoor air concentrations below the commercial PCE IASL (Figure 5.4). The low indoor air concentrations may be due to the much larger air volumes available for mixing in these large commercial buildings compared to those in the commercial establishments located in smaller converted residences such as 508 W. 27th Street.

One exception to the above is the sub-slab PCE concentrations at the commercial building located at 617 W. 26th Street (a converted residence) which were anomalously high compared to the measured indoor air concentrations (Figure 5.4). The indoor air at 617 W. 26th Street was resampled based on the high sub-slab PCE concentrations and high soil vapor concentrations and returned results well below IASLs.

The sub-slab PCE concentrations at the large commercial building located at 2727 Oneil Avenue were anomalously low compared to the measured indoor air concentrations and may not be representative of the true sub-slab concentrations beneath this building (Figure 5.4). The large range in soil vapor PCE concentrations from the northeast corner

to the southwest corner of this building (52,000 to 983 μg/m^3) indicates the potential for a large range in sub-slab concentrations (Figure 5.3).

5.4.3.4 Comparison of Relative Concentrations (VOC Ratio Analysis)

If VI is the source of VOCs in the indoor air, the ratio of two compounds detected in all media (groundwater, soil vapor, sub-slab vapor, indoor air) should be comparable. If the ratio is not comparable between media other potential sources (e.g., internal sources, outdoor air) might be impacting the indoor air quality.

As indicated on Figure 5.8, the concentration of TCE detected in the external soil vapor samples (and sub-slab vapor samples – not shown) was approximately 10% of the concentration of PCE detected in these same samples. Thus, if the source of VOCs detected in the indoor air was only due to VI, a simple ratio comparison would indicate that there would be about 10% as much TCE in indoor air as PCE.

Therefore, based on the measured indoor air PCE concentrations, the maximum VI contribution of TCE in indoor air would be predicted to be approximately 6 μg/m^3. This expectation was confirmed with the indoor air sample collected at 514 W. 26th Street where the maximum indoor air TCE concentration was measured: PCE and TCE were detected at 53 μg/m^3 and 5.6 μg/m^3, respectively (Table 4.7).

Since this ratio of TCE to PCE (1/10) is consistent across all media, if the concentration of PCE detected in indoor air is below its screening level, it would be expected that the level of TCE detected in indoor air would be below its IASL, if due to VI, since the TCE screening level is about 1/10 of the PCE screening level. As indicated in Table 4.7 above, only one location did not fit this expectation; the TCE concentration (1.8 μg/m^3) is substantially larger than the PCE result (0.78 μg/m^3) obtained in the indoor air sample collected from the residence at 522 W. 25th Street. This anomalously high TCE result is also higher than typical background indoor air ranges (Dawson and McAlary, 2009; Kurtz and Folkes, 2002; Foster and others, 2002). Although no known internal source of TCE was identified as contributing to the indoor air concentration detected, the high relative abundance of TCE in this sample strongly suggests an indoor source. Further supporting this suggestion is the fact that the TCE concentration in the nearby shallow well (EMW-03) is 32 times lower than the PCE concentration and the adjacent soil vapor sample (ESV-25) had a TCE to PCE ratio less than 1/10.

5.4.3.5 Other Potential Sources of VOCs in Indoor Air

Investigations at other sites in the western U.S. and pertinent literature have demonstrated that PCE and TCE are routinely found in indoor air that is unaffected by VOCs in groundwater (i.e., no VI) (Kurtz & Folkes, 2002; Foster, et.al., 2002; Dawson and McAlary, 2009). Both of these constituents are also typically found in outdoor air. Potential background sources of these constituents include, but are not limited to: consumer products, dry cleaned clothes, building materials, and industrial, commercial and residential uses of chemicals or products that result in releases of VOCs to the indoor and ambient air. For the purpose of this investigation, VOCs present from these non-groundwater sources are considered "background".

5.4.3.6 Comparison of Concentrations Detected in Indoor Air and Outdoor Air

In general, the concentration of PCE detected in indoor air, when elevated, was significantly higher than the outdoor air PCE concentrations (which range from non-detectable to 0.73 $\mu g/m^3$), suggesting a dominant indoor or subsurface source for PCE in many of these buildings (Table 4.7), although twenty-two buildings have PCE results in the range of outdoor air (<0.4 $\mu g/m^3$). No TCE was detected in the outdoor air samples, other than one sample in the immediate vicinity of the active dry cleaners, indicating either an indoor or subsurface source for TCE when it was detected in these buildings.

5.4.3.7 Comparison of Concentrations Detected in Indoor Air and Background Indoor Air Concentrations

As presented on Table 4.7, in general, the concentration of the TCE and PCE detected in many of the buildings sampled was within typical background indoor air ranges[6]. However, of the residential buildings sampled:

- The concentration of PCE exceeds background levels in all thirteen of the homes where the concentration of PCE also exceeded the IASL for PCE.
- The concentration of TCE detected was above background levels in seven homes. Six of these homes also had a concentration of PCE above its screening level

[6] The 90th percentile of residential background indoor air concentrations of PCE and TCE are 4.0 $\mu g/m^3$ and 0.9 $\mu g/m^3$, respectively (Dawson and McAlary, 2009).

(Tables 4.7). The residence at 522 W. 25th Street had a TCE concentration of 1.8 μg/m^3 which was greater than the associated PCE concentration of 0.78 μg/m^3.

The residential background indoor air levels are used as a conservative measure of commercial background indoor air at this Site. The concentration of PCE detected in the indoor air of nine commercial buildings is above typical residential background indoor air PCE concentrations suggesting some contribution from VI. Other than the former Safeway, these eight other buildings are all located in a one block area between 27th and 28th Streets and Thomes and Oneil Avenues (Figure 5.4). The elevated level of PCE in indoor air in these buildings is consistent with their location over areas of the groundwater plume where the highest PCE concentrations in soil vapor were detected and the greatest VI potential is indicated.

For the commercial buildings located at 508 and 523 W. 27th Street, the concentration of TCE was above the upper end of the typical residential TCE background level of 0.9 ug/m^3. These two buildings also had the highest PCE concentration in indoor air in the Study Area (31 to 62 μg/m^3) indicating a likely VI source for both VOCs.

5.4.4 Indoor Air Mitigation System Recommendations

As presented in Tables 4.7 and 5.1, only three homes in the verification area, three homes in the expanded testing area, and eight homes and two commercial buildings within the worst case area had indoor air results exceeding an IASL indicating an action to mitigate the source of these VOCs may be warranted based on available data. Based on a multiple lines of evidence evaluation, it was concluded that the concentration of TCE detected in indoor air of one of these verification area homes (522 West 25th Street) was likely from an internal source, not VI. One home in the expanded testing area (621 W. 25th Street) had results well below the IASL upon retesting. Furthermore, it was concluded that the concentration of PCE detected in the indoor air of the commercial building located at 523 W. 27th Street was impacted by direct off-gassing of groundwater in an open sump with an unknown contribution from VI (i.e., soil vapors). Thus, as presented in Table 5.2 below, indoor air mitigation systems would only be warranted in ten buildings in the worst case area and five residential buildings in the verification and expanded testing areas based on an evaluation of the buildings tested.

Table 5.2 Summary of VI Evaluation and Recommendations

Testing Area	Building Type	Address	Action Recommended	Rationale	Comment
Worst Case	Residential	409 W. 24th St.	Mitigation System	PCE and TCE above IASLs	System installed
		514 W. 26th St.	Mitigation System	PCE and TCE above IASLs	System installed
		518 W. 26th St.	Mitigation System	PCE and TCE above IASLs	System installed
		2606 Oneil Ave.	Mitigation System	PCE above IASL	System installed
		2610 Oneil Ave.	Mitigation System	PCE above IASL	System installed
		2612 Oneil Ave.	Mitigation System	PCE and TCE above IASLs	System installed
		2622 Oneil Ave.	Mitigation System	PCE and TCE above IASLs	System installed
		2523 Oneil Ave.	Mitigation System	PCE and TCE above IASLs	System installed
	Commercial	508 W. 27th St.	Mitigation System	PCE above IASL	System installed
		523 W. 27th St.	Resample	PCE above IASL	Sump to be sealed
Verification	Residential	522 W. 25th St.	No Further Action	TCE above IASL	Probable indoor source
		613 W. 27th St.	Mitigation System	PCE above IASL	No response
		610 W. 26th St.	Mitigation System	PCE above IASL	System installed
Expanded	Residential	2611 Bent Ave.	Mitigation System	PCE above IASL	System installed
		614 W. 26th St.	Mitigation System	PCE above IASL	No response
		621 W. 25th St.	No Further Action	PCE above IASL	Retest Below IASL

5.4.5 Indoor Air Mitigation Systems

As presented in Table 5.2, based on the findings of this evaluation, DEQ has installed a mitigation system in one commercial building and eight residential buildings located within the "worst case" area, one system in a residential verification testing location just outside the pre-emptive mitigation area[7], and one system in a residential testing location

[7] Although no indoor air testing was done for eight homes and indoor air results were below the IASL for six others, DEQ has installed fourteen other residential mitigation systems within the "worst case" area as of December 31, 2011. The details of all mitigation systems installed are described in the Vapor Intrusion Mitigation Systems Installation Technical Report (EnviroGroup, 2011).

in the expanded testing area. In addition, it was recommended that the sump in the commercial building located at 523 W. 27th Street should be sealed to prevent direct off-gassing of vapors from the groundwater and the indoor air be retested to determine the need for a VI mitigation system. With the exception of seven residences, all buildings within the worst case area were either tested, or received pre-emptive mitigation systems.

In total, twenty five buildings (24 residential and one commercial) at the Site have had indoor air mitigation systems installed by DEQ. Details of the installation and diagnostic testing procedures for these systems are provided in the Vapor Intrusion Mitigation System Installations Technical Memorandum of October 26, 2011 included as Appendix G. A summary of the system type installed and information regarding recommendations for post-mitigation air testing is provided in Table 5.3.

5.4.6 Post Mitigation Indoor Air Testing Results

Seventeen of the 25 mitigated buildings had post-mitigation indoor air tests conducted with the heating, ventilation, and air conditioning (HVAC) units operating under normal conditions (Table 5.4). The buildings requiring post-mitigation indoor air tests (total of seventeen) were those with either partial or complete crawl space ventilation mitigation systems or other types of systems with poor mitigation system diagnostics. Based on post-mitigation air testing, two of the buildings required system enhancements (upgrades) (2606 Oneil Avenue and 409 W. 24th Street). After system upgrades, both of these buildings, operating under normal HVAC conditions, had indoor air results well below screening levels (Table 5.4). All of the post-mitigation indoor air tests for the remaining buildings were well below screening levels.

Four of the eight buildings without post-mitigation indoor air tests were locations where the pre-mitigation test results were already below screening levels or they were located in areas where other indoor air testing indicated no significant VI (pre-emptive mitigation locations). Because these buildings had acceptable system diagnostics and indoor air concentrations below screening levels prior to mitigation no post-mitigation air testing was required. One of the systems was removed at the request of the owner, prior to post-mitigation testing. Of the other three buildings without post-mitigation tests, two had sub-slab depressurization systems with negative pressures indicating acceptable system performance, and one was not available for testing due to access issues.

Based on a comparison of pre-mitigation and post-mitigation indoor air results for PCE, the majority of the mitigation systems produced an 82% to 99% reduction in indoor air concentrations in the buildings tested, after the system was installed (Table 5.4). Only in the case of two residential pre-emptive mitigation locations, where the pre-mitigation indoor air PCE concentrations were well below screening levels, was there little apparent change in indoor air PCE concentrations after the system was installed. The PCE levels in both of these buildings were in the range of normal residential background from indoor and outdoor sources. The system only addresses sub-surface sources and would not be expected to produce measurable changes in the indoor air concentrations when indoor sources are responsible for the observed concentrations.

5.5 Ecological Risk Assessment Results

An ecological exclusion assessment (Step 1 of an Ecological Risk Assessment) was completed for the Site (See Appendix E). The assessment concluded that groundwater was the only affected media on the Site and that there were no sensitive habitats or species impacted by the plume.

5.6 Mt. Sinai Risk Assessment Results

A risk assessment for dermal, inhalation and ingestion exposure to bath water, composed of a mixture of contaminated groundwater and city drinking water, at the Mt. Sinai Synagogue, was completed in June 2010 by Dr. Stephen Foster of TerraMentis.

The results of the risk calculations for groundwater show that the dermal exposure pathway for both the Reasonable Maximum Exposure (RME) and Central Tendency Exposure scenario has the highest risk with PCE driving the risk assessment. The total risk for the RME groundwater scenario is slightly above DEQ's minimum acceptable risk level ($1x10^{-6}$). Additionally, the hazard quotients and hazard indices for all groundwater exposure pathways are below the DEQ's target screening level hazard index of 1.0. Inhalation risks were all well below 1×10^{-6}. After discussions with DEQ, the Synagogue decided to take no actions. The full risk assessment is included as Appendix F.

6 CONCLUSIONS

The following presents a summary of conclusions based on our evaluation of the data, as discussed in Section 5.

6.1 PCE Source Areas

At least four PCE sources areas were identified at the Site.

- A very strong shallow source from the active dry cleaner at 501 Randall Avenue.
- A source impacting deep groundwater at or near the location of the former Randall Rite-Way, with no current VI impacts in the immediate vicinity.
- A diffuse source in the vicinity of the former Safeway at 2512 Pioneer Avenue.
- A strong source near the intersection of Oneil Avenue and 26th to 27th Street. The majority of VI impacts at the Site are found in this vicinity.

No strong evidence was found for a source from the former dry cleaner located at the present location of the Knights of Columbus (507 W. 28th Street).

6.2 Nature and Extent of Contamination

The majority of the groundwater contamination is due to PCE, with subsidiary TCE and trace cis-1,2-DCE. This suggests that the source of contamination was largely PCE, derived from dry cleaning operations, and possibly from auto repair facilities and printing facilities. The highest concentration portion of the shallow groundwater contamination is located between 28th and 26th Streets near Oneil Avenue. No contamination was found north of the dry cleaner at 501 Randall Avenue, or northeast of the former Randall Rite-Way on Randall Avenue. Groundwater contamination was not found to the south of 23rd Street or to the west of Bent Avenue. The southwestern extent of contamination may be in the vicinity of 23rd Street and Reed Avenue, based on soil vapor data and data from one temporary well. No evidence for the presence of residual DNAPL was found in two potential source areas, near 27th and Oneil Avenue and adjacent to the active dry cleaner at 501 Randall.

6.3 Vapor Intrusion Impacts

This evaluation has indicated that the concentration of VOCs in the shallow groundwater correlates well with that detected in the soil vapor. However, a competent clay layer present in some areas may reduce the potential for vapors to migrate into the sub-slab environment and impact indoor air of buildings overlying this groundwater and soil vapor plume. Furthermore, this evaluation has indicated that the DEQs recommendation to proactively mitigate homes within the worst case area without sampling is a conservative approach, likely erring on the safe side.

Based on soil vapor, sub-slab vapor and indoor air results from these sampling events, the main area of VI impacts above PCE screening levels extends from just south of 28th Street to just south of 26th Street between Thomes and Bent Avenues. One other location at 409 W. 24th Street, south of the former Safeway, had VI impacts above screening levels. The majority of buildings with VI impacts above screening levels were in areas where soil vapor PCE concentrations exceeded 2000 ug/m^3, with most in areas with PCE above 10,000 ug/m^3.

A few homes in the worst case area were not tested due to lack of access or due to vacancy in the 2500 block of Thomes Avenue. These homes, or future buildings in these locations, have the potential to exceed indoor air screening levels.

6.4 Mitigation System Installations

One commercial and 24 residential buildings had indoor air mitigation systems installed by DEQ. Eleven of these buildings (ten residential and one commercial) had systems installed based on indoor air testing results above screening levels. Fourteen homes were in the “worst case area” identified from soil vapor sampling and had indoor air mitigation systems installed based solely on the DEQ offer of pre-emptive mitigation.

It should be noted that two owners did not respond to offers of mitigation systems based on their indoor air results within the six months allotted by DEQ; and one commercial building owner was notified that indoor air retesting was recommended after sealing of an open sump in the basement to determine if VI is leading to exceedance of screening levels. No response was received from the building owner regarding this notification.

6.5 Mitigation System Effectiveness

Under normal HVAC operating conditions, 24 of the mitigation systems were found to be effective at the time of testing either based on post-mitigation indoor air testing (total of 17) which indicated results well below screening levels or diagnostic tests that indicated acceptable performance and predicted effectiveness. Post-mitigation testing was not conducted in buildings where the pre-mitigation concentrations were well below screening levels. The effectiveness was not verified at one location, due to access constraints.

It should be noted that the potential for vapor intrusion and indoor air concentrations can vary over time due to seasonal and other factors. Similarly, the effectiveness of mitigation systems can vary to some extent over time. It should also be noted that changes, damage, repairs or alterations to the buildings including but not limited to the building foundations, floor slabs, utilities or other features that penetrate the floor slab, as well as the HVAC system or its operation, can affect the rate of VI and the resultant impact on indoor air quality. Building owners should contact qualified VI consultant if any such changes, damage, repairs or alterations occur so that the potential impact, if any, on the rate of VI can be evaluated.

6.6 Areas Likely to Require Groundwater Remedial Measures

A Remedial Measures Evaluation is needed for two source areas (the active dry cleaner at 501 Randall Avenue and the 26th Street and Oneil Avenue area). These two areas have the highest soil vapor PCE concentrations and are upgradient of the two areas with significant VI impacts on indoor air. In addition, the source of deep groundwater impacts near the former Randall Rite-Way gas station, at 315 W. 27th Street requires additional evaluation to determine if remedial measures are necessary.

The exact source for the 26th Street and Oneil Avenue source is unknown but it may be an extension of the active dry cleaner plume if the shallow well closest to the dry cleaner (EMW-05) was somewhat cross gradient of the center of the plume. Possible residual groundwater contamination related to the former dry cleaning operation at the building currently occupied by the Knights of Columbus (507 W. 28th Street) may also contribute

to the soil vapor plume in this area. The high soil vapor concentrations in the vicinity of 26th Street and Oneil Avenue may be related to one or both of these potential sources, or may be a distinct source.

A source of PCE is impacting deep (25 to 35 foot) groundwater at EMW-10 near the former Randall Rite-Way gas station, at 315 W. 27th Street. The source appears to be derived from the former gas station as it is bounded immediately to the north of the former station by very low PCE concentrations in well MW-4. This source appears to be upgradient of the Safeway source area and cross-gradient to the 501 Randall Avenue source area. Based on soil vapor and indoor air results in this area, this source does not pose a VI risk in the immediate vicinity of MW-4 or EMW-10. However, this deep PCE contamination may pose a risk to the deeper aquifer in the area and requires further evaluation of nature and extent and whether remediation is necessary.

No clear single source is evident in the vicinity of the former Safeway, but limited VI impacts were found in this area. The lack of a clear source and limited VI impact may suggest that a remedial evaluation is not necessary at this time.

Indoor air PCE concentrations of 24 ug/m^3 at the Knights of Columbus (507 W. 28th Street) were slightly below commercial screening levels. No strong evidence of a source of groundwater impacts was detected at this property and indoor air impacts as well as nearby groundwater and soil vapor concentrations of PCE could be due to the apparent source at the 501 Randall Avenue site. If remediation at the latter site does not result in decreasing concentrations over time at the Knights of Columbus property, additional source investigations may be warranted.

7 STUDY LIMITATIONS

EnviroGroup's work presented herein was performed in a manner consistent with the level of care normally exercised by members of our profession practicing in the same geographic area at the time the work is performed. No other warranty is made, expressed or implied, regarding our work. The findings, conclusions and recommendations presented herein are based on our professional judgment and should not be considered scientific certainties.

This work was performed for DEQ based on our understanding of the environmental issues to be addressed and DEQ's schedule, risk tolerance and budget for performing this work. Other parties may have different concerns and levels of risk tolerance and, therefore, rely on this report at their own risk.

We have relied on the work of others during this study. We assume that the work performed by others was done correctly, that the information provided is correct, and assume no liability for the errors or omissions of others.

This report presents and evaluates the results of groundwater, soil vapor, indoor air, sub-slab vapor, and ambient air tests conducted at specific locations and times. The concentrations of VOCs can vary in time and space; therefore, subsequent tests in the same locations and/or tests in new locations are unlikely to produce the same results. Nevertheless, considering the potential for variations in VOC concentrations in time and space, we believe our conclusions and recommendations are reasonable.

Changes, damage, repairs or alterations to the buildings including but not limited to the building foundations, floor slabs, utilities or other features that penetrate the floor slab, as well as the HVAC system or its operation, can affect the rate of VI and the resultant impact on indoor air quality. We recommend that building owners and/or WDEQ contact a qualified VI consultant if any such changes, damage, repairs or alterations occur at buildings with mitigation systems and/or high sub-slab vapor concentrations so that the potential impact, if any, on the rate of VI can be evaluated.

8 REFERENCES

Dawson, H. E. and McAlary, T., 2009. A Compilation of Statistics for VOCs from Post-1990 Indoor Air Concentration Studies in North American Residences Unaffected by Subsurface Vapor Intrusion. Ground Water Monitoring Remediation, V. 29, No. 1, p. 60-69.

EnviroGroup Limited, 2009. Sampling and Analysis Plan, Cheyenne PCE Plume Orphan Site, Cheyenne, Wyoming. October 5, 2009.

EnviroGroup Limited, 2010a. Soil Vapor Investigation Procedures and Results Technical Memorandum, Cheyenne PCE Plume Orphan Site, Cheyenne, Wyoming. December 30, 2010.

EnviroGroup Limited, 2010b. Groundwater Investigation Procedures and Results Technical Memorandum, Cheyenne PCE Plume Orphan Site, Cheyenne, Wyoming. December 28, 2010.

EnviroGroup Limited, 2011a. Structure Sampling Results: Vapor Intrusion Pathway Evaluation, Cheyenne PCE Plume Orphan Site, Cheyenne, Wyoming. February 25, 2011.

EnviroGroup Limited, 2011b. Vapor Intrusion Mitigation System Installations Technical Memorandum, Cheyenne PCE Plume Orphan Site, Cheyenne, Wyoming. October 26, 2011.

Environmental Resources Management, 2002, Phase 1 Environmental Site Assessment, Safeway Store #R-438, 2512 Pioneer Avenue, Cheyenne, Wyoming, August 30, 2002.

Foster, S.J., J.P. Kurtz, and A.K. Woodland. 2002. Background indoor air risks at selected residences in Denver Colorado. In Proceedings: Indoor Air 2002, the proceedings of the 9th International Conference on Indoor Air Quality and Climate, Monterey, CA, June 30–July 5, p. 932-937.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604p.

ITRC, 2007, Vapor Intrusion Pathway: A Practical Guideline. Interstate Technology and Regulatory Council, Vapor Intrusion Team, January 2007.

Kuehster, T., Folkes, D., and Wannamaker, E., 2004, Seasonal Variations of Observed Indoor Air Concentrations Due to Vapor Intrusion; Midwestern States Risk Assessment Symposium, Indianapolis, August 26, 2004.

Kurtz, J.P., and D.J. Folkes. 2002. Background concentrations of selected chlorinated hydrocarbons in residential indoor air. In Proceedings: Indoor Air 2002, the proceedings of the 9th International Conference on Indoor Air Quality and Climate, Monterey, CA, June 30–July 5, p. 920-925.

United States Environmental Protection Agency, 1999. Compendium Method TO-15, Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS), EPA/625/R-96/010b, Center for Environmental Research Information, Office of Research and Development, Cincinnati, Ohio, January.

United States Environmental Protection Agency, 2002. OSWER Draft Guidance for Evaluation the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance), EPA 530-D-02-004, November 2002.

United States Environmental Protection Agency, 2010. U.S. EPA's Vapor Intrusion Database and a Preliminary Evaluation of Attenuation Factors, EPA 530-R-10-002, Office of Solid Waste, March 2010 Draft.

United States Environmental Protection Agency, 2011, Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990 – 2005): A Compilation of Statistics for Assessing Vapor Intrusion, Office of Solid Waste and Emergency Response, EPA-530-R-10-001, June 2011.

Wyoming Department of Environmental Quality, 1984. *Water Quality Rules and Regulations, Chapter 11, Design and Construction Standards for Sewerage Systems, Treatment Works, Disposal Systems or Other Facilities Capable of Causing or Contributing to Pollution and Mobile Home Park and Campground Sewerage and Public Water Supply Distribution Systems. Part G, Well Construction Standards*. Wyoming Department of Environmental Quality. Available at: http://deq.state.wy.us/wqd/wqdrules/Chapter_11.pdf

Wyoming Department of Environmental Quality, 2007, Voluntary Remediation Program Fact Sheet #14, March 6, 2007.

Wyoming Department of Environmental Quality, 2008, Platte County LAUST Project, 2008 Annual Report, Section 13.0.

Wyoming Department of Environmental Quality, 2009, DEQ Voluntary Remediation Program (VRP) Fact Sheet #12, Soil Cleanup Level Look-Up Table.

Wyoming Department of Environmental Quality, 2009, Indoor Air Screening Levels for PCE and TCE in Answers to Frequently Asked Questions, Downtown Cheyenne PCE Plume Orphan Site**.**

Yeskis, D. and Zavala, B, Technology Innovative Office, Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, 2002. Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers (EPA 542-S-02-001), May.

FIGURES

TABLES