Chevron Environmental Management Company

DRAFT SUPPLEMENTAL INVESTIGATION WORK PLAN

Former Chevron Facility 90129

4700 Brooklyn Avenue NE, Seattle WA

FSID: 81966648

CSID: 10632

7/14/2020

DRAFT SUPPLEMENTAL INVESTIGATION WORK PLAN

Prepared for:

Chevron Environmental Management Company

Prepared by:

Arcadis U.S., Inc.
1100 Olive Way
Suite 800
Seattle
Washington 98101
Tel 206 325 5254

[DRAFT]

Ada Hamilton
Project Manager

Our Ref.:

30045258

Date:

7/14/2020

.

CONTENTS

FIGURES

TABLES

APPENDICES

ACRONYMS AND ABBREVIATIONS

AO	Agreed Order
Arcadis	Arcadis U.S., Inc.
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CSID	Cleanup Site Identification Number
CUL	Cleanup Level
DRO	Diesel Range Organics
Ecology	Washington State Department of Ecology
EMC	Chevron Environmental Management Company
FSID	Facility Site Identification Number
GRO	Gasoline Range Organics
HO	Heavy Oil Range Organics
HVOCs	Halogenated Volatile Organic Compounds
MTCA	Model Toxic Control Act
NWTPH-Gx	Northwest Total Petroleum Hydrocarbons Method – Gasoline
NWTPH-Dx	Northwest Total Petroleum Hydrocarbons Method – Diesel
PCE	Tetrachloroethene
PID	Photo ionization detector
Property	4700 Brooklyn Avenue Northeast, Seattle, WA
PVC	polyvinyl chloride
ROW	Right-of-way
SOP	Standard Operating Procedure
TCE	Trichloroethene
TGI	Technical Guidance Document
USEPA	United States Department of Environmental Protection
VOC	Volatile Organic Compounds
Work Plan	Supplemental Investigation Work Plan

1 INTRODUCTION

On behalf of Chevron Environmental Management Company (CEMC), Arcadis U.S., Inc. (Arcadis), has prepared this Draft Supplemental Investigation Work Plan (Work Plan) for the Former Chevron Service Station No. 90129, located at 4700 Brooklyn Avenue Northeast in Seattle, Washington (site). The site is formally known as Former Chevron Facility No. 90129 in the Washington Department of Ecology (Ecology) database. A Site Location Map and Aerial Map are provided as Figure 1 and Figure 2, respectively

This Work Plan addresses a request by Ecology to provide additional data to delineate groundwater impacts to the east of the site and proposes installing additional groundwater monitoring wells and soil vapor probes to further evaluate subsurface conditions at the site.

The methods and procedures used in this groundwater evaluation and are in accordance with the Model Toxics Control Act (MTCA) and the Washington State Department of Ecology (Ecology) Guidance for Remediation of Petroleum Contaminated Sites (Ecology 2016).

2 SITE BACKGROUND

The site was a service station from at least 1919 through 2016. Two 12,000-gallon gasoline underground storage tanks (USTs) and one 12,000-gallon diesel UST were removed by FH Brooklyn in February 2017 (Aspect, 2017b). The service station building, four dispenser islands, and associated piping were removed from the site in 2018. The property owner (FH Brooklyn, LLC) is currently redeveloping the property to a 24-story apartment building with commercial space and two levels of below-grade parking. Previous investigation activities at the site are described in the Draft 2019 Investigation Summary, submitted to Ecology in April 2020.

Several historical dry-cleaning businesses were located in the vicinity of the site, including Carson Cleaners, which was located across Brooklyn Avenue Northeast to the west.

3 SCOPE OF WORK

A review of groundwater data collected in 2019 and 2020 indicated that concentrations of gasoline-range organics (GRO), diesel-range organics (DRO), benzene, vinyl chloride, tetrachloroethene (PCE) and trichloroethane (TCE) exceeded their respective MTCA Method A cleanup levels. MTCA groundwater exceedances are summarized in Table 1.

PCE, TCE, and vinyl chloride are halogenated volatile organic compounds (HVOCs) commonly associated with dry-cleaners, and their source is likely to be the Former Carson Cleaners facility, located at 4701 Brooklyn Avenue NE (Ecology Facility/Site No. 15518216; CSID 14878). As stated in a letter from Ecology to Carson Cleaners, dated April 16, 2019, these HVOCs likely originated from the former dry cleaners, which operated from the early 1960s until 2014 (Ecology 2019). The former Carson Cleaners facility is currently undergoing remedial investigation activities.

Arcadis reviewed a work plan for a Vapor Intrusion Evaluation by Anchor QEA, dated January 2020, on the Ecology site information page for the Carson Cleaners site (Anchor QEA, 2020). The plan is to conduct a vapor intrusion evaluation of the following four properties:

- Former Carson Cleaners facility, located at 4701 Brooklyn Avenue NE (Ecology Facility/Site No. 15518216; CSID 14878)
- Christ Episcopal Church, located at 4548 Brooklyn Avenue NE
- Bank of America Financial Center, located at 4701 University Way NE
- Mixed commercial and residential unit, located at 4557 University Way NE

The work plan indicates the evaluation will include sub slab soil vapor samples, indoor air samples, and external soil gas sampling points. Pending completion of this vapor intrusion evaluation, Arcadis will evaluate the locations of the external soil gas sampling points and the potential to use them to sample soil gas.

Benzene concentrations exceeded the MTCA Method A Cleanup level in groundwater samples collected from MW-17, MW-22, MW-23, MW-25, MW-27, and MW-28. This scope of work includes installation of monitoring wells and soil vapor probes to further delineate contamination at the eastern portion of the site.

3.1 Pre-Field Activities

Before mobilizing to the site, Arcadis will perform the following activities:

- Update the site-specific health and safety plan and prepare job safety analyses and traffic control plans, as appropriate;
- Secure access agreements from City of Seattle for the right of way, as appropriate;
- Notify the property owners and property tenants at least 30 days before field work commences;
- Notify Ecology at least 21 days prior to commencing field work;
- Mark the proposed sample locations and contact the state one-call public locate service a minimum of 72 hours prior to initiating the field activities; and
- Contract a private utility locator to conduct a private utility locate of the entire property to identify potential conflicting utilities or other underground structures in addition to potential preferential pathways.

3.2 Utility Locate

At least 48 hours prior to conducting subsurface activities, the Washington811 will be notified to mark known public utilities within the work area. In addition, Arcadis will oversee a private utility locating company conducting a utility scan, including the use of ground-penetrating radar.

3.3 Monitoring Well Installation, Soil and Groundwater Sampling

3.3.1 Monitoring Well Installation and Construction

Two monitoring wells (MW-30 and MW-31) will be installed in sidewalks, one east of the apartment building which is located across Brooklyn Avenue Northeast from the site, and one south of the Bank of America building which is located to the east of the site. Proposed monitoring well locations are shown on Figure 3.

The borings will be pre-cleared by a combination of air knife, vacuum truck, and/or hand auger to a minimum depth of 5 feet below ground surface (bgs). Boreholes will be advanced using a push probe to a depth of 25 feet bgs.

During preclearance, soil samples will be collected by hand auger at approximately 2.5 feet bgs by hand auger and screened for volatile organic compounds (VOCs) using a photo-ionization detector (PID). After preclearance activities, soil samples will be collected from 5-foot intervals. Soil will be recorded on 5-foot intervals from preclearance to terminal depth. Each borehole will be logged using a combination of Udden-Wentworth, and the Unified Soil Classification System and screened for VOCs using a calibrated PID. Soil samples may be submitted for laboratory analysis based on field observations. Boreholes will be advanced using a push probe to a depth of 25 feet bgs.

The wells will be constructed of 2-inch diameter Schedule 40 polyvinyl chloride (PVC) 0.010-inch slotted screen. Blank PVC casing will be installed from the top of the screen to near surface grade. Sand filter pack will be placed in the annular space of the borehole from the bottom of boring to approximately 1 foot above the top of the well screen, followed by transition seal consisting hydrated bentonite chips to approximately 2 feet bgs. The remaining open borehole annulus will be sealed with neat cement to near ground surface.

The wellhead will be completed at the ground surface with a locking well cap and traffic-rated bolt-down well vault.

3.3.2 Well Development and Groundwater Sampling

Following completion of monitoring well installations, each well will be developed to ensure removal of fine-grained sediments from the vicinity of the well screens. The well development will include surging the screen interval and purging fine-grained material out of the well. Purge water will be contained in Department of Transportation-approved 55-gallon steel drums and temporarily stored on-site.

Groundwater samples will be submitted to a Washington State certified laboratory for analysis under standard chain-of-custody procedures. The monitoring wells will be added to the network of wells sampled quarterly, and groundwater samples will be submitted for the following analyses:

- Gasoline-range organics (GRO) by Northwest TPH-Gx
- Diesel-range organics (DRO) and oil-range organics by Northwest TPH-Dx
- VOCs by USEPA Method 8260C, including BTEX, 1,2-Dichloroethane, cis-1,2-Dichloroethene, trans-1,2-Dichloroethene, methyl tertiary-butyl ether (MTBE), PCE, TCE, and vinyl chloride

- Lead by USEPA Method 6010D

3.4 Soil Vapor Probe Installation and Sampling

3.4.1 Soil Vapor Probe Installation

To evaluate potential soil vapor impacts, two external soil vapor probes (SVP-3 and SVP-4) are proposed at the approximate locations shown on Figure 3. The final location of each soil vapor probe will be determined based on accessibility, potential subsurface utilities identified during the utility location, and feasibility based on subsurface soil saturation conditions.

Soil vapor probe borings will be advanced using hand auger methods to a target depth of 5 feet bgs. Soil will be continuously screened during boring advancement for soil characterization using the USCS methods and VOCs using a calibrated PID. Soil boring details will be captured in boring logs.

The following sections describe installation and sampling activities to be completed as part of this investigation. Soil vapor investigation activities will be completed according to the following Arcadis Technical Guidance Instructions (TGIs) and the Chevron *Soil Vapor and Indoor Air Sampling Technical Toolkit* included in Appendix A and Appendix B, respectively.

- *Soil Drilling and Sampling Collection*
- *Installation of Permanent Soil Vapor Probes*
- *Administering Helium Tracer Gas Leak Test*
- *Sub-Slab Soil Vapor or Soil Vapor Sampling Using Whole Air Canisters Analyzed via USEPA Method TO-15*

The above TGIs have been developed in accordance with the Ecology *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Vapor Intrusion Guidance; Ecology 2018).

3.4.2 Soil Vapor Sampling

Arcadis will collect samples from the two soil vapor probes installed in August 2019 (SVP-1 and SVP-2), and the two vapor probes installed during this investigation. Soil vapor probe locations are shown on Figure 3. Soil vapor samples will be collected using batch certified evacuated 1-liter canisters with 200 milliliter per minute (mL/min) regulators. Additionally, a sorbent tube will be collected using active sampling methods with a laboratory provided plastic syringe. Soil vapor samples will be collected and analyzed for the following:

- TPHs (aliphatic and aromatic), BTEX, and MTBE by USEPA Method TO-15 Low-Level
- Naphthalene by USEPA Method TO-17
- Oxygen, carbon dioxide, methane and helium by American Society for Testing and Materials (ASTM) Method 1946

Quality control measures for external soil vapor samples will include: Shut-in Testing, Duplicate Sampling, Equipment Blank Sampling, and Helium Tracer Leak Testing.

4 DATA EVALUATION

Arcadis will compare groundwater concentrations to MTCA Method A CULs to assess current site COCs. Groundwater will be evaluated to further delineate impacts.

Soil vapor sample analytical results will be evaluated based on the shallow (sub-slab) screening levels in accordance with MTCA Method A indoor air CULs (Ecology 2015). Shallow soil vapor screening levels are derived based on an Ecology default attenuation factor of 0.03. TPH concentrations in soil vapor will be evaluated based on the screening levels provided within the Ecology *Implementation Memorandum No. 18 Petroleum Vapor Intrusion (PVI): Updated Screening Levels, Cleanup Levels, and Assessing PVI Threats to Future Buildings*.

5 MANAGEMENT OF INVESTIGATION-DERIVED WASTE

Soil cuttings and purge water generated during the field activities will be contained in Department of Transportation-approved, 55-gallon steel drums. The drums will be appropriately labeled and temporarily stored on-site pending analytical results. Upon receipt of soil and water analytical results, the drums will be removed from the site and transported to an off-site disposal facility.

6 SCHEDULE AND REPORTING

Following completion of the boring installations and sampling described above, Arcadis will prepare a technical report for submittal to Ecology. This report will document the results of the groundwater samples, and include the following:

- Site conditions and background information
- A scaled site plan illustration of the installed well locations, installed soil vapor probes, and other relevant site features
- Documentation of well installation, including boring logs
- Results of the laboratory analyses performed summarized in table format and laboratory analytical reports.
- Conclusions and recommendations relevant to the investigation objectives.

Arcadis estimates that the well installations and soil boring installations will be conducted within 60 days of receiving Ecology approval of this work plan or agreed upon revisions of this workplan contingent on access and permitting, assuming it is safe to do so.

7 REFERENCES

Anchor QEA. 2020. Vapor Intrusion Evaluation Final Work Plan. January. Reviewed on Washington Department of Ecology site information website: https://apps.ecology.wa.gov/gsp/CleanupSiteDocuments.aspx?csid=14878

Washington Department of Ecology. 2015. Toxicity Values and Sub-Slab Screening Levels. April

Washington Department of Ecology. 2015. Table B-1 Vapor Intrusion Screening Levels. April.

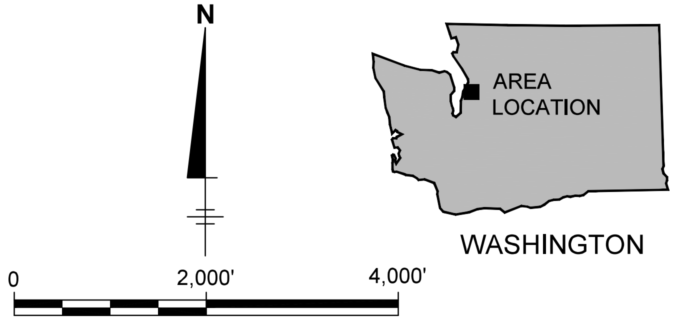
Washington Department of Ecology. 2016. Implementation Memorandum No. 14 - Updated Process for Initially Assessing the Potential for Petroleum Vapor Intrusion. March 31.

Washington Department of Ecology. Revised 2018. Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action. April.

Washington Department of Ecology. 2019. Letter from Ecology to Carson Cleaners, Inc. Early Notice of Release of Hazardous Substances and Preliminary Determination of Liability for Release. April 16. https://apps.ecology.wa.gov/gsp/CleanupSiteDocuments.aspx?csid=14878

FIGURES

SOURCE: BASE MAP USGS 7.5. MIN. TOPO. QUAD., SEATTLE NORTH, WA 2017.



APPROXIMATE SCALE : 1 in. = 2,000 ft.

FORMER CHEVRON FACILITY #90129
4700 BROOKLYN AVENUE NE
SEATTLE, WA 98105

SITE LOCATION MAP

ARCADIS Design & Consultancy for natural and built assets

FIGURE
1

CITY:EMERYVILLE, CA DIV/GROUP:ENVCAD DB:A.REYES
C:\Users\ms0285\BIM 360\Arcadis\ANA - CHEVRON CORPORATION\Project Files\90129 - Brooklyn\2019\30012295\01-DWG\90129 FIG 1 SITE MAP.dwg LAYOUT: 1 SAVED: 1/2/2020 5:08 PM ACADVER: 23.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 1/2/2020 5:18 PM
BY: M, SARAVANAPRIYA

LEGEND:

- – – APPROXIMATE PROPERTY BOUNDARY

N

0 100' 200'

APPROXIMATE SCALE 1 in. = 100 ft.

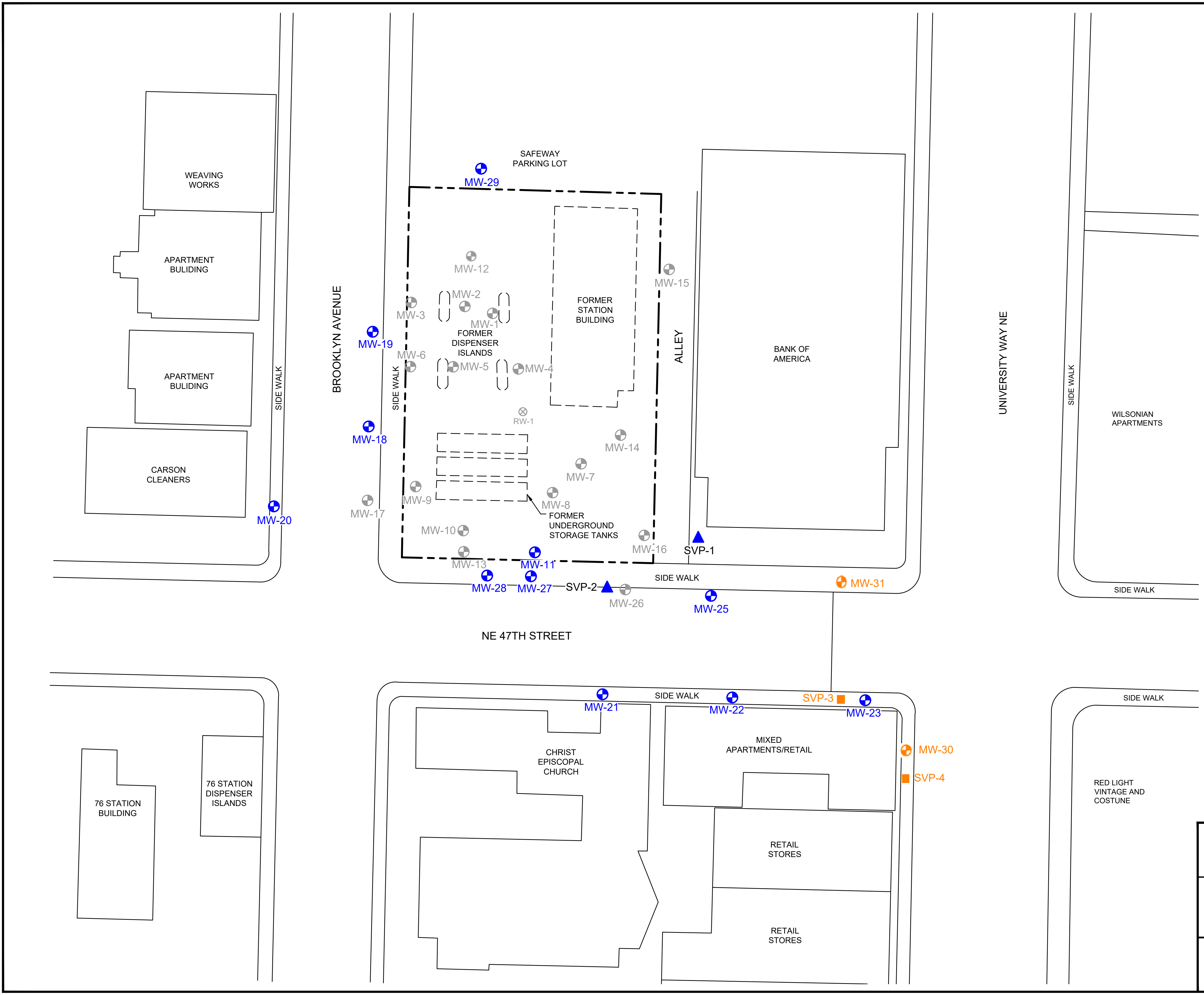
FORMER CHEVRON FACILITY #90129
4700 BROOKLYN AVENUE NE
SEATTLE, WA 98105

AERIAL MAP

ARCADIS Design & Consultancy for natural and built assets

FIGURE
2

CITY:(Reqd) DIV/GROUP:(Reqd) DB:(Reqd) LD:(Opt) PIC:(Opt) PM:(Reqd) TM:(Opt) LYR:(Opt)ON=*;OFF=*REF*
C:\Users\ymb2640\BIM 360\Arcadis\ANA - CHEVRON CORPORATION\Project Files\90129 - Brooklyn\2020\30012295\01-DWG\90129 FIG 2 AERIAL MAP.dwg LAYOUT: 2 SAVED: 1/15/2020 3:41 PM ACADVER: 23.1S (LMS TECH) PAGESETUP: — PLOTSTYLETABLE: — PLOTTED: 1/15/2020 3:47 PM BY:
Y M, BABU



N

LEGEND:

— — —	APPROXIMATE PROPERTY BOUNDARY
MW-7 ⊕	GROUNDWATER MONITORING WELL
MW-4 ⊕	DECOMMISSIONED MONITORING WELL
SVP-1 ▲	SOIL VAPOR PROBE LOCATION
RW-1 ⊗	RECOVERY WELL
MW-30 ⊕	PROPOSED MONITORING WELL LOCATION
SVP-3 ■	PROPOSED SOIL VAPOR POINT LOCATION

0 40' 80'

APPROXIMATE SCALE 1 in. = 40 ft.

FORMER CHEVRON FACILITY #90129
4700 BROOKLYN AVENUE NE
SEATTLE, WA 98105

SITE PLAN

ARCADIS Design & Consultancy for natural and built assets

FIGURE
3

CITY:(Reqd) DIV/GROUP:(Reqd) DB:(Reqd) LD:(Opt) PIC:(Opt) PM:(Reqd) TM:(Opt) LYR:(Opt)ON=*;OFF=*REF*
C:\Users\YMB2640\BIM 360\Arcadis\ANA - CHEVRON CORPORATION\Project Files\90129 - Brooklyn\2020\30012295\01-DWG\90129 FIG 3 SITE PLAN.dwg LAYOUT: 3 SAVED: 6/23/2020 4:26 PM ACADVER: 23.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: ---- PLOTTED: 6/23/2020 4:28 PM BY:
Y. M, BABU

TABLES

Table 1. Groundwater Gauging Data and Select Analytical Results
Chevron Service Station No. 9-0129
4700 Brooklyn Avenue Northeast
Seattle, Washington

Well	Date	TOC	DTW	GWE	GRO	DRO	HO	Benzene	Toluene	Ethylbenzene	Total Xylenes	MTBE	EDB	PCE	TCE	Vinyl Chloride	Total Lead
MTCA Method A CULs					**800/1,000**	**500**	**500**	**5**	**1,000**	**700**	**1,000**	**20**	**0.01**	**5.00**	**5.00**	**0.20**	**15**
MW-17	12/26/2019	215.40	18.09	197.31	240	**610**	<360	3.7	<0.39	6.6	1.2 J	<0.44	<0.0020	**9.50**	3.70	**<0.22**	<2.7
	2/18/2020	215.40	17.15	198.25	**822**	**1930**	267	**9.92**	0.489 J	25.2	32.6	<0.102	<0.0024	4.05	**5.10**	<0.118	<1.9
	4/29/2020	Well abandoned to accommodate utility installation during construction															
MW-18	12/26/2019	215.95	18.70	197.25	<100	<66	<97	<0.53	<0.39	<0.50	<0.75	<0.44	<0.0020	3.80	<0.85	**<0.22**	<2.7
	2/18/2020	215.95	17.84	198.11	38.5 BJ	<66	<83	<0.089	<0.412	<0.158	<0.316	<0.102	<0.0024	2.94	<0.153	<0.118	<1.9
	4/29/2020	215.95	17.87	198.08	79.4 BJ	--	--	<0.0941	<0.278	<0.137	0.335	<0.101	<0.00636	3.90	<0.190	<0.234	<2.9
MW-19	12/26/2019	216.36	18.97	197.39	<100	<63	<93	<0.53	<0.39	<0.50	<0.75	<0.44	<0.0020	<0.41	<0.85	**<0.22**	<2.7
	2/18/2020	216.36	18.39	197.97	42.4 BJ	<66	114 J	<0.089	<0.412	<0.158	<0.316	<0.102	<0.0024	<0.199	<0.153	<0.118	<1.9
	4/29/2020	216.36	18.58	197.78	49 BJ	--	--	<0.0941	<0.278	<0.137	<0.174	<0.101	<0.00536	<0.300	<0.190	<0.234	<2.9
MW-20	12/26/2019	215.87	18.46	197.41	<100	<60	<89	<0.53	<0.39	<0.50	<0.75	<0.44	<0.0020	**100**	**20**	**<0.22**	<2.7
	2/18/2020	215.87	17.51	198.36	62.3 BJ	<66	95.2 J	<0.089	<0.412	<0.158	<0.316	<0.102	<0.0024	**52**	**21.6**	<0.118	<1.9
	4/29/2020	215.87	17.54	198.33	76.4 BJ	--	--	<0.0941	<0.278	<0.137	<0.174	<0.101	<0.00536	**107**	**13.7**	<0.234	<2.9
MW-21	12/26/2019	213.89	17.32	196.57	<100	<64	<95	<0.53	<0.39	<0.50	<0.75	<0.44	<0.0020	<0.41	<0.85	**<0.22**	<2.7
	2/18/2020	213.89	16.42	197.47	<31.6	<66	114 J	<0.089	<0.412	<0.158	<0.316	<0.102	<0.0024	<0.199	<0.153	<0.118	<1.9
	4/29/2020	213.89	16.52	197.37	37.0 BJ	--	--	<0.0941	<0.278	<0.137	<0.174	<0.101	<0.00536	<0.300	<0.190	<0.234	<2.9
MW-22	12/26/2019	212.93	16.80	196.13	<100	73 J	<91	**10**	<0.39	<0.50	<0.75	<0.44	<0.0020	1.1 J	**410**	**6.4**	<2.7
	2/18/2020	212.93	16.22	196.71	536	92.2 J	110 J	**9.33**	<0.412	<0.158	<0.316	<0.102	<0.0024	1.11	**447**	**5.13**	1.98 J
	4/29/2020	212.93	16.25	196.68	549 B	--	--	**8.3**	<0.278	<0.137	<0.174	<0.101	<0.00536	<3.00	**384**	**5.00**	<2.9
MW-23	12/26/2019	211.72	16.15	195.57	<100	<66	<98	**16**	<0.39	<0.50	<0.75	<0.44	<0.0020	<0.41	**130**	**22**	<2.7
	2/18/2020	211.72	15.82	195.90	246	67.2 J	159 J	**8.69**	<0.412	<0.158	<0.316	<0.102	<0.0024	<0.199	**59.8**	**7.85**	<1.9
	4/29/2020	211.72	15.69	196.03	148	--	--	4.1 J	<0.278	<0.137	<0.174	<0.101	<0.00536	<0.300	**14.0**	**4.24 J**	4.59 J
MW-25	12/26/2019	212.81	16.62	196.19	210 J	110 J	<100	**53**	3.4	7	2.8 J	<0.44	<0.0020	**16**	**600**	**180**	<2.7
	2/18/2020	212.81	15.98	196.83	**1500**	107 J	122 J	**42.2**	2.82	2.1	1.58	<0.102	<0.0024	4.49	**530**	**92.7**	<1.9
	5/5/2020	212.81	16.03	196.78	**1630**	--	--	**28.10**	<5.56	<2.74	<3.48	<2.02	<0.00536	**22.8**	**496**	**53.7**	<2.9
MW-27	12/26/2019	214.43	17.32	197.11	**3600**	**5300**	190 J	**6.5**	2.0	140	38	<0.44	<0.0020	0.53 J	**830**	**18**	<2.7
	2/18/2020	214.43	16.46	197.97	**3860**	**7010**	172 J	**7.9**	<10.3	116	30.3	<0.102	<0.0024	<4.98	**1050**	**11.4**	<1.9
	4/29/2020	214.43	16.64	197.79	**3320**	--	--	**4.95**	<6.95	<3.43	<4.35	<2.53	<0.00536	<7.5	**1170**	**12.6**	<2.9
MW-28	12/26/2019	214.44	17.30	197.14	**2800**	**2200**	160 J	**8.1**	1.1 J	170	38	<0.44	<0.0020	**410**	**1800**	**12**	<2.7
	2/18/2020	214.44	16.40	198.04	**3960**	**3020**	152 J	**14.6**	2.820	295	153	<0.102	<0.0024	**64.30**	**158.00**	**2.17**	<1.9
	4/29/2020	214.44	16.57	197.87	**3670**	--	--	**10.4**	<1.39	224	58.3	<0.505	<0.00536	**238**	**713**	**4.01**	3.05 J
MW-29	12/26/2019	217.26	19.63	197.63	<100	<76	<110	<0.53	<0.39	<0.50	<0.75	<0.44	<0.0020	<0.41	<0.85	**<0.22**	<2.7
	2/18/2020	217.26	19.55	197.71	95.4 BJ	<66	155 J	<0.089	<0.412	<0.158	<0.316	<0.102	<0.0024	<0.199	<0.153	<0.118	<1.9
	4/29/2020	217.26	19.62	197.64	92.5 BJ	--	--	<0.941	<0.278	<0.137	<0.174	<0.101	<0.00536	<0.300	0.216	<0.234	<2.9

Notes:
800/1,000 = GRO MTCA Method A CUL with benzene present is 800 µg/L and without is 1,000 µg/L
BOLD and highlighted values are greater than their respective MTCA Method A cleanup level
BOLD values are non-detect below the laboratory method detection limit (MDL), but the MDL is greater than the MTCA Method A cleanup level
Results reported in micrograms per liter (µg/L)

Abbreviations:
TOC = Top of Casing
DTW = Depth to water in feet below TOC
GWE = Groundwater elevation in feet relative to NAVD88
-- = Not applicable, not available, or not analyzed
MTCA = Model Toxics Control Act Cleanup
CUL = Cleanup Level
PCE = Tetrachloroethene
TCE = Trichloroethene
EDB = 1,2-Dibromoethane (Ethylene dibromide)
MTBE = Methyl tertiary butyl ether
GRO = Gasoline Range Organics
DRO = Diesel Range Organics
HO = Heavy Oil Range Organics

Laboratory Qualifiers:
< = Not detected at or above the Method Detection Limit (MDL)
J = Estimated value; result is greater than the laboratory Method Detection Limit (MDL) but less than the RL or LOQ.
B = The same analyte is found in the associated blank

APPENDIX A

Arcadis Technical Guidance Instructions

TGI – SOIL DRILLING AND SAMPLE COLLECTION

Rev #: 0

Rev Date: October 11, 2018

VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
0	October 11, 2018	All	Updated and re-written as a TGI	Marc Killingstad

APPROVAL SIGNATURES

Prepared by:		10/11/2018
	Christopher Keen	Date:
Technical Expert Reviewed by:		10/11/2018
	Marc Killingstad (Technical Expert)	Date:

1 INTRODUCTION

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to any and all projects. It is the CPM's responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project's scope of work based upon site conditions, staffing expertise, state-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

2 SCOPE AND APPLICATION

This Technical Guidance Instruction (TGI) describes general drilling procedures and the methods to be used to field screen and collect soil samples for laboratory analysis in unconsolidated sediments. For soil description procedures, please refer to the *TGI - Soil Description*. For monitoring well installation in granular aquifers, please refer to the *TGI - Monitoring Well Installation*.

Overburden (unconsolidated sediments) drilling is commonly performed using the hollow-stem auger drilling method. Other drilling methods suitable for overburden drilling, which are sometimes necessary due to site-specific geologic conditions, include: drive-and-wash, spun casing, rotasonic, dual-rotary (Barber Rig), and fluid/mud rotary with core barrel or roller bit. Direct-push techniques (e.g., Geoprobe or cone penetrometer) and hand tools may also be used. Drilling within consolidated materials such as fractured bedrock is commonly performed using water-rotary (coring or tri-cone roller bit), air rotary or rotasonic methods. For guidance when drilling in consolidated materials (i.e., bedrock), please refer to the *TGI – Bedrock Core Collection and Description*.

The drilling method to be used at a given site will be selected based on site-specific consideration of anticipated drilling depths, site or regional geologic knowledge, types of sampling to be conducted, required sample quality and volume, and cost.

Field screening of soil samples is commonly performed using a photoionization detector (PID) and/or a flame ionization detector (FID). These instruments are used to measure relative concentrations of volatile organic compounds (VOCs) for the selection of samples for further laboratory or field analysis. Field screening for dense non-aqueous phase liquids (DNAPL) may be performed using hydrophobic dye (Oil Red O or Sudan IV), which is pertinent at chlorinated solvent sites.

Collection of soil samples for laboratory analysis may be performed using a variety of techniques including grab samples and composite or homogenized samples. Samples may require homogenization across a given depth interval, or several discrete grabs (usually five) may be combined into a composite sample. Samples for VOC analysis will not be homogenized or composited and are collected as discrete grab samples.

No oils or grease will be used on equipment introduced into the boring (e.g., drill rod, casing, or sampling tools).

3 PERSONNEL QUALIFICATIONS

Arcadis field personnel will have completed or are in the process of completing site-specific training as well as having current health and safety training as required by Arcadis, client, or state/federal regulations, such as 40-hour HAZWOPER training and/or OSHA HAZWOPER site supervisor training. Arcadis personnel will also have current training as identified in the site-specific Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. The HASP will also identify any access control requirements.

Prior to mobilizing to the field, Arcadis field personnel will review and be thoroughly familiar with relevant site-specific documents including but not limited to the task-specific work plan or field implementation plan (FIP), Quality Assurance Project Plan (QAPP), HASP, historical information, and other relevant site documents.

Arcadis field personnel will be knowledgeable in the relevant processes, procedures, and TGIs and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. Personnel responsible for overseeing drilling operations will have at least 16 hours of prior training overseeing drilling activities with an experienced geologist, environmental scientist, or engineer with at least 2 years of prior experience.

Arcadis personnel directing, supervising, or leading soil sampling activities will have a minimum of 1 year of previous environmental soil sampling experience. Field employees with less than 6 months of experience will be accompanied by a supervisor (as described above) to ensure that proper sample collection techniques are employed.

Additionally, the Arcadis field team will review and be thoroughly familiar with documentation provided by equipment manufacturers and become familiar with the operation of (i.e., hands-on experience) all equipment that will be used in the field prior to mobilization.

4 EQUIPMENT LIST

The following materials will be available, as required, during soil boring drilling, field screening, and sampling activities:

- Site-specific HASP and health and safety documents identified in the HASP
- Field Implementation Plan (FIP)/work plan that includes site map with proposed boring locations, field sampling plan (with corresponding depths, sample analyses, sample volume required, and sample holding time), and previous boring logs (as available)
- Appropriate personal protective equipment (PPE), as specified in the HASP
- Traffic cones, delineators, and caution tape as appropriate for securing the work area as specified in the Traffic Safety Plan (TSP)
- Photoionization detector (PID), flame ionization detector (FID) or other air monitoring equipment, as needed, in accordance with the HASP
- Drilling equipment required by *ASTM D1586*, when performing split-spoon sampling
- Disposable plastic liners, when drilling with direct-push equipment
- Appropriate soil sampling equipment (e.g., stainless steel spatulas/spoons/bowls, knife)
- Stainless steel hand auger and stainless-steel spade if using manual methods
- Indelible ink pens
- Engineer’s ruler or survey rod
- Sealable plastic bags (e.g., Ziploc®)
- Air-tight sample containers and 8-oz. glass Mason jars or driller’s jars
- Aluminum foil
- Plastic sheeting (e.g., Weatherall Visqueen)
- Decontamination equipment (buckets, distilled or deionized water, cleansers appropriate for removing expected chemicals of concern, paper towels)
- Appropriate sample blanks (trip blank supplied by the laboratory), as specified in the FSP
- Soil sample containers and labels (supplied by the laboratory) appropriate for the analytical method(s) with preservative, as needed (parameter-specific)
- Appropriate transport containers (coolers) with ice and appropriate labeling, packing, and shipping materials;
- Appropriate soil boring log (**Attachment 1**)
- Chain-of-custody forms
- Field notebook.

- Digital camera (or smart phone with camera)
- Drums or other containers appropriate for soil and decontamination water, as specified by the site investigation-derived waste (IDW) management plan, and appropriate drum labels

5 CAUTIONS

Prior to beginning field work, underground utilities in the vicinity of the drilling areas will be delineated by the drilling contractor or an independent underground utility locator service. See appropriate guidance for proper utility clearance protocol. Work will be performed in accordance with the Arcadis *Utility Location and Clearance Health and Safety Standard* and the *Utilities and Structures Checklist* will be completed before beginning any intrusive work.

Prior to beginning field work, the project technical team will ensure that all field logistics (e.g., access issues, health and safety issues, communication network, schedules, etc.) and task objectives are clearly understood by all team members. An internal call with the project technical team to review the FIP/work plan scope and objectives is strongly recommended prior to mobilization to ensure that the field work will be effectively and efficiently executed.

Some regulatory agencies have specific requirements regarding borehole abandonment and grout mixtures. Determine whether the oversight agency has any such requirements prior to finalizing the drilling plan.

If DNAPL is known or expected to exist at the site, refer to the project specific documents (e.g., DNAPL Contingency Plan) for additional details regarding drilling to reduce the potential for inadvertent DNAPL remobilization.

Similarly, if light non-aqueous phase liquid (LNAPL) is known or expected to be present as "perched" layers above the water table, refer to the DNAPL Contingency Plan. Follow the general provisions and concepts in the DNAPL contingency plan during drilling above the water table at known or expected LNAPL sites.

Avoid using drilling fluids or materials that could impact groundwater or soil quality, or could be incompatible with the subsurface conditions.

Water used for drilling, decontamination of drilling/sampling equipment, or grouting boreholes upon completion will be of a quality acceptable for project objectives. Testing of water supply will be considered.

Specifications of materials used for backfilling the borehole will be obtained, reviewed and approved to meet project quality objectives. Bentonite is not recommended where DNAPL is likely to be present or in groundwater with high salinity. In these situations, neat cement grout is preferred.

Store and/or stage empty and full sample containers and coolers out of direct sunlight. Be careful not to over-tighten lids with Teflon® liners or septa. Over-tightening can impair the integrity of the seal and can cause the glass to shatter and create a risk for hand injuries.

NOTE: *Field logs and some forms are considered to be legal documents. All field logs and forms will therefore be filled out in indelible ink. Do not use permanent marker or felt-tipped pens for labels on* *sample container or sample coolers. Permanent markers could introduce volatile constituents into the samples.*

NOTE: *An Arcadis employee that is appropriately trained at the correct level of internal hazardous materials/DOT (Department of Transportation) shipping must complete an Arcadis shipping determination to address applicable DOT and IATA (International Air Transport Association) shipping requirements. Review the applicable Arcadis procedures and guidance instructions for sample packaging and labeling. Prior to using air transportation, confirm air shipment is acceptable under DOT and IATA regulations.*

6 HEALTH AND SAFETY CONSIDERATIONS

The HASP will be followed, as appropriate, to ensure the safety of field personnel.

Appropriate personal protective equipment (PPE) will be worn at all times in line with the task and the site-specific HASP.

Review all site-specific and procedural hazards as they are provided in the HASP, and review Job Safety Analysis (JSA) documents in the field each day prior to beginning work.

Working outside at sites with suspected contamination may expose field personnel to hazardous materials such as contaminated groundwater or non-aqueous phase liquid (NAPL) (e.g., oil). Other potential hazards include biological hazards (e.g., stinging insects, ticks in long grass/weeds, etc.), and potentially the use of sharp cutting tools (scissors, knife). Only use non-toxic peppermint oil spray for stinging insect nests. Review client-specific health and safety requirements, which may preclude the use of fixed/folding-blade knives and use appropriate hand protection.

If thunder or lighting is present, discontinue drilling and sampling until 30 minutes have passed after the last occurrence of thunder or lighting.

7 PROCEDURE

The procedures for drilling and the methods to be used to field screen and collect soil samples for laboratory analysis are presented below:

DRILLING PROCEDURES

Hollow-Stem Auger, Drive-and-Wash, Spun Casing, Fluid/Mud Rotary, Rotasonic, and Dual-Rotary Drilling Methods

1. Find/identify boring location, establish work zone, and set up sampling equipment decontamination area.
2. Advance boring to designated depth:
    a. Collect soil samples at appropriate interval as specified in the FIP/work plan (or equivalent)
    b. Collect, document, and store samples for laboratory analysis as specified in the FIP/work plan (or equivalent)

   c. Decontaminate equipment between samples in accordance with the FIP/work plan (or equivalent)

   d. A common sampling method that produces high-quality soil samples with relatively little soil disturbance is described in *ASTM D1586 – Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils* (ASTM D1586).

      i. Split-spoon samples are obtained during drilling using hollow-stem auger, drive-and-wash, spun casing, and fluid/mud rotary

   e. Rotasonic drilling produces soil cores that, for the most part, are relatively undisturbed, but note that when drilling in consolidated or finer-grained sediment the vibratory action during core barrel advancement may create secondary fractures or breaks

   f. Dual-rotary removes cuttings by compressed air or water/mud and allow only a general assessment of geology

3. Describe each soil sample as outlined in the appropriate project records (refer to the description procedures outlined in the *TGI - Soil Description*)

   a. Record descriptions on the soil boring log (**Attachment 1**) and/or field notebook.

   b. When possible photo document the samples (e.g., soil cores, split-spoons)

   c. During soil boring advancement, document all drilling events in field notebook, including blow counts (i.e., the number of blows from a soil sampling drive weight [140 pounds] required to drive the split-barrel sampler in 6-inch increments) and work stoppages

   d. Blow counts will not be available if rotasonic, dual-rotary, or direct-push methods are used; however, if standard penetration testing is required during rotasonic drilling, an automatic drop hammer may be used in conjunction with the method to switch from core barrel advancement to standard penetration testing

4. The drilling contractor will be responsible for obtaining accurate and representative samples, informing the supervising Arcadis geologist of changes in drilling pressure, and keeping a separate general log of soils encountered, including blow counts

   a. The term “samples” means soil materials from particular depth intervals, whether or not portions of these materials are submitted for laboratory analyses

   b. Records will also be kept of occurrences of premature refusal due to boulders or construction materials that may have been used as fill

   c. Where a boring cannot be advanced to the desired depth, the boring will be abandoned, and an additional boring will be advanced at an adjacent location to obtain the required sample

   d. Where it is desirable to avoid leaving vertical connections between depth intervals (e.g., if DNAPL or perched LNAPL are known or expected to exist at the site), the borehole will be sealed using cement and/or bentonite (see **Section 5** above)

    e. Multiple refusals may lead to a decision by the supervising geologist to abandon that sampling location

Direct-Push Method

The direct-push drilling method may also be used to complete soil borings. Examples of this technique include Geoprobe®, Diedrich Environmental Soil Probe (ESP) System, or AMS PowerProbe. Environmental probe systems typically use a hydraulically operated percussion hammer.

Depending on the equipment used, the hammer delivers 140- to 350-foot pounds of energy with each blow. The hammer provides the force needed to penetrate very stiff to medium dense soil formations. The hammer simultaneously advances an outer steel casing that contains a dual tube liner for sampling soil (dual tube sampling system).

The outside diameter (OD) of the outer casing ranges from 2.25 to 6 inches and the OD of the inner sampling tube diameter ranges from 1.4 to 4.5 inches. The outer casing isolates overlying soil and permits the unit to continue to probe at depth. The dual tube sampling system provides a borehole that may be tremie-grouted from the bottom up. Alternatively, a single rod system may be used that does not provide a cased boring and which does not allow for tremie-grouting from the bottom up.

The known or expected site conditions (e.g., presence of NAPL) will be evaluated when selecting the type of direct-push sampling system to be employed.

Direct-push drilling can generally achieve target depths 100 feet or less and the achievable depth is based on the site geology.

1. Find/identify boring location, establish work zone, and set up sampling equipment decontamination area
2. Advance soil boring to designated depth.
    a. Collect soil samples at appropriate interval as specified in in the FIP/work plan (or equivalent)
    b. Collect, document, and store samples for laboratory analysis as specified in in the FIP/work plan (or equivalent)
    c. Decontaminate equipment between samples in accordance with in the FIP/work plan (or equivalent)
    d. Samples will be collected using dedicated, disposable, plastic liners
3. Describe samples in accordance with the procedures outlined in **Step 3** under ***Hollow-Stem Auger, Drive-and-Wash, Spun Casing, Fluid/Mud Rotary, Rotasonic, and Dual-Rotary Drilling Methods*** above (refer to the description procedures outlined in the *TGI - Soil Description*)

Manual Methods

Manual methods may also be used to complete shallow soil borings. Examples of this technique include using a spade, spoon, scoop, hand auger, or slide hammer. Manual methods are typically used to collect surface soil samples (0 to 6 inches) or to complete soil borings/collect soil samples from a depth of 5 feet or less.

1. Find/identify boring location, establish work zone, and set up sampling equipment decontamination area
2. Clear the ground surface of brush, root mat, grass, leaves, or other debris
3. Use a spade, spoon, scoop, hand auger, or slide hammer to collect a sample of the required depth interval
4. Use an engineer's ruler or survey rod to verify that the sample is collected to the correct depth and record the top and bottom depths from the ground surface
5. To collect samples below the surface interval, remove the surface interval first; then collect the deeper interval
    a. To prevent the hole from collapsing, it may be necessary to remove a wider section from the surface or use cut polyvinyl chloride (PVC) pipe to maintain the opening
    b. Collect soil samples at appropriate interval as specified in the FIP/work plan (or equivalent)
    c. Collect, document, and store samples for laboratory analysis as specified in the FIP/work plan (or equivalent)
    d. Decontaminate equipment between samples in accordance with the FIP/work plan (or equivalent)
6. Describe samples in accordance with the procedures outlined in **Step 3** under ***Hollow-Stem Auger, Drive-and-Wash, Spun Casing, Fluid/Mud Rotary, Rotasonic, and Dual-Rotary Drilling Methods*** above (refer to the description procedures outlined in the *TGI - Soil Description*)

FIELD SCREENING PROCEDURES

PID and FID Screening

Soils are typically field screened with a PID or FID for a relative measure of the total VOCs at sites where VOCs are known or suspected to exist. The PID employs a UV lamp to measure VOCs and the ionization energy (IE) of the site constituents need to be considered when selecting the type of lamp (e.g., 10.6 eV, 11.7 eV) that will be used. In general, any compound with an IE lower than that of the lamp photons can be measured. The FID has a wide linear range and responds to almost all VOCs. Field screening is performed using one (or both) of the following two methods:

1. Upon opening the sampler, the soil is split open and the PID or FID probe is placed in the opening and covered with a gloved hand. Such readings will be obtained at several locations along the length of the sample.
2. A portion of the collected soil is placed in a jar, which is covered with aluminum foil, sealed, and allowed to warm to room temperature. After warming, the cover is removed, the foil is pierced with the PID or FID probe, and a reading is obtained.

Initial PID readings will be recorded on the soil boring log (**Attachment 1**) and/or in the field notebook. The soil sample will be separated from the slough material (if any) by using disposable gloves and a pre-cleaned stainless-steel spoon.

For the second method, a representative portion of the sample will be placed in a pre-cleaned air-tight 8-ounce container (as quickly as possible to avoid loss of VOCs), filling the container half full to allow for the accumulation of vapors above the soil. An aluminum foil seal will be placed between the glass and metal cap and the cap will be screwed on tightly. Unless the screening will be performed immediately after the sample is placed in the container, the sample containers will be stored in a cooler chilled to approximately 4ºC until screening can be performed.

The headspace of the 8-ounce container will be measured using a PID or FID as follows:

1. Samples will be taken to a warm work space and allowed to equilibrate to room temperature for at least one hour.
2. Prior to measuring the soil vapor headspace concentration, the 8-ounce container will be shaken.
3. The headspace of the sample will then be measured directly from the 8-ounce container by piercing the aluminum foil seal with the probe of the PID or FID and measuring the relative concentration of VOCs in the headspace of the soil sample. The initial (peak) reading must be recorded.

The PID or FID must be calibrated according to the manufacturer's specifications at a minimum frequency of once per day prior to collecting PID or FID readings. The PID will be calibrated to a benzene-related compound (isobutylene) while the FID will be calibrated to methane.

The time, date, and calibration procedure must be clearly documented in the field notebook and/or the calibration log book.

If at any time the PID or FID results appear erratic or inconsistent with field observations, then the instrument will be recalibrated.

If calibration is difficult to achieve, then the PID’s lamp will be checked for dirt or moisture and cleaned, or technical assistance will be required. Maintenance and calibration records will be kept as part of the field quality assurance program.

NAPL Screening

To screen for the potential presence of non-aqueous phase liquid (NAPL) in soil, drilling procedures must allow for high-quality porous media samples to be taken. Split-spoon samplers or direct-push samplers will be collected continuously ahead of the auger, drill casing/rods, or probe rods.

Upon opening each split-spoon sampler or direct-push plastic liner sleeve, the soil will immediately be evaluated for the presence of visible NAPL. If NAPL is immediately visible in the sample, its depth will be noted.

Additionally, the soil will be screened for the presence of organic vapors using a PID or FID. During screening, the soil will be split open using a clean spatula or knife and the PID or FID probe will be placed in the opening and covered with a gloved hand (**Method 1** above). Such readings will be obtained along the entire length of the sample. Alternatively, **Method 2** for PID/FID screening (outlined above) may also be performed. If the PID or FID examination reveals the presence of organic vapors above 100 parts per million (ppm), the sample will undergo further detailed evaluation for visible NAPL.

The assessment for NAPL will include the following tests/observations:

- Evaluation for Visible NAPL Sheen or Free-Phase NAPL in Soil Sampler
    - NAPL sheen will be a colorful iridescent appearance on the soil sample
    - NAPL may also appear as droplets or continuous accumulations of liquid with a color typically ranging from yellow to brown to black, depending on the type of NAPL
    - Creosote DNAPL (associated with wood-treating sites) and coal tar DNAPL (associated with manufactured gas plant [MGP] sites) are typically black and have a characteristic, pungent odor
    - Pure chlorinated solvents may be colorless in the absence of hydrophobic dye. Solvents mixed with oils may appear brown
    - Particular care will be taken to fully describe any sheens observed, staining, discoloration, droplets (blebs), or NAPL saturation
- Soil-Water Pan Test
    - A portion of the selected soil interval with the highest PID or FID reading above 100 ppm will be placed in a disposable polyethylene dish along with a small volume of potable or distilled water
    - The dish will be gently tilted back and forth to mix the soil and water, and the surface of the water will be viewed in natural light to observe the development of a sheen, if any
    - A small quantity of Oil Red O or Sudan IV hydrophobic dye powder will be added, and the soil and dye will be manually mixed for approximately 30 to 60 seconds and smeared in the dish to create a paste-like consistency
    - A positive test result will be indicated by a sheen on the surface of the water and/or a bright red color imparted to the soil following mixing with dye
- Soil-Water Shake Test
    - A small quantity of soil (up to 15 cc) will be placed in a clear, colorless, jar containing an equal volume of potable or distilled water (40-mL vials are well suited to this purpose, but not required)
    - After the soil settles into the water, the surface of the water will be evaluated for a visible sheen under natural light
    - The jar will be closed and gently shaken for approximately 10 to 20 seconds
    - Again, the surface of the water will be evaluated for a visible sheen or a temporary layer of foam
    - A small quantity (approximately 0.5 to 1 cc) of Oil Red O or Sudan IV powder will be placed in the jar
    - The sheen layer, if present, will be evaluated for a reaction to the dye (change to bright red color)
    - The jar will be closed and gently shaken for approximately 10 to 20 seconds
    - The contents in the closed jar will be examined under natural light for visible bright red dyed liquid inside the jar

  - A positive test result will be indicated by the presence of a visible sheen or foam on the surface of water, a reaction between the dye and the sheen layer upon first addition of the dye powder, a bright red coating on the inside of the vial (particularly above the water line), or red-dyed droplets within the soil

NOTE: *If NAPL is obviously present upon opening the soil sampler or evaluating the soil sample within the split-spoon sampler or direct-push liner sleeve, it is not necessary to perform a soil-water pan test or soil-water shake test. In addition, it is not necessary to perform both a soil-water pan test and a soil-water shake test; either test method is acceptable. The pan test may be preferred in some circumstances because the presence of a sheen may be easier to see on a wider surface.*

NOTE: *When using hydrophobic dye in the tests above, color will be assessed outdoors under natural light during the period between sunrise and sunset, regardless of the degree of cloud cover. The hydrophobic dye Safety Data Sheets (SDS) will be incorporated into the HASP and reviewed prior to use and the dyes will be carefully handled and disposed in accordance with regulations*.

SOIL SAMPLE COLLECTION FOR LABORATORY PROCEDURES

If not specifically identified in the FIP, soil samples will be selected for laboratory analysis based on:

1. Their position in relation to identified source areas
2. The visual presence of source residues (e.g., NAPL)
3. The relative levels of total VOCs based on field screening measurements
4. The judgment of the field coordinator

Samples designated for laboratory analysis will be placed in the appropriate containers.

Sample containers for VOC analysis will be filled first immediately following soil core retrieval to reduce loss of VOCs.

If samples will be collected for other analytical parameters, a sufficient amount of the remaining soil will then be homogenized as described below and sample containers will be filled for other parameters.

VOC samples will be collected as discrete samples using a small diameter core sampler (e.g., En Core® Sampler, Terra Core™ Sampler).

The En Core® Sampler is a disposable volumetric sampling device that collects, stores and delivers soil samples without in-field chemical preservation. The En Core® Sampler requires the use of a reusable T-handle.

The Terra Core™ Sampler is a one-time use transfer tool, designed to collect soil samples and transfer them to the appropriate containers for in-field chemical preservation (e.g., methanol).

The small diameter core sampler will be used according to the manufacturer's instructions (e.g., En Novative Technologies). Some regulatory agencies have specific requirements regarding VOC sample collection. Determine whether the oversight agency has specific requirements prior to commencing sampling and collect samples at appropriate interval as specified in the FIP/work plan (or equivalent). Samples may require homogenization across a given depth interval, or several discrete grabs (usually five) may be combined into a composite sample.

NOTE: *Samples for VOC analysis will NOT be homogenized or composited and will be collected as discrete samples as described above*.

The procedure for mixing samples is provided below.

1. Mix the materials in a stainless steel (or appropriate non-reactive material) bowl using a stainless-steel spoon (or disposable equivalents)
    a. When dealing with large sample quantities, use disposable plastic sheeting and a shovel or trowel
    b. NOTE: *When preparing samples for metals analyses, do not use disposable aluminum (or metal tools or trays other than stainless steel), as it may influence the analytical results*
2. Flatten the pile by pressing the top without further mixing
3. Divide the circular pile by into equal quarters by dividing out two diameters at right angles
4. Mix each quarter individually using appropriate non-reactive bowls, spoons and/or sheeting
5. Mix two quarters (as described above) to form halves, then mix the two halves to form a composite or homogenized sample
6. Place composite or homogenized sample into specified containers
7. Remaining material will be disposed of in accordance with project requirements and applicable regulations
8. Sample containers will be labeled with sample identification number, date, and time of collection and placed on ice in a cooler (target 4° Celsius)
9. Samples selected for laboratory analysis will be documented (chain-of-custody forms), handled, packed, and shipped in accordance with the procedures outlined in the FIP/work plan (or equivalent).

8 WASTE MANAGEMENT

Investigative-Derived Waste (IDW) generated during drilling activities, including soil and excess drilling fluids (if used), decontamination liquids, and disposable materials (plastic sheeting, PPE, etc.) will be stored on site in appropriately labeled containers (disposable materials will be contained separately) and disposed of properly. Containers must be labeled at the time of collection and will include date, location(s), site name, city, state, and description of matrix contained (e.g., soil, PPE). Waste will be managed in accordance with the *TGI – Investigation-Derived Waste Handling and Storage,* the procedures identified in the FIP or QAPP as well as state-, federal- or client-specific requirements. Be certain that waste containers are properly labeled and documented in the field log book.

9 DATA RECORDING AND MANAGEMENT

Management of the original documents from the field will be completed in accordance with the site-specific QAPP.

In general, drilling activities will be documented on appropriate field/log forms as well as in a proper field notebook. All field data will be recorded in indelible ink. Field forms, logs/notes (including daily field and calibration logs), digital records, and chain-of-custody records will be maintained by the field team lead.

Initial field logs and chain-of-custody records will be transmitted to the Arcadis Certified Project Manager (CPM) and Technical Lead at the end of each day unless otherwise directed by the CPM. The field team leader retains copies of the field documentation.

Additionally, all documents (and photographs) will be scanned and electronically filed in the appropriate project directory for easy access. Pertinent information will include personnel present on site, times of arrival and departure, significant weather conditions, timing of drilling activities, soil descriptions, soil boring information, and quantities of materials used.

In addition, the locations of soil borings will be documented photographically and in a site sketch. If appropriate, a measuring wheel or engineer’s tape will be used to determine approximate distances between important site features.

Records generated as a result of this TGI will be controlled and maintained in the project record files in accordance with project requirements.

10 QUALITY ASSURANCE

Quality assurance procedures shall be conducted in accordance with the Arcadis Quality Management System or the site-specific QAPP.

All drilling equipment and associated tools (including augers, drill rods, sampling equipment, wrenches, and any other equipment or tools) that may have come in contact with soil will be cleaned in accordance with the procedures outlined in the appropriate TGI.

Field-derived quality assurance blanks will be collected as specified in the FIP/work plan and/or site-specific QAPP, depending on the project quality objectives. Typically, field rinse blanks (equipment blanks) will be collected when non-dedicated equipment (e.g., split-spoon sampler, stainless steel spoon) is used during soil sampling. Field rinse blanks will be used to confirm that decontamination procedures are sufficient and samples are representative of site conditions. Trip blanks for VOCs, which aid in the detection of contaminants from other media, sources, or the container itself, will be kept with the coolers and the sample containers throughout the sampling activities and during transport to the laboratory.

Operate all monitoring instrumentation in accordance with manufacturer’s instructions and calibration procedures. Calibrate instruments at the beginning of each day and verify the calibration at the end of each day. Record all calibration activities in the field notebook.

11 REFERENCES

ASTM D1586 - *Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils*. ASTM International. West Conshohocken, Pennsylvania.

12 ATTACHMENTS

Attachment 1. Soil Boring Log Form

ATTACHMENT 1

Soil Boring Log Form

ARCADIS Design & Consultancy for natural and built assets

SOIL BORING LOG

Boring/Well ____________ Project ______________________________ Page ___ of ___

Site Location ______________________________ Drilling Started ____________

Total Depth Drilled ______ Feet Hole Diameter ______ inches Drilling Completed ____________

Type of Sample or Coring Device ________ Length and Diameter of Coring Device ____________ Sampling Interval ________ feet

Drilling Method ________ Drilling Fluid Used ________

Drilling Contractor ______________________ Driller ____________

Prepared By ______________________ Helper ____________

Core Recovery (feet)	PID Reading (ppm)	Sample Depth (ft bgs)	MUD		SAND					GRAVEL				**Udden-Wentworth Description:** principal components, (angularity, plasticity, dilatency); minor components, (angularity, plasticity, dilatency); sorting, moisture content, consistency/density, color, additional comments
			clay	silt	very fine	fine	medium	coarse	very coarse	granular	pebble	cobble	boulder	

ARCADIS Design & Consultancy for natural and built assets

SOIL BORING LOG (CONT'D)

Boring/Well ____________________ Prepared By ____________________ Page ____ of ____

Core Recovery (feet)	PID Reading (ppm)	Sample Depth (ft bgs)	MUD		SAND					GRAVEL				Udden-Wentworth Description: principal components, (angularity, plasticity, dilatency); minor components, (angularity, plasticity, dilatency); sorting, moisture content, consistency/density, color, addtl. Comments
			clay	silt	very fine	fine	medium	coarse	very coarse	granular	pebble	cobble	boulder	

TECHNICAL GUIDANCE INSTRUCTIONS: INSTALLATION OF PERMANENT SOIL VAPOR PROBES

Rev: 0

Rev Date: 12/12/2017

VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
0	12/12/2017			Technical Expert Name Procedure Librarian Name

APPROVAL SIGNATURES

Prepared by: 12/12/2017

Eric Epple

Date:

Technical Expert Reviewed by: 12/12/2017

Daniel Zuck, CPG

Date:

Technical Expert Reviewed by: 12/12/2017

Mitch Wacksman

Date:

1 INTRODUCTION

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

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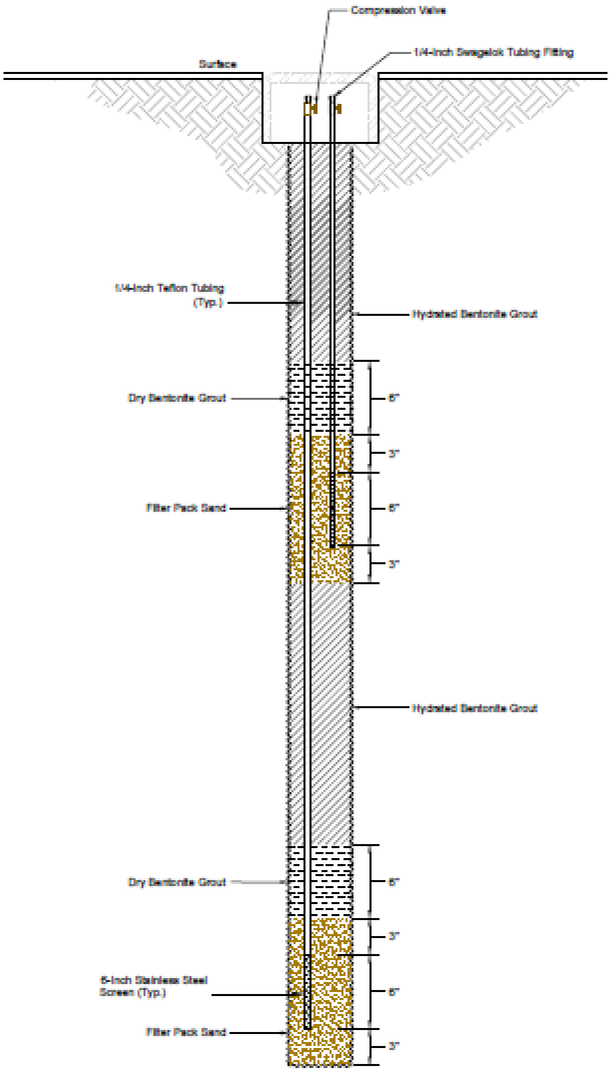
2 SCOPE AND APPLICATION

This technical guidance instructions (TGI) is recommended as a practical approach for the installation of permanent soil vapor sampling probes where the intent is to collect soil vapor samples over one or more sampling events. Nested sample soil vapor probes (i.e., multiple sample depths inside a single boring) can also be installed using these methods. Methods that can be used to advance the soil vapor probes installation include: hand auger, direct push, and auger. Rotary sonic drilling should be avoided. Soil vapor samples are often used during vapor intrusion investigations associated with subsurface impacts. Methods for soil vapor sample collection are described in Arcadis documents *TGI: Sub-Slab Soil Vapor or Soil Vapor Sampling Using Whole Air Canisters Analyzed Via USEPA Method TO-15* and *SOP: Soil-Gas Sampling and Analysis Using Sorbent Tubes*. The project team is responsible for ensuring this procedure meets all applicable guidance or regulations in the jurisdiction where work is performed. Receiving approval/concurrence from the leading regulatory agency for the project is suggested prior to implementation.

Water level gauging, geotechnical sampling, soil sampling, and soil logging are often executed during soil vapor sampling or as part of a vapor intrusion investigation. These activities are outside the scope of this TGI.

The depth of each soil vapor probe should be discussed and determined by the project team prior to beginning installation procedures. Under normal circumstances soil vapor probe should not be shallower than 5’ below ground surface. Soil vapor probe placement is project specific and based on site objectives, however as a general consideration soil vapor probe are often placed approximately 2.5’ above the highest known groundwater elevation.

An example of a finished soil vapor probe is presented in the schematic below.



3 PERSONNEL QUALIFICATIONS

Soil vapor probe installation activities will be performed by persons who have been trained in proper installation procedures. If geotechnical sampling, soil sampling, or soil logging are required as part of the scope of work it is critical that field personnel are appropriately trained for these additional tasks as described in the appropriate Standard Operating Procedures (SOPs) and/or Technical Guidance Instructions(TGI)s for those activities.

4 EQUIPMENT LIST

The following materials will be available during soil vapor probe installation and soil logging activities, as required:

- Site Plan figure presenting proposed soil boring/well locations
- Work Plan (or equivalent)
- Site-specific Health and Safety Plan (HASP) with task specific Job Safety Analysis (JSA(s))
- Personal protective equipment (PPE), as required by the HASP and JSA
- Traffic cones, delineators, caution tape, and/or fencing, as appropriate
- Probe tubing – new 1/4-inch or 3/8-inch outer diameter (OD) Teflon, Teflon-lined, or Nylon tubing
- Probe cap (to seal the tubing during equilibration) – Swagelok® part number SS-400-;
- Probe screen and anchor point – ½-inch OD stainless steel screen, such as the Geoprobe Systems® implant, or similar. Several screen lengths are available (1-inch, 6-inch, 14-inch, 21-inch), for discrete intervals required in Vapor Intrusion investigations, a 6-inch screen is typically recommended. Make sure the diameter of the tubing connection (i.e. barbed, Swagelok®) on the top side of the screen matches the diameter of the sample tubing used for the installation.
- Hand tools including appropriate-sized open-end wrenches (typically 9/16-inch, 1/2-inch, and 3/4-inch), tubing cutters, etc.
- Drum labels as required for investigation derived waste handling
- Labels for sample soil vapor probe tubing. Stamped metal tags affixed with zip ties are recommended
- MultiRae® four or five-gas meter for health and safety monitoring during drilling. A photoionization detector (PID) capable of parts per billion (ppb) readings (e.g., ppbRAE); and/or Landtec® GEM 2000 landfill gas meter (or equivalent) may be used instead of the five-gas meter when only VOC hazards exist
- Particulate Dust Meter (PDR-1000) as required by HASP
- Decontamination equipment (bucket, distilled or deionized water, cleansers (Alconox® or similar) appropriate for removing expected chemicals of concern, paper towels)
- Engineer’s tape/measuring wheel
- Weighted tape
- Digital camera or phone with camera (confirm client approval)
- Field notebook or Personal Digital Assistant (PDA)
- Appropriate field forms

If soil sampling or soil logging is required by the project additional materials may be required per the appropriate TGIs for these tasks.

Prior to mobilizing to the site, Arcadis personnel will contact the drilling subcontractor to confirm that appropriate equipment will be provided. Specifications of the installation equipment are expected to vary by project, and so communication with the driller is necessary to ensure that the materials provided will meet the project objectives. It is strongly recommended that Arcadis personnel provide sample tubing and not drillers.

Equipment/materials typically provided by the driller could include:

- Disposable plastic liners (when drilling with direct-push equipment);
- Drums for investigation derived waste;
- Drilling decontamination materials;
- Decontamination pad materials, if required;
- Boring equipment: hand auger, air knife with vac-truck, and/or drill rig equipped with direct push or rotary auger capability;
- Clean filter silica sand (#2 or larger);
- Granular bentonite and bentonite powder;
- Hydraulic or non-shrink cement grout;
- Tremie pipe with funnel or manual grout pump (1-inch OD PVC Pipe);
- Applicable materials to install water tight protective casing (flush or stand-pipe) to be discussed with drilling contractor prior to mobilization.

5 PRECAUTIONS

Pre-installation considerations:

- Underground utilities in the vicinity of the drilling areas must be delineated by the drilling contractor or an independent underground utility locator service prior to soil vapor probe installation. See AUS Utility Clearance HS Standard and HASP for detail. An AUS Utility Clearance Checklist must be completed and discussed with the project manager and team. There should be a clear understanding of subsurface conditions at the site, with a minimum of 3 good lines of evidence used.
- A field mobilization memo, work plan or scope of work should be reviewed and discussed with team members (office, field, and subcontractors) prior to implementation to ensure that all field logistics (e.g., access issues, health and safety issues, communication network, schedules, etc.) and task objectives are clearly understood by all.
- Soil vapor probe installation should not be performed within 48 hours after a significant rain event (defined as >1 inch of rainfall), as saturated soils could present a false saturated soil interval which could lead to inaccurate screen settings.
- Field personnel should not handle substances that could contain VOCs and lead to cross-contamination. These include marking paint, fuels and solvents or oils prior to handling soil vapor construction materials. Clean nitrile gloves should be used when handling any probe components (this include the drilling contractor). Field personnel should <u>not use sharpie markers</u> during installation or note taking.

- Gravel or dense clay may make direct push installation impracticable. Site geology should be discussed with the project technical lead and drilling contractor prior to field work.
- Ensure all soil vapor sampling probes are decontaminated and compatible with sample tubing prior to field mobilization. A two-stage decontamination process is preferred consisting of a soap wash that consists of distilled water and a non-phosphate detergent (Alconox® or similar), then a final rinse with distilled water. The equipment should be allowed to air dry before use.

Installation Considerations:

- Depth to Groundwater – soil vapor samples must be collected in the vadose zone (and above the capillary fringe). The bottom of the soil vapor probe must be above the capillary fringe. Depths of perched water zones should also be considered.
- If using an air knife for utility clearing, soils should be removed via hand auger or direct push beginning a minimum of 1 foot above the top of the sampling interval.
- Vapor probes can be finished at the ground surface with a flush mount road box (preferred) or with a stand pipe protective casing, similar to groundwater monitoring wells.
- Soil permeability - It may not be feasible to collect soil vapor from finer-grained or tight soils with little pore volume, such as clays or dense dry silts; if there are known clay layers present in the subsurface, these intervals should be avoided when setting vapor probes. During the installation process, it is advisable to collect a soil core from the proposed sampling interval prior to installing the soil vapor probe to identify the exact depth of the capillary fringe and/or determine where the most permeable soil layers are located. For sampling in tighter soils, it is recommended that permanent soil vapor implants be installed with a wider borehole diameter.

6 HEALTH AND SAFETY CONSIDERATIONS

Field activities associated with soil vapor probe installation will be performed in accordance with a site-specific HASP and applicable JSA, a copy of which will be present on site during such activities.

7 PROCEDURE

All drilling equipment must be decontaminated prior to use. Handle and store decontaminated soil vapor probes in a manner that prevents contamination, such as in a Ziploc® bag prior to use.

Inspect vapor probe parts and drilling equipment for wear and faulty parts. Have the driller replace probe tips, o-rings, adapters, and probe rods as appropriate.

The procedures below allow the installation of a soil vapor probe similar to that presented in the figure below. If multiple depths are to be installed, steps 3-6 are repeated, starting with the deepest sample interval.

1. Hand clear boring location as specified in HASP. If an air knife is used, discontinue use 1-foot above the top of the sample interval and finish boring using a hand auger or drill rig.

2. Record in the field log the soil type and any PID readings that were collected from soil cuttings removed during installation. If saturated soils are encountered, plug the interval(s) with granulated bentonite up through the last dry interval.
3. After reaching the desired depth, install sample screen and tubing. Place the screen and tubing into the open borehole or have the driller place inside the direct push drill pipe along with the push tip.
4. Once in place, install the required amount of clean silica sand (as specified in Step 3 based on soil type). Add clean silica sand to create an appropriate sand pack. Typically, there are 3 inches of clean silica sand both above and below a 6-inch sample screen, along with the clean silica sand surrounding the screen, creating a 12 inches total sampling interval.
5. Withdraw the drill pipe 6-inches and place 6 inches of dry granulated bentonite on top of the clean sand layer.
6. Add hydrated bentonite to 12-inches below the ground surface, or bottom of next sample interval (for nested installations). Install appropriate surface finish (i.e., bolting water tight road box, stick-up). If nested ports are not installed and the depth is greater than 10-feet below grade, a bentonite slurry grout may be placed above the granulated bentonite to 1-foot below grade.
7. Fill the remaining annulus within the road box with non-shrink grout cement to approximately 0.5-foot below ground surface, or enough to seal the tubing to the protective casing. A small amount of sand may need to be placed on top of the cement to ensure that the tubing does not make contact with the cement during curing.
8. Cut sample tubing long enough to allow enough length to reach a sample container or sorbent tube in the future. For flush mounted casings, 2-3 feet of tubing is recommended. For stand-pipe casing, make sure there is at least 6-7-feet of tubing extending above grade. Terminate sample tubing using an air tight plug or valve. Swagelok® or similar stainless-steel fittings are recommended.
9. Clearly label sample probe and protective casing with ID and depth. Stamped metal tags affixed with stainless zip ties are recommended.
10. Allow at least 24-hours for soil vapor probe equilibration and cement curing prior to leak testing and sampling. See applicable TGIs for these procedures.

8 WASTE MANAGEMENT

Investigation-derived wastes (IDW), including soil cuttings, decontamination liquids, and disposable materials (material packages, PPE, etc.), will be placed in clearly labeled, appropriate containers, or managed as otherwise specified in the Work Plan (or equivalent), field sampling plan (FSP), and/or IDW management guidance document.

9 DATA RECORDING AND MANAGEMENT

Drilling activities should be documented on appropriate field/log forms (see Attachment A) as well as in a proper field notebook and/or PDA. Additionally, all documents (and photographs) should be scanned and electronically filed in the appropriate project directory for easy access. Pertinent information will include personnel present on site, times of arrival and departure, significant weather conditions, timing of installation activities, soil descriptions, construction specifications (backfill material and borehole diameter, tubing length, screen details, seal type), and quantities of materials used. In addition, the locations of newly-installed soil vapor probes will be documented photographically or in a site sketch. If appropriate, a measuring wheel or engineer's tape will be used to determine approximate distances between important site features. The well location will be surveyed using the method specified in the site Work Plan (or equivalent).

10 QUALITY ASSURANCE

All drilling equipment and associated tools (including augers, drill rods, sampling equipment, wrenches, and any other equipment or tools) that may have come in contact with soil will be cleaned in accordance with the procedures outlined in the appropriate SOP. Soil vapor probe materials will also be cleaned prior to well installation.

11 REFERENCES

California Environmental Protection Agency (CalEPA) – Department of Toxic Substances Control (DTSC). 2012. Advisory – Active Soil Gas Investigations (https://www.dtsc.ca.gov/SiteCleanup/upload/VI_ActiveSoilGasAdvisory_FINAL_043012.pdf). April.

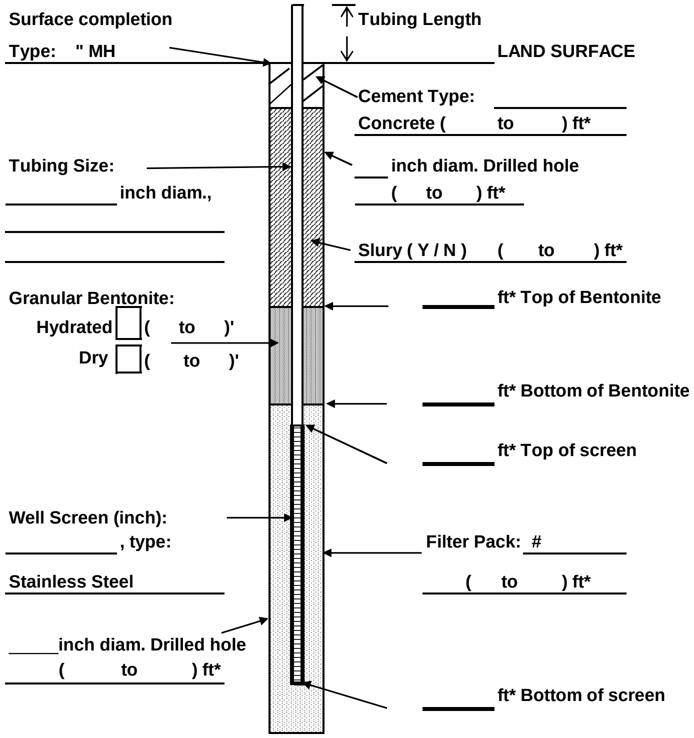
Interstate Technology Regulatory Council (ITRC). 2007. Technical and Regulatory Guidance. Vapor Intrusion Pathway: A Practical Guideline (http://www.itrcweb.org/documents/VI-1.pdf). January.

New Jersey Department of Environmental Protection (NJDEP) – Site Remediation and Waste Management Program. 2016. Vapor Intrusion Technical Guidance (http://www.nj.gov/dep/srp/guidance/vaporintrusion/vig_main.pdf?version_4). August.

United States Environmental Protection Agency (USEPA) – Office of Solid Waste and Emergency Response (OSWER). 2015. Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (https://www.epa.gov/sites/production/files/2015-09/documents/oswer-vapor-intrusion-technical-guide-final.pdf). June.

Arcadis

Permanent Soil Vapor Probe Construction Log



Surface completion
Type: " MH

Tubing Length

LAND SURFACE

Cement Type: ____________
Concrete (to) ft*

Tubing Size:
____________ inch diam.,
____
____

___ inch diam. Drilled hole
(to) ft*

Slury (Y / N) (to) ft*

Granular Bentonite:
Hydrated ☐ (to)'
Dry ☐ (to)'

____ ft* Top of Bentonite

____ ft* Bottom of Bentonite

____ ft* Top of screen

Well Screen (inch):
____________ , type:
Stainless Steel

Filter Pack: #
(to) ft*

_____inch diam. Drilled hole
(to) ft*

____ ft* Bottom of screen

Project Name and No.: ____________

SV Probe ID: ____________ Address: ____________

Town/City: ____________ State: ____________

Land-Surface Elevation and Datum:

____________ feet ☐ Surveyed ☐ Estimated

Coordinates- Northing: ____________ Easting: ____________

Installation Date(s): ____________

Drilling Contractor: ____________
(Diller/Helper)

Installation Method: ____________

Equipment Used: ____________

Groundwater Information:

Well ID: ____________

Well Screen Setting: ____________

Static Depth to Water: ____________

SV Probe Purpose: ____________

Remarks: Soils: ____________

**Measuring Point is Top of Well Casing Unless Otherwise Noted.

Prepared by ____________

TGI - ADMINISTERING HELIUM TRACER GAS LEAK TEST

Rev #: 1

Rev Date: October 14, 2016

APPROVAL SIGNATURES

Prepared by: Eric ______________________ Date: 10/14/2016

Eric Cathcart

Reviewed by: Mitch Wacksman ______________________ Date: 10/14/2016

Mitch Wacksman

I. INTRODUCTION

This Technical Guidance Instruction (TGI) document describes the procedures to conduct a building survey prior to indoor air sampling.

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II. SCOPE AND APPLICATION

When collecting subsurface vapor samples as part of a vapor intrusion evaluation, a tracer gas serves as a quality assurance/quality control method to verify the integrity of the vapor port seal and the numerous connections comprising the sample train. Without the use of a tracer, verification that a soil vapor sample has not been diluted by ambient or indoor air is difficult.

This Technical Guidance Instruction (TGI) focuses on using helium as a tracer gas. It should be noted that a field helium meter could register a false positive if methane is present in the subsurface. In this case an alternative method should be employed (i.e., water dam test), The protocol for using a tracer gas includes the following basic steps: (1) enrich the atmosphere in the immediate vicinity of the sample port where ambient air could enter the sampling train during sampling with the tracer gas; and (2) measure a vapor sample from the sample tubing for the presence of elevated concentrations (> 10%) of the tracer. A plastic pail, bucket, garbage can or even a plastic bag can serve as a shroud to keep the tracer gas in contact with the port during the testing.

There are two basic approaches to testing for the tracer gas:

1. Include the tracer gas in the list of target analytes reported by the laboratory; and/or

2. Use a portable monitoring device to analyze a sample of soil vapor for the tracer prior to sampling for the compounds of concern. (Note that tracer gas samples can be collected via syringe, Tedlar bag, etc. They need not be collected in SUMMA® canisters or mini-cans.)

This TGI focuses on monitoring helium using a portable sampling device, although helium can also be analyzed by the laboratory along with other volatile organic compounds (VOCs). Real-time tracer sampling allows the investigator to confirm the integrity of the port seals prior to formal sample collection.

During the initial stages of a subsurface vapor sampling program, tracer gas samples should be collected at each of the sampling points. If the results of the initial samples indicate that the port seals are adequate, the Project Manager can consider reducing the number of locations at which tracer gas samples are used in future monitoring rounds. At a minimum, at least 10% of the subsequent samples should be supported with tracer gas analyses. When using permanent soil vapor points as part of a long-term monitoring program, the port should be tested prior to the first sampling event. Tracer gas testing of subsequent sampling events may often be reduced or eliminated unless conditions have changed at the site. Soil gas port integrity should certainly be rechecked with Tracer gas if land clearing/grading activities, freeze thaw cycles, or soil desiccation may have occurred. Points should also be rechecked if more than 2 years have elapsed since the last check of that port.

III. PERSONNEL QUALIFICATIONS

Arcadis field sampling personnel will have current health and safety training, including 40-hour HAZWOPER training, site supervisor training, site-specific training, first aid, and cardiopulmonary resuscitation (CPR), as needed. Arcadis field sampling personnel will be competent in the relevant procedures and possess the required skills and experience necessary to successfully complete the desired field work. Arcadis personnel responsible for directing tracer gas testing must have previous experience conducting similar tests without direct supervision.

IV. EQUIPMENT LIST

The equipment required to conduct a helium tracer gas test is presented below:

- Appropriate PPE for site (as required by the Health and Safety Plan)
- Helium (laboratory grade)
- Regulator for helium tank
- Shroud (plastic bucket, garbage can, plastic bag, etc)

  - The size of the shroud should be sufficient to fit over the sample port. It is worth noting that using the smallest shroud possible will minimize the volume of helium needed; this may be important when projects require a large number of helium tracer tests.
  - The shroud will need to have three small holes in it. These holes will include one on the top (to accommodate the sample tubing), and two on the side (one for the helium detector probe, and one for the helium line).
  - The shroud should ideally enclose the sample port and as much as possible of the sampling train.
- Helium detector capable of measuring from 1 - 100% (Dielectric MGD-2002, Mark Model 9522, or equivalent)
- Tedlar bag
- Seal material for shroud (rubber gasket, VOC-free modeling clay, bentonite, etc) to keep helium levels in shroud high in windy conditions. Although the sealing material is not in direct contact with the sample if leakage does not occur, sealing materials with high levels of VOC emissions should be avoided, since they could contaminate a sample if a leak occurs.
- Sample logs
- Field notebook

V. CAUTIONS

Helium is an asphyxiant! Be cautious with its use indoors! Never release large volumes of helium within a closed room!

Field sampling equipment must be carefully handled to minimize the potential for injury and the spread of hazardous substances. All sampling personnel should review the appropriate health and safety plan (HASP) and job safety analysis (JSA) prior to beginning work to be aware of all potential hazards associated with the job site and the specific task. Field staff should review the attachment on safely handling compressed gas cylinders prior to commencing field work.

Compressed gas cylinders should be handled with caution; see attachment on the use and storage of compressed gasses before beginning field work.

Care should be taken not to pressurize the shroud while introducing helium. If the shroud is completely air tight and the helium is introduced quickly, the shroud can be over-pressurized and helium can be pushed into the ground. Provide a relief valve or small gap where the helium can escape.

Because minor leakage around the port seal should not materially affect the usability of the soil vapor sampling results, the mere presence of the tracer gas in the sample should not be a cause for alarm. Consequently, portable field monitoring devices with detection limits in the low ppm range are more than adequate for screening samples for the tracer. If high concentrations (> 10%) of tracer gas are observed in a sample, the port seal should be enhanced and fittings within the sampling train should be should be checked and/or tightened to reduce the infiltration of ambient air and the tracer test re-administered. If the problem cannot be rectified, a new sample point should be installed or an alternate sampling train used.

VI. PROCEDURE

The helium tracer test can be conducted when using temporary or permanent sampling points and inside or outside a facility. A visual of an example helium tracer gas test equipment set up in included as Figure 1.

1. Attach Teflon or nylon (Nylaflow) sample tubing to the sample point. This can be accomplished utilizing a number of different methods depending on the sample install (i.e., Swage-Lok or comparable fittings).
2. Place the shroud over the sample point and tubing.
3. Pull the tubing through hole in top of shroud. Seal opening at top of shroud with VOC free modeling clay.
4. Place weight on top of shroud to help maintain a good seal with the ground.
5. Insert helium tubing and helium detector probe into side of shroud. Seal both with modeling clay to prevent leaks.
6. Fill shroud with helium. Fill shroud slowly, allowing atmospheric air to escape either by leaving a gap where the shroud meets the ground surface or by providing a release value on the side of the shroud. Do not pressurize the shroud!
7. Use the helium detector to monitor helium concentration within the shroud from the lowest hole drilled in the shroud (bottom of the shroud nearest where the sample tubing intersects the ground). Helium should be added until the environment inside the shroud has > 40% helium.
8. Purge the sample point through the sample tubing into a Tedlar bag using a syringe equipped with a three-way leur lock valve. The purge rate should at least match the sample collection rate but not exceed 100 ml/min. Test the air in the Tedlar bag for helium using portable helium detector. If the point is free of leaks there should be very low helium in the purge air from the soil. The natural concentration of helium in the atmosphere is 0.00052% by volume and there are few if any natural sources of helium to soil gas.
9. If > 10% of the amount of helium present in the shroud is noted in purge air, rectify issues with the seal at the sample port and repeat the testing procedure. If the seal cannot be fixed, reinstall sample point.
10. Monitor and record helium level in shroud before, during and after tracer test.
11. Monitor and record helium level in purge exhaust.
12. At successful completion of tracer test and sample point purging, the soil vapor sample can be collected (if the helium shroud must be removed prior to sample collection be mindful not disturb the sample tubing and any established seals.

VII. WASTE MANAGEMENT

No specific waste management procedures are required.

VIII. DATA RECORDING AND MANAGEMENT

Measurements will be recorded on the sample logs at the time of measurement with notations of the project name, sample date, sample start and finish time, sample location, and the helium concentrations in both the shroud and the purge air before, during, and after tracer testing. Any problems encountered should also be recorded in the field notes.

IX. QUALITY ASSURANCE

Conduct quality assurance as required by the project-specific work plan and/or Quality Assurance Project Plan (QAPP).

ATTACHMENT: Compressed Gases – Use and Storage

In general, a compressed gas is any material contained under pressure that is dissolved or liquefied by compression or refrigeration. Compressed gas cylinders should be handled as high- energy sources and therefore as potential explosives and projectiles. Prudent safety practices should be followed when handling compressed gases since they expose workers to both chemical and physical hazards.

Handling

- Safety glasses with side shields (or safety goggles) and other appropriate personal protective equipment should be worn when working with compressed gases.
- Cylinders should be marked with a label that clearly identifies the contents.
- All cylinders should be checked for damage prior to use. Do not repair damaged cylinders or valves. Damaged or defective cylinders, valves, etc., should be taken out of use immediately and returned to the manufacturer/distributor for repair.
- All gas cylinders (full or empty) should be rigidly secured to a substantial structure at 2/3 height. Only two cylinders per restraint are allowed in the laboratory and only soldered link chains or belts with buckles are acceptable. Cylinder stands are also acceptable but not preferred.
- Handcarts shall be used when moving gas cylinders. Cylinders must be chained to the carts.
- All cylinders must be fitted with safety valve covers before they are moved.
- Only three-wheeled or four-wheeled carts should be used to move cylinders.
- A pressure-regulating device shall be used at all times to control the flow of gas from the cylinder.
- The main cylinder valve shall be the only means by which gas flow is to be shut off. The correct position for the main valve is all the way on or all the way off.
- Cylinder valves should never be lubricated, modified, forced, or tampered with.
- After connecting a cylinder, check for leaks at connections. Periodically check for leaks while the cylinder is in use.
- Regulators and valves should be tightened firmly with the proper size wrench. Do not use adjustable wrenches or pliers because they may damage the nuts.
- Cylinders should not be placed near heat or where they can become part of an electrical circuit.
- Cylinders should not be exposed to temperatures above 50 °C (122 °F). Some rupture devices on cylinders will release at about 65 °C (149 °F). Some small cylinders, such as

lecture bottles, are not fitted with rupture devices and may explode if exposed to high temperatures.

- Rapid release of a compressed gas should be avoided because it will cause an unsecured gas hose to whip dangerously and also may build up enough static charge to ignite a flammable gas.
- Appropriate regulators should be used on each gas cylinder. Threads and the configuration of valve outlets are different for each family of gases to avoid improper use. Adaptors and homemade modifications are prohibited.
- Cylinders should never be bled completely empty. Leave a slight pressure to keep contaminants out.

Storage

- When not in use, cylinders should be stored with their main valve closed and the valve safety cap in place.
- Cylinders must be stored upright and not on their side. All cylinders should be secured.
- Cylinders awaiting use should be stored according to their hazard classes.
- Cylinders should not be located where objects may strike or fall on them.
- Cylinders should not be stored in damp areas or near salt, corrosive chemicals, chemical vapors, heat, or direct sunlight. Cylinders stored outside should be protected from the weather.

Special Precautions

Flammable Gases

- No more than two cylinders should be manifolded together; however, several instruments or outlets are permitted for a single cylinder.
- Valves on flammable gas cylinders should be shut off when the laboratory is unattended and no experimental process is in progress.
- Flames involving a highly flammable gas should not be extinguished until the source of the gas has been safely shut off; otherwise it can reignite causing an explosion.

Acetylene Gas Cylinders

- Acetylene cylinders must always be stored upright. They contain acetone, which can discharge instead of or along with acetylene. Do not use an acetylene cylinder that has been stored or handled in a nonupright position until it has remained in an upright position for at least 30 minutes.
- A flame arrestor must protect the outlet line of an acetylene cylinder.

- Compatible tubing should be used to transport gaseous acetylene. Some tubing like copper forms explosive acetylides.

Lecture Bottles

- All lecture bottles should be marked with a label that clearly identifies the contents.
- Lecture bottles should be stored according to their hazard classes.
- Lecture bottles that contain toxic gases should be stored in a ventilated cabinet.
- Lecture bottles should be stored in a secure place to eliminate them from rolling or falling.
- Lecture bottles should not be stored near corrosives, heat, direct sunlight, or in damp areas.
- To avoid costly disposal fees, lecture bottles should only be purchased from suppliers that will accept returned bottles (full or empty). Contact the supplier before purchasing lecture bottles to ensure that they have a return policy.
- Lecture bottles should be dated upon initial use. It is advised that bottles be sent back to the supplier after one year to avoid accumulation of old bottles.

TGI - SUB-SLAB SOIL VAPOR OR SOIL VAPOR SAMPLING USING WHOLE AIR CANISTERS ANALYZED VIA USEPA METHOD TO-15

Rev #: 1

Date: September 18, 2016

SOP VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
1	9/18/2016	All	Updated Rev0	Mitch Wacksman

APPROVAL SIGNATURES

Prepared by: ______________________ Date: 9/18/2016
Eric Cathcart

Reviewed by: ______________________ Date: 9/18/2016
Mitch Wacksman (Technical Expert)

I. INTRODUCTION

This Technical Guidance Instruction (TGI) document describes the procedures to conduct a building survey prior to indoor air sampling.

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to all projects. It is the CPM's responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project's scope of work based upon site conditions, staffing expertise, regulation-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

II. SCOPE AND APPLICATION

This document describes the procedures for collecting exterior soil vapor or sub-slab soil vapor (herein referred to as "soil vapor") samples using whole air canisters for the analysis of volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method TO-15 (TO-15). This document assumes a sample port – either sub-slab or exterior soil vapor – has already been installed. This document covers the above ground assembly and sampling methods.

Method TO-15 uses a 1-liter 3-liter or 6-liter SUMMA® passivated stainless steel canister to collect a whole-air sample. The whole-air sample is then analyzed for VOCs using a quadrupole or ion-trap gas chromatograph/mass spectrometer (GS/MS) system to provide typical compound detection limits of 0.5 parts per billion volume (ppbv).

The following sections list the necessary equipment and detailed instructions for collecting soil vapor samples for VOC analysis.

III. PERSONNEL QUALIFICATIONS

Arcadis field sampling personnel will have current health and safety training, including 40-hour HAZWOPER training, site supervisor training, site-specific training, first-aid, and cardiopulmonary resuscitation (CPR), as needed. Arcadis field sampling personnel will be well versed in the relevant technical guidance instructions (TGIs) and possess the required skills and experience necessary to successfully complete the desired field work. Arcadis personnel responsible for leading soil vapor sample collection activities must have previous soil vapor sampling experience.

IV. EQUIPMENT LIST

The equipment required for soil vapor sample collection is presented below:

- 1,3, or 6 – liter stainless steel SUMMA® canisters (order at least one extra, if feasible) (batch certified canisters or individual certified canisters as required by the project);

- Flow controllers with in-line particulate filters and vacuum gauges; flow controllers are pre-calibrated to specified sample duration (e.g.,5-, 10, or 30- minutes) or flow rate (e.g., < 200 milliliters per minute [mL/min]); confirm with the laboratory that the flow controller comes with an in-line particulate filter and pressure gauge (order at least one extra, if feasible);

- 1/4-inch OD tubing (Teflon®, or similar);

- Extra 1/4-inch Swagelok front and back compression sleeves

- Decontaminated stainless steel Swagelok or comparable “T” fitting and ball or needle valve for isolation of purge leg of sample train;

- Stainless steel duplicate “T” fitting provided by the laboratory (if collecting duplicate [i.e., split] samples);

- 60-mL syringe equipped with a three-way leur lock valve;

- Appropriate equipment and materials for quality assurance testing as laid out in the respective quality assurance TGIs (i.e., helium leak testing, water dam testing, methane testing);

- Appropriate-sized open-end wrench (typically 9/16-inch and ½”);

- Tedlar® bag to collect purge air for venting outside a structure if working inside;

- Portable weather meter, if appropriate;

- Chain-of-custody (COC) form;
- Sample collection log (attached);
- Nitrile gloves;
- Work gloves; and
- Field notebook

V. CAUTIONS

The following cautions and field tips should be reviewed and considered prior to installing or collecting a soil vapor sample.

- Sampling personnel should not handle hazardous substances (such as gasoline), permanent marking pens (sharpies), wear/apply fragrances, or smoke cigarettes/cigars before and/or during the sampling event.

- Ensure that the flow controller is pre-calibrated to the proper sample collection duration (confirm with laboratory). Sample integrity can be compromised if sample collection is extended to the point that the canister reaches atmospheric pressure. Sample integrity is maintained if sample collection is terminated prior to the target duration and a measurable vacuum (e.g., 3 -7 – inches Hg) remains in the canister when sample collection is terminated.

- The integrity of the sample train will be tested in accordance with the project specific requirements. These procedures are contained in their own TGI documents and include helium leak testing, water dam testing, and methane screening.

- It is important to record the canister pressure, start and stop times, and sample identification on a proper field sampling form. You should observe and record the time/pressure at the start, and then again one or two hours after starting the sample collection. It is a good practice to lightly tap the pressure gauge with your finger before reading it to make sure it is not stuck. If the canister is running correctly for a 24-hour period, the vacuum will have decreased slightly after one or two hours (for example from 29 inches to 27 inches). Consult your project manager, risk assessor or air sampling expert by phone if the SUMMA canister does not appear to be working properly.

- Ensure that there is still measurable vacuum in the SUMMA® after sampling. Sometimes the gauges sent from labs have offset errors, or they stick.

- When sampling carefully consider elevation. If your site is over 2,000’ above sea level or the difference in elevation between your site and your lab is more than 2,000’ then pressure effects will be significant. If you take your samples at a high elevation they will contain less air for a given ending pressure reading. High elevation samples analyzed at low elevation will result in more dilution at the lab, which could affect reporting limits. Conversely low elevation samples when received at high elevation may appear to not have much vacuum left in them. http://www.uigi.com/Atmos_pressure.html.

- If possible, have equipment shipped a two to three days before the scheduled start of the sampling event so that all materials can be checked. Order replacements if needed.
- Requesting extra canisters and flow controllers from the laboratory should also be considered to ensure that you have enough equipment on site in case of an equipment failure.
- Check the seal around the soil vapor sampling port by using a tracer gas (e.g., helium) or other method established in the appropriate guidance document. See TGI library and project specific instructions for appropriate TGIs.

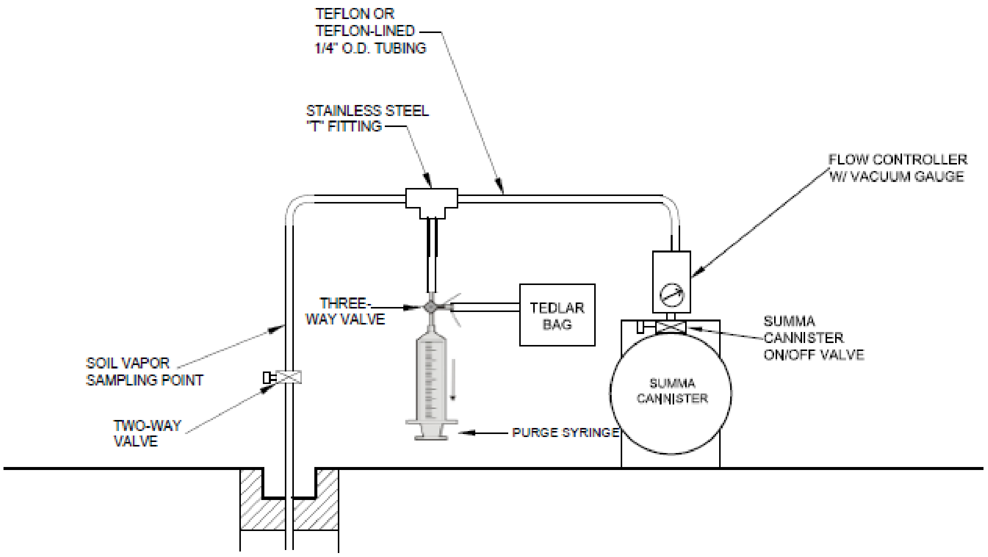
VI. HEALTH AND SAFETY CONSIDERATIONS

All sampling personnel should review the appropriate health and safety plan (HASP) and job safety analysis (JSA) prior to beginning work to be aware of all potential hazards associated with the job site and the specific task. Field sampling must be carefully performed to minimize the potential for injury and the spread of hazardous substances.

VII. SOIL VAPOR SAMPLE COLLECTION

Sample Train Assembly

The following procedures should be used to collect a soil vapor sample using a whole air canister (i.e., SUMMA canister). These methods can be used for both exterior soil vapor samples and interior sub-slab soil vapor samples collected from both permanent or temporary sample points installations. A schematic of the suggested sample train set up is included below



1. Assemble the sample train by removing the cap from the SUMMA canister and connecting the flow controller with in-line particulate filter and vacuum gauge. The flow controller attaches directly to the canister and dictates the sample duration. This piece will come preset from the laboratory.

2. Attach the canister and flow controller assembly to a stainless steel T-fitting using a short length of 1/4-inch OD Teflon tubing. This T-fitting adds a leg to the sample train that will be used to purge “dead” air from the sample train in order to collect a more representative sample.

3. Connect the purge syringe with three-way valve to one of the free ends of the T-fitting using a length of Teflon sample tubing, Swagelok compression fittings and silicon tubing.

4. Attach the Swagelok two-way valve to the remaining free end of the T-fitting using a short length of ¼-inch OD Teflon tubing. The two-way valve will be immediately adjacent to the sample point in the train assembly. This valve is used to isolate the sample train from the sample point prior to sampling in order to test the sample train’s integrity.

5. When collecting duplicate or other quality assurance/quality control (QA/QC) samples as required by applicable regulations and guidance, couple two SUMMA canisters using stainless steel Swagelok duplicate sample T-fitting supplied by the laboratory. Attach flow controller with in-line particulate filter and vacuum gauge to duplicate sample T-fitting provided by the laboratory.

6. Attach the terminal end of the two-way Swagelok valve to the sample port as appropriate. This may be done using the options below:

a. Use a section of silicon tube to connect the Teflon sample tubing to the barbed fitting of a Vapor Pin^{TM} port.

b. Use Swagelok compression fittings to connect Teflon tubing to sampling port. Teflon tape should never be used on Swagelok compression fitting connections.

c. Wrap the Teflon tubing with Teflon tape to seal around the slab then use VOC free clay to further seal around the slab if using temporary points.

Sample Documentation

1. Record on the sample log and COC form the flow controller number with the appropriate SUMMA® canister number.

2. Record the following information on the sample log, if appropriate (contact the local airport or other suitable information source [e.g., site-specific measurements, weatherunderground.com] to obtain the information):

   a. wind speed and direction;

   b. ambient temperature;

   c. barometric pressure; and

   d. relative humidity.

3. Take a photograph of the SUMMA® canister and surrounding area.

Sample Collection

1. Perform a leak-down-test by closing the two-way valve to the sample port. Open the three-way valve to the syringe and pull a vacuum. Quickly close the three-way valve and record the pressure indicated on the gauge connected to the canister. If there are no leaks in the system this vacuum should be held. If vacuum holds proceed with sample collection; if not attempt to rectify the situation by tightening fittings.

2. Open the two-way valve and purge the soil vapor sampling port and tubing with the portable sampling pump. Purge approximately three volumes of air from the soil vapor sampling port and sampling line using a flow rate of 200 mL/min. Purge volume is calculated by the following equation “purge volume = 3 x Pi x inner radius of tubing^2 x length of tubing. Purge air will be collected into a Tedlar bag to provide that VOCs are not released into interior spaces. Perform quality control method tests concurrently, as appropriate

3. Close the three-way valve to the syringe in order to isolate this leg of the sample train.

4. Open the SUMMA® canister valve to initiate sample collection. Record on the sample log (attached) the time sampling began and the canister pressure.

   If the initial vacuum pressure registers less than -25 inches of Hg, then the SUMMA® canister is not appropriate for use and another canister should be used.

5. Check the SUMMA canister approximately half way through the sample duration and note progress on sample logs.

Termination of Sample Collection

1. Arrive at the SUMMA® canister prior to the end of sample collection.

2. Record the final vacuum pressure. Stop collecting the sample by closing the SUMMA® canister valves. The canister should have a minimum amount of vacuum (approximately 5 inches of Hg or slightly greater).

3. Record the date and local time (24-hour basis) of valve closing on the sample collection log and COC form.

4. Disconnect sample tubing from the sample port; replace any coverings or abandon as appropriate to mitigate tripping hazards.

5. Remove the particulate filter and flow controller from the SUMMA® canister, re-install the brass plug on the canister fitting, and tighten with the appropriate wrench.

6. Package the canister and flow controller per Department of Transportation regulations for return shipment to the laboratory. These regulations can be found at the Transportation Safety Program’s Team Site on the Source. The SUMMA® canister does not require preservation with ice or refrigeration during shipment.

7. Complete the appropriate forms and sample labels as directed by the laboratory (e.g., affix card with a string).

8. Complete the COC form and place the requisite copies in a shipping container. Close the shipping container and affix a custody seal to the container closure. Ship the container to the laboratory via overnight carrier (e.g., Federal Express) for analysis.

VIII. WASTE MANAGEMENT

No specific waste management procedures are required.

IX. DATA RECORDING AND MANAGEMENT

Measurements will be recorded on the sample log at the time of measurement with notations of the project name, sample date, sample start and finish time, sample location (e.g., GPS coordinates, distance from permanent structure [e.g., two walls, corner of room]), canister serial number, flow controller serial number, initial vacuum reading, and final pressure reading. Field sampling logs and COC records will be transmitted to the Project Manager.

X. QUALITY ASSURANCE

Duplicate samples should be collected in the field as a quality assurance step per project requirements. Generally, duplicates are taken from 10% of samples, but project specific requirements should take precedence.

XI. REFERENCES

DiGiulio et. al. 2003. Draft Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA TO-15 to Support Vapor Intrusion Investigations. http://www.cdphe.state.co.us/hm/indoorair.pdf (Attachment C)

Di Giulio et. Al. 2006. Assessment of Vapor intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples. USEPA. EPA/600/R-05/147.

New York State Department of Health (NYSDOH). 2005. DRAFT “Guidance for Evaluating Soil Vapor Intrusion in the State of New York” February 23, 2005.

APPENDIX B

Chevron Soil Vapor and Indoor Air Sampling Technical Toolkit

Soil Vapor & Indoor Air Sampling Technical Toolkit

Version 1.8

This work was funded by Chevron Environmental Management Company and performed by Chevron Energy Technology Company, Health, Environment and Safety Group, Environmental Unit.

Tom Peargin, Senior Staff Hydrogeologist
Ravi Kolhatkar, Staff Environmental Hydrogeologist
Hong (Emma) Luo, Environmental Hydrogeologist

Environmental Unit
Health, Environment and Safety Department
Chevron Energy Technology Company

March 20, 2013

TABLE OF CONTENTS

FIGURES

TABLES

1 INTRODUCTION

The Chevron (CVX) Soil Vapor Sampling Technical Toolkit provides technical guidance to suppliers conducting vapor migration pathway (VIP) investigations at petroleum hydrocarbon contaminated sites. The toolkit is a collation of identified "best practices" in planning and conducting soil vapor surveys. Maintaining consistency in best practices across the Chevron portfolio is a primary driver for this toolkit, as this will enhance the defensibility of the soil vapor data gathered at these sites. The toolkit is intended to remain "evergreen": that is, as new best practices are developed, the toolkit will be edited to incorporate those developments. In this manner the most up-to-date technologies and methods can be implemented in the field.

The toolkit is primarily focused on petroleum hydrocarbon impacted sites; that is, sites where biodegradation of vapor phase contaminants can play a role in attenuation. However, many elements of the toolkit can also be applied at sites where biodegradation of vapor phase contaminants is unlikely to occur (e.g., chlorinated solvent contaminated sites). The toolkit is organized into sections focusing on soil vapor sampling probes, soil vapor sampling, analytical techniques, and data reporting. Diagrams are included to provide further description of the processes and equipment discussed. Further technical information and advice is available by contacting the Chevron Energy Technology Co. VIP Team members:

Tom Peargin, Senior Staff Hydrogeologist, tpeargin@chevron.com, 925-842-5586
Ravi Kolhatkar, Staff Environmental Hydrogeologist, kolhatrv@chevron.com, 713-954-6082
Hong (Emma) Luo, Environmental Hydrogeologist , Emma.Hong.Luo@chevron.com, 713-954-6101

2 SOIL VAPOR PROBE INSTALLATION

All standard protocols required before initiating any drilling activities (e.g., regulatory permits, underground utility markings, clearances from overhead lines etc.) need to be followed when preparing the site for installation of soil vapor probes.

2.1 Permanent vs. Temporary Probes

Permanent soil vapor sampling probes are required for soil vapor surveys conducted for human health risk assessment to ensure that samples from a given location can be collected repeatedly. **Chevron recommends permanent probes to increase the accuracy and technical defensibility of samples used to assess human health risk.** Temporary probes (which are sampled only once) are suitable only for non-human health risk assessment soil vapor samples, such as in support of delineation of a vapor phase contaminant plume.

Permanent probes also facilitate repeated sampling rounds if this is deemed necessary to represent soil vapor concentrations during different seasons, during high and low water table conditions, or during periods of frozen ground. If a sample is only taken once at a particular point, the result could be misleading due to variable water table elevations, and the variation of NAPL/air interaction that comes with these seasonal changes.

2.2 Borehole Clearance

The use of air knife for borehole clearance is not recommended for direct emplacement of soil vapor sampling points at shallow depths (e.g., 5 ft). This is because air knife utilizes high pressure air and is expected to significantly disturb the soil vapor profile around the installation, and it could take weeks to months for the profile to re-equilibrate (API 2005). Instead, hand auguring is preferred for installing soil vapor sampling points at a shallow depth of 5 ft.

Air knife borehole clearance (typically performed to a depth of 8 ft) is acceptable for installation of deeper soil vapor sampling points (10 ft deep or greater). Following the borehole clearance, these deeper points could be installed using either direct push or hollow stem auger methods.

2.3 Water Table Elevation and Soil Vapor Sampling Probe Depth

Prior to installing permanent soil vapor probes it is critical to review the historical range of site groundwater elevation data to determine the proper depth for probe installation. Soil vapor sampling probes should ideally be installed so that the vapor sampling screen is situated 2 to 3 ft above the historical high groundwater elevation, which will reduce the likelihood that the probe will be submerged during periods of elevated groundwater, and will enable the probe to sample that interval of the subsurface with the potentially highest soil vapor volatile organic compound (VOC) concentrations.

The US EPA and most state regulatory guidance require a minimum of 5 ft depth for the shallowest soil vapor sampling probes. For sites with shallow water tables (high water table elevation is within 5-7 ft of the surface) it is acceptable to place the soil vapor sampling probe at a depth of 5 ft, even though this depth may cause the point to be submerged, or occluded with water from the capillary fringe during certain portions of the season. **Placing soil vapor sampling points at depths less than 5 ft. should be performed only on an exception basis and with approval of Chevron Project Manager**. **When approval has been granted to install a soil vapor sampling point shallower than 5 ft, it is critical to take extra care to ensure there are no leaks due to potential short-circuiting from the surface.**

2.4 Single vs. Multilevel Soil Vapor Sampling

Chevron recommends installation of multilevel probes in order to understand the source of soil vapors (impacted vadose zone soil vs. impacted groundwater) and to qualitatively evaluate the depth and degree of biodegradation of soil vapors in the vadose zone (using concentration versus depth profiles of VOCs, methane, oxygen and carbon dioxide). In addition, several VI guidance documents (e.g., CA DTSC, 2011) recommend multilevel probe installation, with the sample containing the highest concentration (regardless of depth) used for comparison to Tier I screening tables.

EPA and most state regulatory guidance documents state that soil vapor samples used for vapor intrusion screening should not be collected shallower than 5 ft depth. Agency guidance states that this is intended to minimize the potential for short-circuiting of atmospheric air into soil vapor samples. **See section 2.3 for sites where depth to groundwater is about 5 ft or less from the ground surface or less**. The deepest probe should be installed 2 to 3 ft above the historical high groundwater elevation, with shallower probes installed at defined intervals above the deepest probe (e.g., 5 ft intervals). For example, at a site where the seasonal high groundwater elevation is 18 ft below grade, probes could be emplaced at depths of 15, 10, and 5 ft below grade.

2.5 Soil Vapor Probe Installation using Hollow-stem Augers

A conventional drill rig equipped with a hollow-stem auger should be used for permanent soil vapor probe installation. Use of methods such as rotosonic, air rotary, or mud rotary drilling methods can influence soil vapor sample results and/or alter the physical properties of the subsurface adjacent to the sampling probe, although they may be necessary due to stratigraphic limitations (e.g., cobbles). **If rotosonic, air rotary, or mud rotary drilling methods are deemed necessary they should be utilized only on an exception basis and with approval of the Chevron Project Manager**.

2.5.1 Soil Sample Collection

During drilling, soil cores should be collected for lithologic and stratigraphic description, and, **if required by CEMC project managers, for evaluation of soil porosity and moisture content (ASTM D2216) for potential vapor transport modeling**. Soil samples should be collected and preserved for off-site chemical and physical analyses. Sampling interval selection is site specific, based on stratigraphic heterogeneity and Chevron recommends continuous logging and taking soil sample at each lithology or planned screen interval. Chemical analyses are chosen based on the site contaminants, but typically would include TPHg and TPHd (EPA 8015B) and BTEX (EPA 8260B) for gasoline release sites. Undisturbed soil samples should be collected in stainless steel or brass liners and capped with Teflon® sheeting and plastic end caps and placed in re-sealable plastic bags. The liners should then be stored in iced coolers and transported to a certified laboratory under chain-of-custody documentation.

2.5.2 Soil Vapor Sampling Probe Construction

After the borehole is drilled to its maximum depth, the deepest soil vapor sampling probe is installed (Figure 1). Each sampling probe tip should be approximately 6 inches long, and of small diameter (¼-inch is typical) to minimize dead space within the probe. Screens constructed of stainless steel and PVC are acceptable, Each 6-inch-long screen tip is vertically centered in a 1-ft long interval containing standard sand pack, resulting in 3 inches of sand being above and below each screen. It is important to correctly size the sand pack for the probe screen diameter. Each sand pack is covered with a 1 ft interval of dry granular bentonite, which is then covered with ≥ 2 ft of hydrated granular bentonite slurry to the bottom of the next sand pack (i.e., the next sampling interval). The dry granular bentonite is emplaced immediately above the sand pack to ensure that hydrated granular bentonite slurry does not flow down to the probe screen and seal it off from the adjacent soil. Following the emplacement of 1 ft of dry granular bentonite immediately

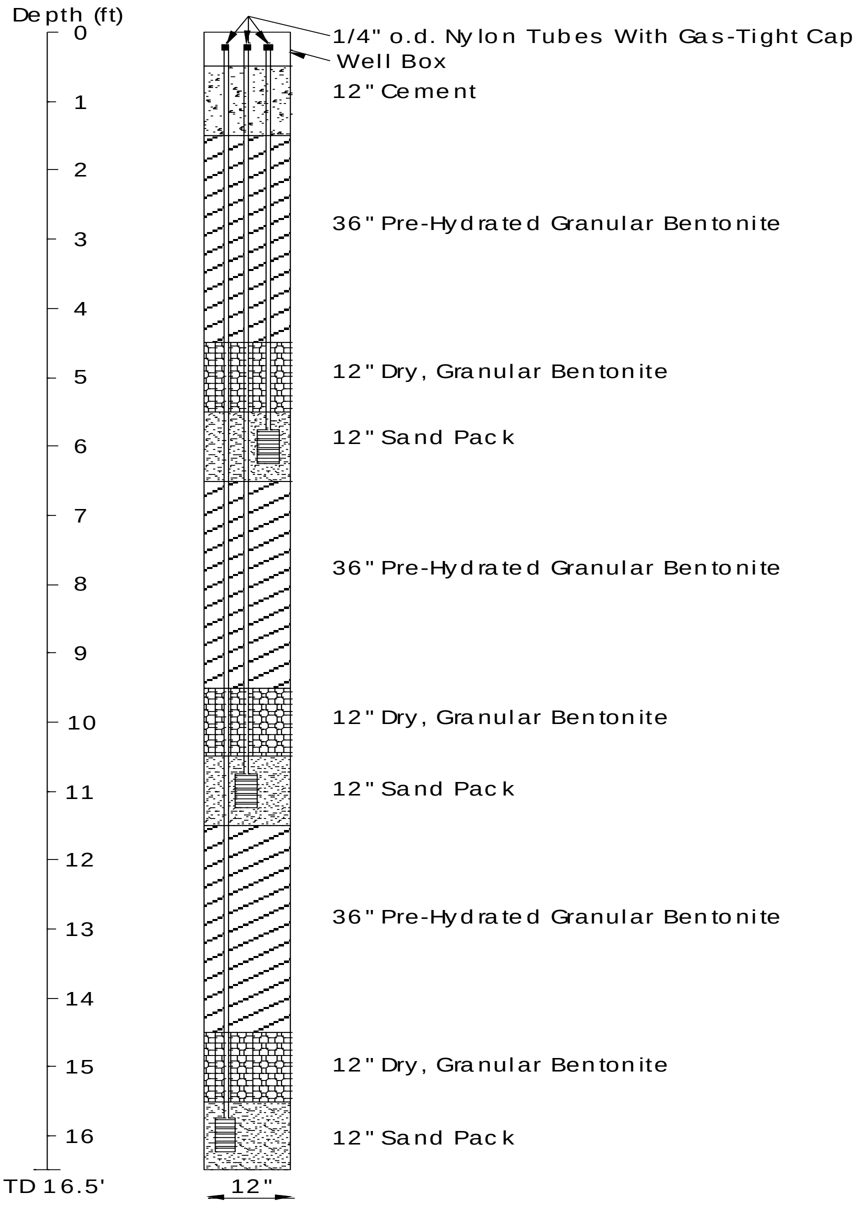


Figure 1. Augered, permanent multilevel soil vapor sampling probe (by Chuck Zuspan, ETC)

above the uppermost sampling interval (sand pack), the remainder of the borehole should be filled with hydrated granular bentonite slurry (mixed at the surface and poured in) and, at the top, a 1-ft cement cap. A flush-mounted, locked utility vault of sufficient size to contain the tubing lines should be set in the cement cap.

Probes should have screen and end caps fitted with a Swagelok® fitting connected to the upper end cap. Use chromatography-grade 316 stainless steel compression fittings to ensure that fitting materials are not a source of VOCs. Tubing should be ¼-inch outer diameter Teflon® or Nylon or stainless steel. Hose clamps, push-on barbed fittings, and other types of connectors should be avoided as they may not provide an air-tight seal. Two studies have been done to evaluate different types of tubing. Air Toxics (Hayes et. al, 2006) conducted tests of three tubing types (Teflon®, nylon, PEEK) that showed little difference in the tubing type with respect to cleanliness and inertness to the chemicals tested. Low-level blanks were detected in nylon, but the values were far below required soil-gas risk-based screening levels. An earlier study presented at a conference in 2004 (Ouellette, 2004) compared the adsorption of a hydrocarbon standard by five tubing types (Teflon®, nylon, polyethylene, vinyl and flexible Tygon®). Nylon and Teflon® showed insignificant adsorption (<10%), but the others showed higher adsorption, especially the flexible tubing, where losses of the tested hydrocarbon standard were up to 80 percent. **For this reason, flexible tubing materials such as Polyethylene, vinyl and Tygon® are not acceptable for use at Chevron sites**.

Also very important is where the tubing is stored and how it is handled. Any type of tubing will become contaminated and contribute to false positives if it is stored near volatile chemicals. For this reason, all tubing should be new, carefully stored, and blank tested (see QA/QC section).

Each of the tubing lines must be clearly and permanently marked at the land surface to denote its corresponding screened interval. Do not use markers. Each tube must be fitted with a gas-tight, Swagelok® valve or cap at the ground surface to eliminate the potential for atmospheric air getting into the tubing. If a cap is used, it must be removed before sampling, which creates an opportunity for atmospheric air entry to the probe, so the period between removing the cap and assembling the sampling train should be as brief as possible and purging (discussed later in this toolkit) is required before sampling.

2.6 Soil Vapor Sampling using Direct-push Techniques

Single or multilevel soil vapor sampling can be performed with a direct-push rig (e.g., Geoprobe®) in certain soil type (e.g. non-clayey soil). These rigs can install permanent soil vapor sampling probes, or can be used to collect soil vapor data during a direct-push where no permanent probe is installed. **Chevron requires human health risk assessments to be performed with data collected from permanent soil vapor sampling probes** but soil vapor samples collected from tubing during a single push (temporary direct-push, e.g. Post-Run Tubing System) can be useful to delineate areas of elevated soil vapor concentrations, and can help identify location and depth of permanent soil vapor sampling probes if needed (but not for human health risk assessment).

2.6.1 Temporary Direct-Push Soil Vapor Sampling (Post-Run Tubing System)

Soil vapor surveys using direct push techniques (non-permanent installations) are sometimes useful in determining the depth and extent of localized petroleum hydrocarbon vapors, especially when sourced from residual soil contamination in the vadose zone.

Once delineated, these data can be used to determine the location of permanently installed sampling probes for human health risk assessment.

Temporary direct-push soil vapor concentration data does not represent the most technically defensible sampling available, since it is difficult to insure that samples from temporary direct-push probes have not leaked to the surface (which might yield false-negative data), and the technique precludes collection of multiple samples over time to verify the presence or absence of temporal variation. **As a result, use of temporary direct-push soil vapor sample data in assessing human health risk should only be considered on an exception basis and with approval of Chevron Project Manager.**

The Post-Run Tubing (PRT) system involves the use of a drive point holder (located just above the drive point) that also serves as the soil vapor sampling probe (Figure 2). Both expendable and retrievable drive point/drive point holder systems are available. The PRT system allows for soil vapor samples to be obtained from multiple depths from a single borehole during a single sampling event. First, the drill rods and drive point/drive point holder are pushed to the shallowest designated depth. Then, an adapter connected to Teflon® or nylon (Nylaflow®) sampling tubing that extends to the ground surface is attached to the drive point holder. Leakage of atmospheric air through the drive rods into the drive point holder (the vapor sampling probe) is prevented by o-rings that are part of the adaptor assembly. After obtaining a soil vapor sample (described in Section 3), the adaptor/tubing assembly is removed, and the tubing is discarded. The drive point/drive point holder is then pushed deeper into the subsurface until the next designated sampling depth is reached. The adaptor/tubing assembly, with a new piece of tubing attached, is then connected to the drive point holder and the soil vapor sampling process is repeated. This process can be repeated over multiple depths, but if lower concentrations exist beneath high concentrations, the samples in the deeper interval may have a positive bias. With the expendable PRT system, the drive point/drive point holder assembly remains in the subsurface when the rods are withdrawn, while for the retrievable PRT system the entire apparatus is removed.

There is no sand pack or hydrated bentonite seal needed in the borehole annulus. However, there is potential for cross-contamination resulting from contaminants being pushed downward by the drilling rods. Avoid lateral movement of the drive rods during the push and sampling processes, and if the probe is deflected by cobbles, or wavering of the rig, it is preferable to remove the probe, and retry to obtain a linear unwavering entry to avoid leakage along the outer wall of the casing. To avoid potential surface leakage due to these difficulties, a surface seal of hydrated granular bentonite is recommended with the PRT system.

2.6.2 Permanent Direct-push Soil Vapor Sampling Probes

Direct-push techniques to install permanent soil vapor sampling probes involves use of a truck-mounted hydraulic ram to push hollow metal rods equipped with a drive point to a designated depth. Table 1 describes the advantages and disadvantages of using direct push techniques over hollow-stem auger for installing soil vapor probes.

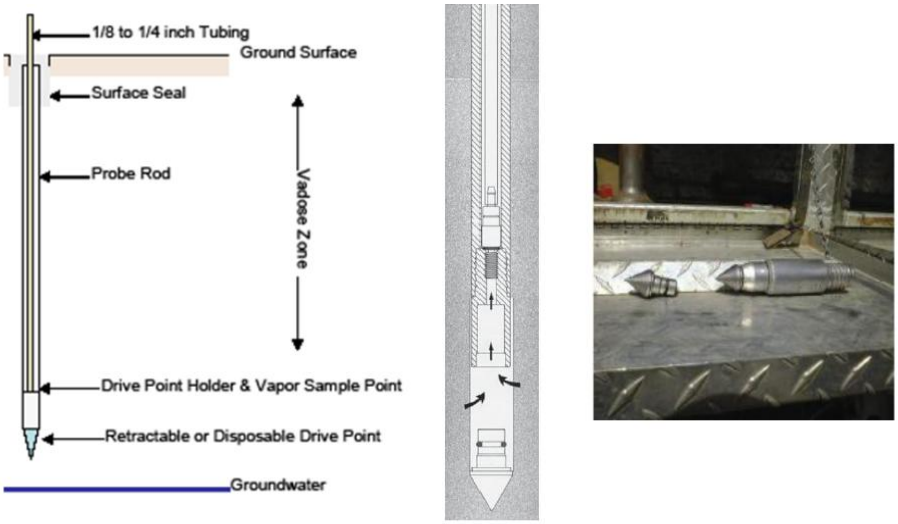


Figure 2. Direct-push soil vapor sampling probe (PRT; Geoprobe ®)

Pro Direct Push	Con Direct Push
• Usually quicker and cheaper to install and cause less disruption to subsurface, therefore requires far less equilibration time prior to sampling. • Optimal for shallow-depth (up to about 20 ft), or in conjunction with an on-site, mobile laboratory enabling real-time adjustments to the sampling program. • Allows soil vapor sample collection very close to the building minimizing concern about interpolation or extrapolation of data to conditions beneath the building	• Multi-level sampling requires larger footprint. • Likely to fail in some lithologies (e.g. soil with cobbles, calcified sediments etc). • Difficult to obtain soil samples for chemical and physical analyses. • Difficult to install sand packs and bentonite seals through direct push rods.

Table 1. Pros and Cons for direct-push technique over hollow-stem auger for probe installation.

The soil vapor sampling probes consist of an implant of tubular stainless steel screen with a length of 6 inches, outer diameter of ¼ inch, and typically a pore size of 0.0057 inches. Note that the implant is not retrievable and at site closure must be abandoned in place. The implant is connected to a Teflon® or nylon (Nylaflow®) sampling tube of sufficient length to reach the ground surface. A direct-push rig (i.e., Geoprobe®) is used to push a series of drive rods to a designated depth. When this depth is reached, the implant is slid down the bore of the drive rods and is attached to the drive point at the bottom. Then the drive rods are removed, leaving the implant and drive point in the subsurface (Figure 3).

As the drive rods are removed the borehole may collapse around the sampling probe. Also, as the drive rods are removed a sand pack can be installed around the implant, followed by a hydrated granular bentonite seal extending to the ground surface. A surface seal of hydrated granular bentonite is applied where the drive rods meet the ground surface.

One of the potential drawbacks of soil vapor sampling probe implants is the difficulty in installing a sand pack and hydrated granular bentonite seal through the drive rods as they are removed from the borehole. As a result, lateral movement of the sampling tubes and drive rods should be avoided to prevent atmospheric air from entering the soil vapor sample. Soil vapor probes installed using direct push technique as described above are acceptable for human health risk assessment.

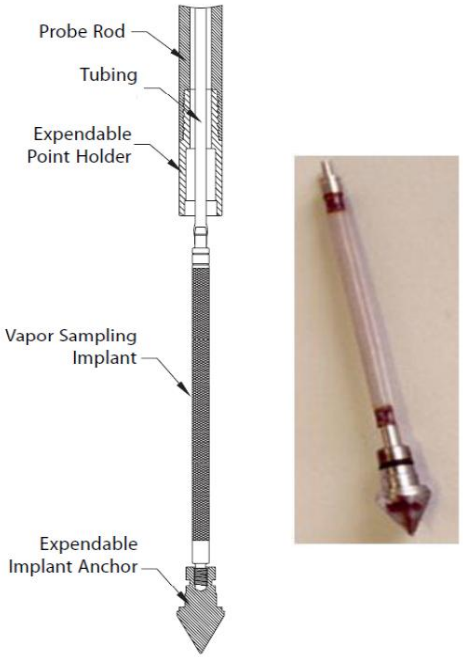


Figure 3. Direct-push soil vapor sampling probe (implant type; Geoprobe®).

3 NEAR-SLAB SOIL VAPOR SAMPLING

The proper collection of near-slab soil vapor samples is a critical step in producing reliable concentration data. A number of factors are important in ensuring the reliability of the data; each is discussed below. Note that some regulatory agencies have specific guidelines for soil vapor collection that may differ from those within the Chevron Sampling Toolkit. **Where possible, Chevron recommends following the Sampling Toolkit protocols unless specifically directed to do otherwise by local agencies.**

Prior to beginning a near-slab soil vapor sampling program, it is important to obtain the correct sampling equipment and to write a site-specific sampling plan. Written documentation of the equipment used and the sampling processes employed is critical.

Consistency in equipment and sampling processes between probe locations and between multiple sampling events is important in order to minimize potential discrepancies in soil vapor concentration data.

Chevron recommends that near-slab soil vapor probes be installed at a minimum two depths (when possible based on depth to groundwater) at each sampling location: one at a shallow depth (i.e. near ground surface, e.g. 5 ft bgs) and one at a deeper depth (i.e. close to groundwater capillary fringe). This is to help identify the likely source of soil vapors (from the groundwater or from contaminated soils in the vadose zone). Also, given the typical screening rationale for near slab soil vapor sampling, in general Chevron recommends conducting one round of near-slab soil vapor sampling (unless there is significant groundwater fluctuation at the site).

3.1 Sampling Equipment

Numerous types and combinations of tubing, connectors, valves, and pumps have been used for soil vapor sampling. The tubing, gauges, and pump (if any) should be connected by tubing that is flexible, air-tight, and has a low capacity for adsorption of VOC's. **Teflon® or Nylon tubing (marketed under the NylaFlow® name) with ¼-" OD is recommended. Tygon®, rubber, and Polyethylene tubing should not be used. Swagelok® type connectors/fittings (Figure 4) should be used for all connections between tubing and other sampling components to ensure that fitting materials are not a source of VOCs.** These connectors are air-tight and reliable. Hose clamps, push-on barbed fittings, and other types of connectors should be avoided as they may not provide an air-tight seal. The lack of an air-tight seal can allow air to enter the sample, thus diluting the vapor concentrations and compromising the integrity of the sample. Leak testing (discussed in Section 3.4) is used to ensure the integrity of soil vapor samples.

A vacuum must be created in order to draw the soil vapor to the ground surface. The vacuum can be created by a battery powered pump, a syringe, or a sampling container that is under a vacuum (such as a Summa™ canister, discussed below). **If a pump is used, it is important to ensure that the sample collection point is on the intake side of the pump.** This will prevent any contaminants present in the pump from being drawn

Figure 4. Swagelok® connectors (image from equipsales.com)

into the vapor sample. A typical soil vapor sampling train using a helium shroud (for leak detection) and a flow-calibrated pump (for purging) is shown in Figure 5.

Although a number of sampling containers have been used for soil vapor sample collection, including Summa$^{\text{TM}}$ canisters, Tedlar$^{\circledR}$ bags, Cali-5-Bond$^{\circledR}$ bags, syringes, and sorbent sampling tubes, at Chevron sites, **Summa$^{\text{TM}}$ canisters (Figure 6) are required for soil vapor samples, for they provide samples with the highest possible integrity when collected using the appropriate sampling protocol.** Tedlar$^{\circledR}$ bags are not recommended, primarily because of the concerns about integrity of soil vapor samples beyond a holding time of 48 hours as well as presence of trace levels of VOCs in new Tedlar bags (Hartman, 2006). Soil vapor samples can be collected in syringes for on-site soil vapor analyses *only* where the sample is immediately injected into a gas chromatograph (GC).

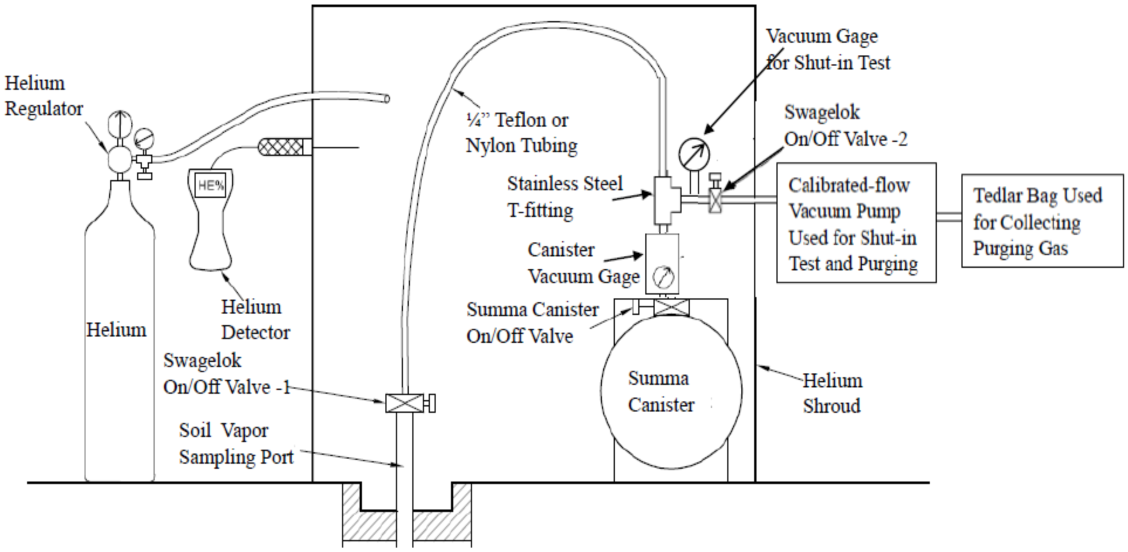


Figure 5. Picture of a sampling system for soil gas sampling train leak test, soil gas purging and sampling (Adapted from ARCADIS)

A Summa$^{\text{TM}}$ canister is a stainless steel, gas-tight, opaque and laboratory-certified clean sample container with a passivated internal surface. The passivation process utilizes electro polishing and chemical deactivation to create a chemically inert surface. Containers range in size from < 1 L to 15 L and are provided by the analytical laboratory. Canisters are typically certified clean at the 10 % level (i.e. every one out of 10 canisters is certified after cleaning) or at the 100 % level (i.e. every canister is certified after cleaning). The cleaning process is the same for both certification levels and utilizes dilution, heat, and high vacuum. The certification process utilizes EPA Method TO-15 (GC/MS) to ensure that VOC concentrations are <1 ppb$_{\text{V}}$. **It is acceptable to use canisters certified at the 10% level for soil vapor sampling activities. However, the use of 100 % certified canisters is required for sub-slab soil vapor, indoor air and ambient air sampling in order to minimize potential interferences in analyzing low**

VOC concentrations for human health risk assessment. The required size of the canister depends upon the laboratory's capabilities. **Before ordering canisters, contact the laboratory to inquire about what size canisters are required to meet the reporting levels necessary to meet site data quality objectives.**

After cleaning, the canister is evacuated until a vacuum of 29.9 in Hg is obtained. The canister will hold a vacuum of greater than 25 in Hg for more than 30 days. The maximum holding time for canisters following sample collection varies from state to state. Check the locally applicable regulations to determine the maximum holding time for the site in question. As discussed below, the soil vapor sample flows into the canister due to the pressure gradient between the vadose zone and the canister. A flow controller/particulate filter, provided by the laboratory, controls the vapor flow rate into the canister. Be aware that the flow controller may be defective and it is best practice to have some extra available.

Figure 6. 6 L Summa^{TM} canister with ¼" stainless steel bellows valve (image from Air Toxics Ltd.)

Regardless of the design of the sampling equipment, there are a number of important topics to address in order to obtain reliable soil vapor concentration data. These topics are discussed below.

3.2 Field Activities Prior to Sampling/Documentation

Written documentation of field conditions during sampling is required. This includes weather conditions (temperature, barometric pressure, wind direction and speed, humidity, degree of cloud cover); surface soil conditions (presence of standing water, wet soil, irrigation activities, etc.) and groundwater elevations. Some agencies are concerned that the rain will affect the validity of the sample (> 0.5 inch precipitation during 24-hour period as in California EPA, 2012). Under wet soil conditions, one should follow the state soil vapor sampling guidance for detailed requirements on soil gas sampling or consult with Chevron project manager if no such state guidance exists. Maintain detailed field records of all activities, conditions, and sampling processes, including names of field personnel, dates and times, etc. It is important to maintain consistency in sampling activities between sampling events (e.g., purging volume and purge rate, sampling volume, leak testing methods, equipment used). Carefully plan all sampling activities to maintain consistency between sampling events and to avoid errors that can affect soil vapor concentrations.

3.3 Equilibration Time

The installation of soil vapor sampling probes can introduce oxygen into anaerobic portions of the vadose zone. An equilibration time is required to account for the effects of soil vapor probe installation; this allows for equilibration of vapor component concentrations between the probe and subsurface (API 2005). Soil vapor samples should not be obtained until after the equilibration time is reached. **Probes installed using hollow stem or hand auger methods should be allowed at least 48 hours of equilibration time while probes installed using direct-push techniques should be allowed at least two hours of equilibrium time (California EPA, 2012).**

3.4 Evaluating Leaks in Sampling Train

Leakage of atmospheric air into the sampling equipment during sampling can compromise sample integrity and dilute measured soil vapor hydrocarbon concentrations, possibly to the point of an incorrect decision such as failing to identify a concentration of concern (i.e., a “false negative”). Contaminants in ambient air can also enter the sampling system and be interpreted as originating from diffusive transport from a subsurface source (i.e., a “false positive”). Air leakage can occur at the land surface into the probe and, more typically, through loose fittings in the above-ground sampling equipment.

Leakage of air into the below-ground sampling system is unlikely if the probe has been properly constructed and a proper bentonite or concrete surface seal (described earlier) has been emplaced. Temporary (direct-push) probes are most susceptible to leakage around the rods. Sub-slab soil vapor sampling probes also are susceptible to leakage of indoor air due to the difficulties of ensuring a proper seal between stainless steel probe and slab concrete. Sampling equipment must be thoroughly inspected to ensure tight fittings between all components. Be aware that leakage locations may not be obvious. Elevated O_2 concentrations in samples from deeper depths in multi-level probes may be indicative of leakage, but in some cases this alone would not provide definitive evidence for leakage. If O_2 concentrations remain high with increasing depth and petroleum hydrocarbon concentrations are also high, this is evidence that leakage is likely to be occuring. **To minimize the potential for leakage, the soil vapor sampling rate should be kept at < 200 mL/min per EPA guidance (Section 3.6).** Repair or replacement of the sampling probe may be necessary if it is determined that leakage through the probe is occurring. Refer to state or regional guidance to determine if a prescribed course of action applies for probe replacement.

After the soil vapor sampling ports and probes are constructed and installed and soil vapor has equilibrated, leaks in the sampling train should be tested, including a complete shut-in test and system leak test.

3.4.1 Shut-in Test

After the soil vapor probe construction, soil vapor sampling probe installation, and sufficient time for the soil vapor to reach equilibrium, a shut-in test should be conducted to check for leaks in the above-ground sampling system. The equipment set-up for shut-in test is also shown in Figure 5. In this case, the helium shroud and the Tedlar bag may not be needed. To conduct a shut-in test, assemble the above-ground valves, lines and fittings downstream from the top of the probe as shown in Figure 5. The Swagelok valve-1 and Summa Canister valve are kept closed, evacuate the system to a minimum measured vacuum of about 100 inches of water using a purge pump and close Swagelok valve-2. Observe the vacuum gauge connected to the system with a “T”-fitting for at least one minute or longer. If there is any observable loss of vacuum, adjust the fittings until the vacuum in the sample train does not noticeably dissipate. After the shut-in test is validated, the sampling train should not be altered. The vacuum gauge should be calibrated and sensitive enough to indicate a water pressure change of 0.5 inches. If the shut-in test failed, then specific measures are needed such as tightening all the fittings and repeating the test until it is validated before proceeding to the next test.

3.4.2 Leak Test

3.4.2.1 Leak test tracer

A tracer is used to test for an ambient air leakage into the sampling system. Numerous tracer compounds have been referenced in regulatory and industry guidance documents, including isopropanol, isobutene, propane, butane, helium, and sulphur hexaflouride. **Chevron does not recommend use of isopropanol** because, due to its high vapor pressure, even a small leak will result in laboratory dilutions that will compromise the data quality objectives (i.e. reporting limits higher than screening levels). **Chevron does not recommend use of isobutene, propane, or butane** as leak detection tracers because their purity cannot be easily verified, resulting in a likelihood of low level impurities such as BTEX compounds. **Chevron does not recommend use of sulphur hexaflouride** because it has a very high greenhouse gas potential, and therefore difficult to acquire and use as a tracer compound. **Chevron does not recommend use of Freon** because it is not possible to determine the degree of leakage that has taken place and there is a possibility that Freon is present in the soil gas due to ubiquitous use of Freon as coolant for air conditioning units. **Chevron recommends use of laboratory grade helium as a leak detection tracer gas where practical to do so, based on accessibility.** Helium is readily available, has low toxicity, does not disrupt analytical measurements, will not be found at fuel contaminated sites, and has a high purity. Small volume bottles of helium can be purchased at party stores but contain industrial grade helium, which may contain organic compounds as impurities. **Lab grade helium is recommended**, and will require time for the sampling crew to acquire through the analytical laboratory or an alternate source. A possible drawback of helium is that its small molecular size may cause it to permeate the sampling materials more readily than larger VOC molecules (Hartman, 2006). Of all the tracer compounds described in various regulatory guidance documents, only the leak detection method using helium gas provides a quantitative estimate of leakage rate. **If lab-grade helium supply is scarce (as has been recently reported), Chevron recommends using 1,1-difluroethane (1,1-DFA) as an alternative leak tracer gas, with prior concurrence from EMC project manager and ETC.**

Small amounts of sample train leakage may be permissible, subject to regulatory standards and analytical limits applicable to the site. **For sites located in California, Chevron follows the CAEPA guidance (CAEPA, 2012) and recommends a maximum leak percentage of 5% be used to determine sample validity. For sites located outside California, Chevron recommends a maximum leak percentage of 10% be used to determine sample validity**. This is consistent with the VI guidance in New Jersey (NJDEP 2012). The presence of any leakage should be recorded, as should all techniques used in the leak testing process. Maintain consistency of the leak testing process over multiple sampling events.

Where multi-level soil vapor probes are intended to acquire soil vapor concentrations to be used either as a basis for an attenuation factor screening step, or as a source term for Johnson & Ettinger modeling, leakage of as much as 10% may allow back calculation of an adjusted soil vapor concentration. However, this may not be possible if the overall compounds of interest concentrations are low, and the reporting limits have been increased above acceptable screening values due to the necessity to dilute the sample to avoid loading the GC column with tracer gas. In such cases, the probes must be re-sampled.

3.4.2.2 Leak test using helium as a tracer

The New York State Department of Health (NYSDOH, 2006) has prepared guidance for using helium as a tracer gas, suggests construction of a shroud around the sampling probe but not the sampling train. To test the integrity of the whole sampling train, **Chevron recommends building a shroud to cover the entire sampling train (probe to Summa canister) in order to detect possible leaks in all fittings and tubing of the sampling system (Figure 5 and Figure 7).** This enables detection of helium ingress into the sampling train and can be used to estimate the leakage rate as shown at the end of this section. The shroud should be filled with helium before purging the sampling point. It is important to ensure that the pressure in the shroud is close to atmospheric pressure, so that normal sampling conditions exist (NYSDOH, 2006). **Introducing helium from a pressurized cylinder for several seconds will generally be sufficient to create concentrations in the shroud up to 10% by volume or higher. The helium concentration in the shroud should be monitored and maintained relatively stable at the target concentration, i.e. 10% or higher (CAEPA, 2012) during the course of soil vapor sampling.** This can be done with a helium detector connected to a port on the shroud. Portable detectors are available for rental. It is required that the selected portable detector have a minimum helium detection limit of 0.5% by volume.

The following guidance on constructing the helium shroud is adapted from the EPRI Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air (EPRI, 2005). The shroud can be in the form of a clear plastic container (e.g. large Tupperware™ or Rubbermaid® container or a tent made of clear plastic sheet large enough to surround the soil vapor probe and valves and fittings at the top of the probe as in Figure 5 and Figure 7. The shroud will typically have three ports, one for helium addition, one port for monitoring helium concentration inside the shroud and another port for the ¼-inch Nylon tubing coming out of the shroud for the vacuum pump located outside the shroud.

Chevron recommends using one Summa canister under a helium shroud for leak-test (helium checking in the soil gas sample) and soil vapor sampling (chemical analysis in the soil vapor sample) simultaneously. A separate Summa Canister is not needed for leak-test. Figure 5 illustrates conducting a simultaneous leak-test and soil vapor sampling from a sub-slab soil vapor sampling point. In this case, the Tedlar bag may not needed and the Swagelok valve 2 remains closed. Turn on the Summa canister valve to collect a soil vapor sample for analysis of helium and chemicals in the lab. To access the sampling train, the shroud can be lifted and the canister valves opened. The shroud can then be placed back again on the ground/floor and filled with helium within a half-minute or less. The samples typically take at least 5 minutes to fill, so the first few seconds of no helium in the shroud is not problematic as long as the helium concentration in the shroud is maintained relatively stable at the target concentration.

The analytical laboratory should be notified that helium is to be used as a leak detection tracer prior to sampling. The integrity of the soil vapor samples can be assessed by estimating the % leakage as follows.

$$\%leakage = \frac{\text{helium concentration in the soil vapor sample (ug/m}^3\text{)}}{\text{average helium concentration measured inside the shroud (ug/m}^3\text{)}} \times 100$$

3.5 Purging

The US EPA conducted a comparison of chlorinated hydrocarbon soil vapor concentrations collected utilizing a broad range of purge volumes (0.5 to 100L) at a site with relatively coarse-grained soils and found no significant differences based on the purge volumes (DiGiulio et al 2006b). McAlary and Creamer (2006) performed similar experiments at a Chevron research site for high concentration petroleum hydrocarbon vapors and also observed no effect in sample concentration as a function of purge volume. While it is not clear to what degree purging may affect sample concentration, all regulatory guidance requires stagnant air in the sampling tubes be removed prior to sample collection. This is believed to ensure that the soil vapor sample is representative of actual soil vapor concentrations.

Field notes containing information about the above-ground sampling equipment and below-ground tubing length and inner diameter should be used to calculate the "dead volume" to be purged. The "dead volume" should also include the borehole sand pack. The volume of a sample container, such as a Summa^{TM} canister (which is not used during purging), should not be included in this calculation. **Check to make sure that all connections, fittings, etc. are tightly fit in the sampling equipment prior to purging**.

Figure 7. Helium shroud used for leak-testing soil vapor sampling train.

Figure 5 also shows the equipment set-up recommended by Chevron when purging a soil vapor sampling port. In some cases, the regulatory agency requires one to develop the number of purging volumes. In that case, as shown in Figure 5, a battery powered, flow-calibrated pump and a Tedlar bag can be used to purge the system and determine the number of required purge volumes. The purging gas collected by the Tedlar bag is analyzed on site for chemical concentrations till the concentrations become stabilized. From the volume of gas purged which is measured by the flow-calibrated pump, the number of purging volume can be determined and recorded and then the soil vapor sampling can proceed. If the number of purging volumes is not required, Tedlar bag only serves as a collector of purging gas to protect the environment from potential adverse impact from the contaminants in the soil vapor.

The maximum flow rate for purging should not exceed the flow rate limit used for subsequent sampling (< 200 mL/min). Guidance documents from different agencies recommend different purge volumes, ranging from 1 to 10 purge volumes (CSDDEH, 2002; API, 2004, CAEPA, 2012). **Chevron recommends that 3 volumes be purged unless otherwise required by applicable guidance.** The purge test data (calculated purge volume, purging rate, and duration of purging) should be recorded for each soil vapor sampling point. It is important to ensure that the same purge volumes and rates are used at a given probe for each sampling event.

For fine-grained soils large sample volumes are often not possible or difficult to collect. Also, if large sample volumes are attempted, the chances of leakage in the sampling train increase. A larger sample volume also increases the uncertainty about the location of soil vapor sampled. Given these uncertainties, it is best to minimize the "dead volume" that needs to be purged in the sampling train.

3.6 Sample collection

There are numerous combinations of tubing, connectors, pumps, and sampling containers that have been used for soil vapor sample collection. As noted above, the design of the sampling equipment should be such that the dead volume is minimized in order to keep the necessary purge volume small. In all cases, a vacuum is used to draw soil vapor from the subsurface to the sample container. Note that equipment must be decontaminated prior to sampling, shut-in test should be performed before purging and sampling, and leak-testing should be performed during the sampling process. An example of the equipment arrangement used for soil vapor purging (with a flow-calibrated pump) and sampling (with Summa^{TM} canister) is shown previously in Figure 5. In Figure 5, to collect a sample, Swagelok valve 1 and the Summa canister valve should be open and Swagelok valve 2 should be closed. The soil vapor sample collected will be analyzed for helium (for leak test), COCs and fixed gases.

The exact procedure used in obtaining a soil vapor sample will vary as a function of the equipment used, but the following considerations are important to ensure that a high quality sample is collected.

3.6.1 Vacuum And Flow Rate Considerations

The vacuum and resulting sampling flow rate should be minimized in order to limit enhanced volatilization of VOCs from water and soil into the soil vapor sample. Consistency in vacuum and sample flow rates should be maintained between sampling probes and over multiple sampling events. The vacuum and flow rate should be documented in the field notes. A flow rate between 100 ml/min and 200 ml/min and a vacuum less than 100 inches of water (approx. 7.3 in Hg at 4^{o}C) should be maintained during purging and sampling (California EPA, 2012).

The Summa^{TM} canister system utilizes a flow controller to control the flow rate. The flow controller contains a critical orifice flow restrictor intended to maintain a relatively constant flow rate over a 0.5 to 8 hour period, even though the vacuum in the canister is decreasing over that time (which would otherwise cause the flow rate to concurrently decrease). A vacuum gauge is built in to the flow controller to monitor sampling progress. The laboratory (e.g., Eurofins Air Toxics Inc.) sets up the flow controller for the flow rate specified. Table 2 shows the range of flow rates for given sampling time intervals. A particulate filter is built into the flow controller device which serves to prevent particulates from fouling the flow controller or entering the Summa^{TM} canister. The recommended sampling time interval for soil vapor samples is approximately 30 minutes, but in any case the flow rate should not exceed 200 mL/min.

Sampling Interval (hrs)	0.5	1	2	4	8	12	24
6 L Canister	167	83.3	41.7	20.8	11.5	7.6	3.5
1 L Canister	26.6	13.3	6.7				

Table 2. Flow rates (mL/min) for given sampling time intervals using the flow controller (from Eurofins Air Toxics Inc.)

3.6.2 Other Sampling Considerations

Once the above listed topics have been addressed, after making certain that all connections between the Summa^{TM} canister, flow controller, and all other portions of the sampling equipment are tight, and arrangements have been made with the analytical laboratory regarding sample shipment and analysis, soil vapor sampling can commence. Sampling of all probes should preferably be completed within a one day time period, with a maximum collection period of one week. Sample collection from a purged soil vapor probe should begin as soon as possible once purging is completed. Leak-testing should be performed concurrently with sampling as described above. To begin sampling, open the valve on the Summa^{TM} canister. As the canister fills, observe the vacuum gauge on the flow controller to ensure that the vacuum in the canister is decreasing over time. If the flow controller is working correctly, the planned sampling completion time will be reached when the canister vacuum has decreased to 5 in Hg. Note that low permeability soils characterized by low soil vapor flow rates may require sampling to cease before the canister vacuum has decreased to 5 in Hg.

Quality control (QC) of soil vapor samples must be addressed through the collection of equipment blanks and field duplicates. An equipment blank should be collected at the site during sampling activities by collecting a sample of clean air or nitrogen through the probe materials before installation in the ground. Analysis of the equipment blank can provide information on the cleanliness of new materials and/or the effectiveness of decontamination procedures used in the field. Clean stainless steel, Nylon or Teflon® tubing and a certified regulator should be used. Only 100% certified canisters (the sample canister and the source canister/cylinder, if applicable) should be used to collect equipment blank. **Trip blanks were previously recommended, however with the use of 100% certified Summa^{TM} canisters, trip blanks are not necessary**.

At least one duplicate sample should be obtained each day of sampling, or from at least 10 % of the samples obtained. A duplicate sample should be collected by using a splitter (such as a T fitting) located between the flow controller and sample canisters, with separate sampling tubes connecting the splitter to two Summa^{TM} canisters as shown in Figure 8. The flow controller must be set such that the flow rate from the sampling probe is < 200 mL/min; this will double the required sampling time since two canisters are being filled simultaneously.

After sample collection, canisters must not be chilled since contaminants may condense in the canister at low temperatures. Make certain that all samples are correctly and clearly labeled. Follow standard chain-of-custody procedures, including noting the final canister vacuum and serial numbers of the canisters and flow controllers. The laboratory checks the vacuum on receipt to ensure that there were no leaks during shipment. See Section 3.1 for canister maximum holding time information. Document all procedures, sampling times, conditions, problems, etc

If the initial assessment of subsurface soil vapors indicates potential for vapor intrusion to indoor air, further characterization will usually require entry into the affected building(s) to conduct sub-slab vapor sampling and concurrent indoor and ambient outdoor air sampling as described in the following sections. EMC environmental attorneys will be able to help in getting the necessary access agreements before these sampling activities commence.

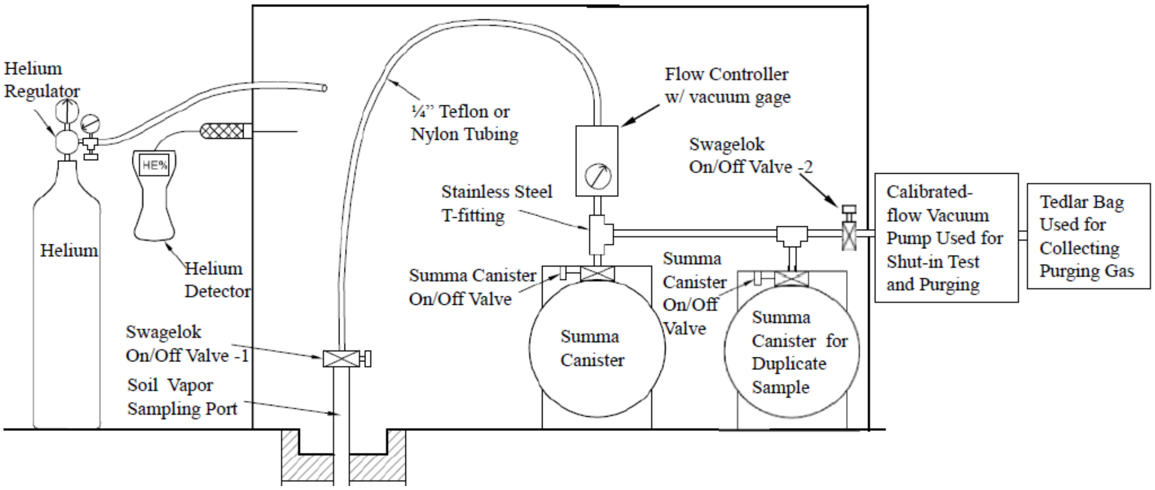


Figure 8. Soil vapor sampling train using two Summa canisters for a sample and a duplicate sample (Adapted from ENSR)

4 SUB-SLAB VAPOR SAMPLING

4.1 Sub-slab soil vapor probe installation

Sub-slab vapor sampling probes allow for collection of soil vapor data from directly beneath the slab from a layer of granular fill material that is highly permeable and well-drained for structural purposes. These samples are useful to evaluate a possible relationship to indoor air samples and are recommended if indoor sampling is deemed necessary. It is critical to obtain building construction details as much as possible (i.e., slab thickness, depth and type, presence of vapor barrier, location of utility trenching etc) to appropriately locate sub-slab vapor sampling locations. **Sub-slab sampling may not be possible when groundwater or a partially saturated capillary fringe is present directly below the slab.** Do not drill through the slab if it is suspected that the penetration could allow groundwater to enter the building during high water table conditions. Also, it is important to determine prior to drilling if the slab has a vapor barrier; if so, **make sure the vapor barrier is not punctuated during the drilling**. **Drilling through tension slabs is not recommended.** Tension slabs contain embedded steel cables that have been pulled tight after the concrete has cured. The tension in the cables strengthens the slab and helps prevent cracking. The slab can be damaged if a cable is cut during drilling.

Petroleum hydrocarbons are amenable to aerobic biodegradation. Therefore, a conservative approach supports obtaining soil vapor samples at the center of the slab where lowest oxygen concentrations in soil are likely to occur (California EPA 2011) and away from utility conduits,. **At least two probes should be placed, for foundation area**

up to 5000 ft^2 with one located in the center of the slab, and the other in the likely direction of potential subsurface impacts, (California EPA, 2005, 2011). US EPA recommends several probes for single-family dwellings to assess spatial variability (e.g., 3 to 5; DiGiulio, 2006a).

Prior to drilling holes in a slab, identify and mark utilities coming into the building from the outside (e.g., gas, water, sewer, electrical lines) and determine any internal locations where utilities penetrate the slab (e.g., furnace, water heater, circuit breaker box, water or sewer lines). **Avoid installing sub-slab monitoring points where the utilities penetrate the slab as these may be potential entry points for downward oxygen migration through the slab. Also, avoid installing sub-slab points along straight-line points where utility trenches may have been installed beneath the slab during building construction.**

Prior to fabrication of sub-slab vapor probes, remove carpeting from the drilling location, if present. This can be done by cutting a small ½ inch square flap that can be glued back down after the probe is installed. Obtain any available information (e.g., from the owner, construction plans) to determine the thickness of the slab. **Do not drill a pilot hole to assess the thickness of a slab.** As illustrated in Figure 9, use a rotary hammer drill to create a “shallow” (e.g., 2.5 cm or 1 inch deep) “outer” hole (e.g., 2.2 cm or 7/8 inch diameter) that partially penetrates the slab. Do not completely penetrate the slab with the shallow hole. Use a small portable vacuum cleaner to remove cuttings from the hole. Removal of cuttings in this manner in a non-penetrated slab will not compromise soil vapor samples because of lack of pneumatic communication between sub-slab material and the vacuum cleaner.

Next, use the rotary hammer drill to create a smaller diameter “inner” hole (e.g., 0.8 cm or 5/16 inch diameter) through the remainder of the slab and some depth (e.g., 7 to 8 cm or 3 inch) into sub-slab material. Drilling into sub-slab material will create an open cavity which will prevent obstruction of probes by small pieces of gravel.

The basic design of a sub-slab vapor probe is illustrated in Figure 10. Once the thickness of the slab is known, tubing should be cut to ensure that the probe tubing does not reach the bottom of the hole (to avoid obstruction of the probe with sub-slab material). **Chevron prefer use of stainless steel tubing materials although recent data comparing the performance of Teflon® and Nylon tubing with stainless steel tubing suggest that it would be appropriate to use these materials for constructing the sub-slab vapor probes too (Hartman 2008).** An advantage in using Nylon and Teflon® tubing is that there will likely be fewer sealing difficulties between the probe and concrete. If using stainless steel, construct sub-slab vapor probes from small diameter (e.g., 0.64 cm or ¼ inch outer diameter (OD) x 0.46 cm or 0.18 inch inner diameter (ID)) chromatography grade 316 stainless steel tubing and stainless-steel compression to thread fittings (e.g., 0.64 cm or ¼ inch OD x 0.32 cm or ⅛ inch (ID) Swagelok® or NPT female thread connectors) as illustrated in Figure 10. **Use stainless-steel to ensure that construction materials are not a source of VOCs.** Brass fittings (tubing, nipples and couplings) readily available at hardware stores are machined using cutting oils and could be a potential source of trace level VOCs and as such are not recommended to be used for constructing sub-slab vapor probes. In addition, use of Teflon® tape is recommended on any NPT threaded joints to ensure a good seal and to reduce the torque needed install and remove the probe plug, thus reducing the stress on the cement bond.

Set the sub-slab vapor probe in the hole. As illustrated in Figure 10, the top of the probe should be completed flush with the slab and have recessed stainless steel plugs so as not interfere with day-to-day use of the building. **The seal between the stainless steel sub-slab probe and the concrete floor is a common source of leakage.** Modeling clay or cement is typically used for surface seals. Unfortunately, there are few sealants that are non-adsorptive, do not give off vapors, and adhere well to both concrete and metal surfaces. Hydrating (swelling) cement adheres reasonably well to concrete, but not as well to metal tubing, so it is not unusual for the tubing to spin while fittings are being attached. Attaching all fittings before the probe is installed may minimize stresses on the seal. Mix a quick-drying Portland cement which is "VOC free" with water (e.g. hydro-cement available at building supply stores) which expands upon drying to ensure a tight seal) to form a slurry, Inject or push the slurry into the annular space between the probe and outside of the "outer" hole. Allow the cement to cure for at least 24 hours prior to sampling.

4.2 Sub-slab soil vapor sampling train tests, purging and sampling

After sub-slab soil vapor sampling probes are installed and soil vapor reaches equilibrium, a shut-in test should be done before purging and sampling. The procedures of shut-in test and leak test while sampling are the same as described in section 3 and as shown in Figure 5 and Figure 7.

After shut-in test, the probe is ready for purging and sampling. Please refer to section 3 for procedures of purging and sampling. **For sub-slab soil vapor sampling, 1 L 100 % certified Summa™ canisters are preferred in order to minimize the volume of soil vapor collected.** Collecting a smaller sub-slab sample will minimize the duration of inconvenience to the building occupants by minimizing the amount of time the helium shroud has to be monitored.

5 INDOOR AND AMBIENT (OUTDOOR) AIR SAMPLING

In some situations, it may be necessary to conduct indoor air and ambient air sampling to assess the potential for vapor intrusion to indoor air from subsurface contamination. **It is recommended to collect these concurrently with the sub-slab soil vapor samples.** Indoor air samples may contain BTEX and other VOCs within the concentration ranges commonly seen as background values measured at sites where no subsurface petroleum hydrocarbon contamination is known to be present. Unfortunately, these background VOC concentrations are also within (or even greater than) the range of risk-based concentrations (RBC) assuming a cancer risk range of 1E-06 to 1E-04 or hazard quotient of 1 (Figure 11, from Dawson & McAlary, 2009). There are many sources of background contamination inside buildings. Materials and substances commonly found in commercial and residential settings, such as paints, paint thinners, gasoline-powered machinery, building materials, cleaning products, dry cleaned clothing, and cigarette smoke, can potentially contribute to VOC detections in indoor air testing. Table 3 shows a list of common household petroleum – related VOC sources (NJDEP 2005). In urban areas, outdoor air also often contains background concentrations of VOCs that exceed risk-based indoor air target levels. **Therefore, outdoor ambient air samples should be collected whenever indoor air samples are collected to characterize the contribution from outdoor air.** It is not recommended to collect indoor air samples from buildings outside the assessed footprint of VOCs in the subsurface in an attempt to characterize the contribution from indoor sources, because consumer products, building materials and occupant habits vary from building to building.

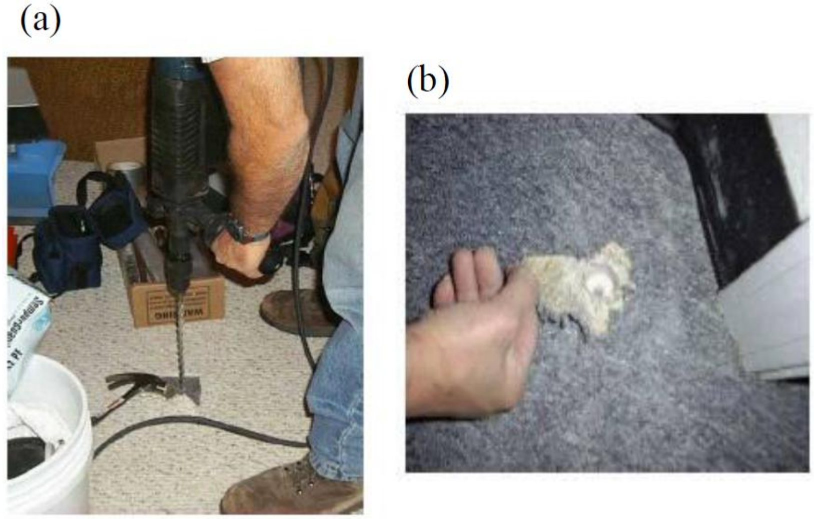


Figure 9. (a)Drilling through a slab, and (b) inner and outer holes (EPA).

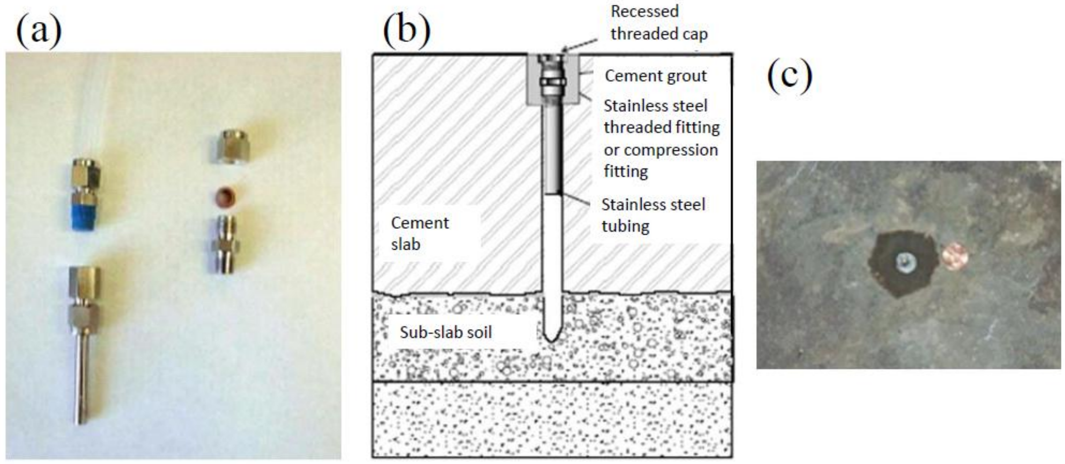


Figure 10. (a) Stainless steel sub-slab vapor probe components; (b) general schematic of sub-slab vapor probe and (c) completed sub-slab vapor probe. (EPA)

5.1 Indoor Air Sampling

Given the multitude of sources for VOCs in indoor air and that for some VOCs, the background indoor air concentrations could exceed the risk-based concentrations, it is critical to carefully plan any sampling event. Specifically for benzene in urban environments, indoor air sampling is not considered to be a first choice assessment option for residential structures unless the State has raised the acceptable indoor air benzene values above ambient levels. **This toolkit makes recommendations on the key elements of the plan. The project team should also consult appropriate state guidance for detailed information on indoor air sampling strategies, building inspection/surveys and household products inventory forms** (e.g., NYSDOH 2005, 2006, MADEP 2002, California EPA 2011, ITRC 2007).

Indoor air sampling may require multiple visits to the subject building(s). A pre-sampling site visit should be arranged at least 24 hours in advance of the sampling (NYSDOH 2005, MADEP 2002, California EPA 2011). This is used to interview the occupants and doing a building survey to gather the following information.

- Contact information for the occupants and owner
- Type of building construction
- Foundation characteristics
- Heating, Ventilating and Air Conditioning (HVAC) system details
- Water wells and sewage disposal

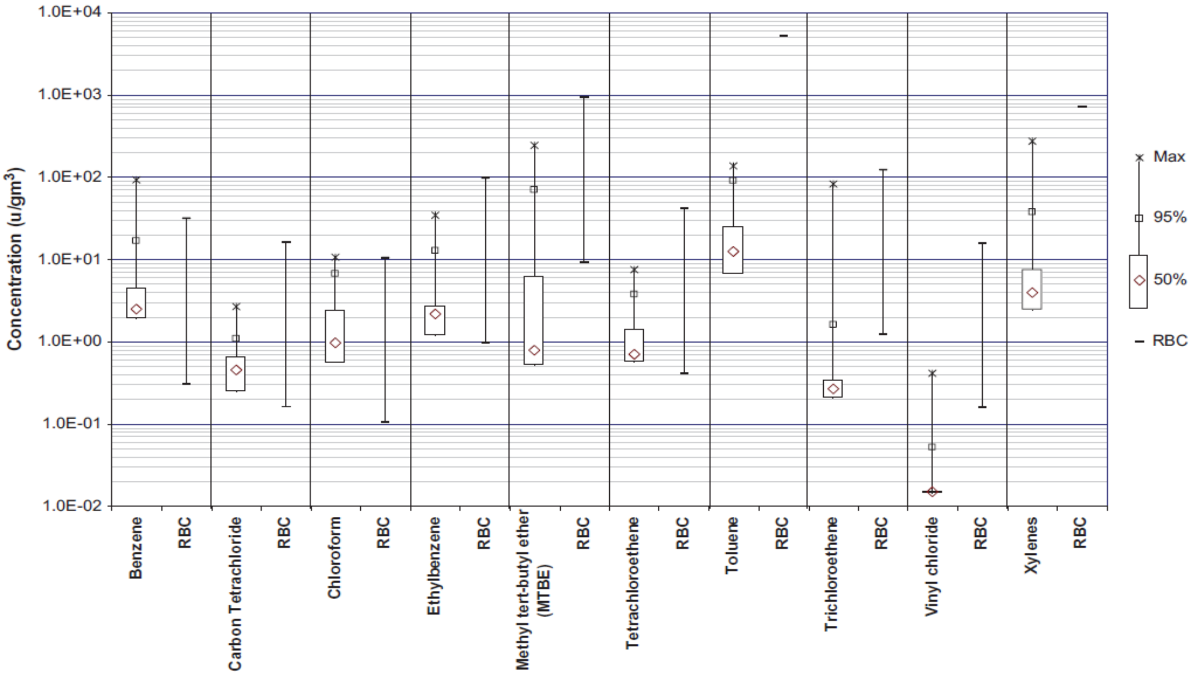


Figure 11. VOC concentrations in background indoor air compared to RBC.

- Potential indoor sources of VOC vapors, particularly those containing hydrocarbons, such as fuels, combustion products, cleaners, solvents and lubricants containing petroleum distillates and tobacco products. It is advisable to remove consumer products that contain VOCs or SVOCs from the building and any attached garage or shed at the time of the pre-sampling survey. Any unavoidable exceptions should be documented (including appropriate photographs) and highlighted with the results of the indoor air analysis.
- Plan view showing the sampling location(s) and pertinent information on floor layout including chemical storage areas, garages, doorways, stairways, basement sumps, plumbing and electrical conduits, elevator shafts etc.
- Potential outdoor sources of VOCs in ambient outdoor air. This will include a diagram of the area surrounding the building(s) being sampled showing potential sources such as service stations, repair shops, retail shops, landfills etc.

Indoor air sampling should be done in an environment that is representative of normal building use. Heating and air conditioning systems should be operated normally for the season and time of day. **Use 6 L 100% certified Summa™ canisters placed in the center of the room on the lowest floor at 3 to 5 ft above floor level to provide a sample representative of the breathing zone.** In order to mimic the anticipated daily exposure by inhalation, the **sampling duration for commercial/industrial buildings is 8 hours and for residential building is 24 hours (California EPA 2011).** Upon deployment of the sampling equipment, the Building Survey Form is updated to include the location of the sampling equipment, time, date, identification number, and environmental conditions.

As far as possible, the following activities should be avoided during the indoor air sampling event. Any unavoidable exceptions should be documented and highlighted with the results of the indoor air analysis:

- Allowing containers of gasoline or oil within the building or garage area, except for heating fuel oil tanks.
- Cleaning, waxing or polishing of furniture or floors (if cleaning is needed, use water only).
- Smoking cigars, cigarettes or pipes.
- Using air fresheners or odor eliminators.
- Using materials containing VOCs (dry markers, white out, glues, etc.).
- Using cosmetics including hairspray, nail polish, nail polish removers, perfume, and cologne.
- Applying pesticides.

5.2 Outdoor Ambient Air Sampling

Chevron recommends collecting ambient air samples at the same time the indoor air samples are collected. This will provide information about outside influences on indoor air quality. The outdoor ambient air sample will identify vapors from automotive fuels and exhaust, point sources such as gasoline stations, stack emissions and possible unique situations (paving crews, forest fires etc). **Use 6 L 100% certified Summa canisters**

placed 3-5 ft above grade at an upwind location protected from the elements (wind, rain, snow or ice) on the upwind side of the building (5-15 ft away). It is recommended that ambient air sampling begin at least 1 hour prior to indoor air sampling and should continue at least 30 minutes prior to the end of the indoor air sampling period.

6 ANALYTICAL TECHNIQUES

The analytical methods used are specific to the components analyzed and the reporting limits required to meet the data quality objectives. For example, reporting limits for fixed gases such as O_2, CO_2, N_2, and CH_4 of about 1% v/v are sufficient for interpretation; whereas VOCs such as benzene often have target concentrations in the low $\mu g/m^3$ range or lower, although this varies considerably between States. **Analytical reporting limits for indoor air samples should be lower than the risk-based target indoor air concentration, unless it is technically impracticable.** Analytical reporting limits for soil vapor samples could be higher because soil vapor concentrations attenuate upon entry to indoor air to varying degree. These could be estimated as a ratio of the indoor air target concentration to a conservative attenuation factor for the location of soil vapor sample (e.g., 1 for crawl space, 0.05 for sub-slab vapor and 0.002 for a deeper soil vapor sample in CAEPA 2011 VI guidance). Confer with the laboratory and applicable guidance to ensure that the necessary detection limits are met.

Before sampling and analysis begins, refer to applicable state and/or regional guidance and regulations to ensure that all requirements are complied with in sampling and analysis, including the number of analytes, analytical methods, reporting limits, and any requirement for state certification of the analytical laboratory. Maintain consistency of analytical methods between sampling events, as this can help reduce uncertainties in data results and interpretation. Table 4 provides a summary of required analytes for different samples and recommended analytical methods used for several common analytes during vapor intrusion investigations (adapted from API 2005).

Prior to sampling and analysis, the specific chemical components of concern at the site should be identified. These components commonly consist of the VOCs and SVOCs that have been identified as chemicals of interest at the site. In addition, some regulatory agencies have specified which chemicals of interest must be included in the list of analytes.

Prior to analysis, it is important to verify that a calibration for the chemicals of interest, or at a minimum calibration for the classes of chemicals of interest, has been developed. The mass spectrometer (MS) yields different response factors for different classes of compounds. **The tracer compound (helium) used during leak testing should also be included in the list of laboratory analyses for soil vapor samples. A laboratory-modified version of ASTM method D1946 may be needed because helium is not listed as an analyte in the method.** The analytical method used should be capable of quantifying these components at a concentration such that the subsurface vapor to indoor air exposure pathway can be adequately evaluated.

Chemical	Common Household Sources
Acetone	Rubber cement, cleaning fluids, scented candles and nail polish remover
Benzene	Automobile exhaust, gasoline, cigarette smoke, scented candles, scatter rugs and carpet glue
1,3-Butadiene	Automobile exhaust and residential wood combustion
2-Butanone (MEK)	Automobile exhaust, printing inks, fragrance/flavoring agent in candy and perfume, paint, glue, cleaning agents and cigarette smoke
Ethylbenzene	Paint, paint thinners, insecticides, wood office furniture, scented candles and gasoline
Formaldehyde	Building materials (particle board), furniture, insulation and cigarette smoke
n-Heptane	Gasoline, nail polishes, wood office furniture and petroleum products
n- Hexane	Gasoline, rubber cement, typing correction fluid and aerosols in perfumes
Methyl isobutyl ketone (MIBK)	Paints, varnishes, dry cleaning preparations, naturally found in oranges, grapes and vinegar
Methyl tert butyl ether (MTBE)	Gasoline (oxygenating agent)
Naphthalene	Cigarette smoke, automobile exhaust, residential wood combustion, insecticides and moth balls
Styrene	Cigarette smoke, automobile exhaust, fiberglass, rubber and epoxy adhesives, occurs naturally in various fruits, vegetables, nuts and meats
Tertiary butyl alcohol (TBA)	Gasoline (oxygenating agent)
Toluene	Gasoline, automobile exhaust, polishes, nail polish, synthetic fragrances, paint, scented candles, paint thinner, adhesives and cigarette smoke
1, 2, 4-Trimethylbenzene	Gasoline and automobile exhaust
1, 3, 5–Trimethylbenzene	Gasoline and automobile exhaust
2 ,2, 4-Trimethylpentane	Gasoline and automobile exhaust
Xylenes, total	Water sealer, gasoline, automobile exhaust, markers, paint, floor polish and cigarette smoke

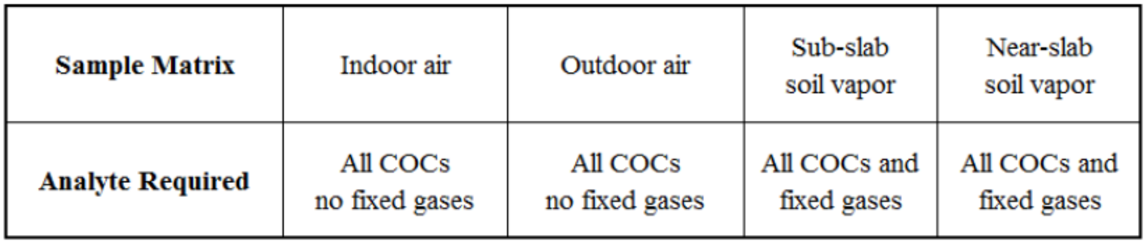
Table 3 Common household sources of petroleum hydrocarbons in background indoor air (Adapted from NJDEP, 2005)

6.1 VOCs/SVOCs

Gas chromatography/mass spectrometer (GC/MS) methods are recommended for all VOC and SVOC analyses. In the past we have recommended using EPA method TO-15 for analyzing VOC and SVOC concentrations in all types of VI investigations, however, a number of studies (Hayes et al 2005, Picker 2005 and Digiulio et al 2006a) have compared analytical results using methods TO-15 and 8260B. These data indicate that both give equivalent results down to levels as low as 10 μg/m^3. TO methods and hardware are designed for measuring low VOC levels in ambient air and not for high concentrations likely to be seen in soil vapor samples (which can exceed 100000 μg/m^3). **It is recommended that method 8260B be used for analyzing soil vapor samples and TO-15 be used for analyzing sub-slab vapor, indoor air and outdoor ambient air samples.** High concentrations in soil vapor samples can lead to system carryover, large dilutions and contaminated Summa^{TM} canisters increasing the potential for false positives, elevated reporting levels and problems associated with managing canisters (Hartman 2006).

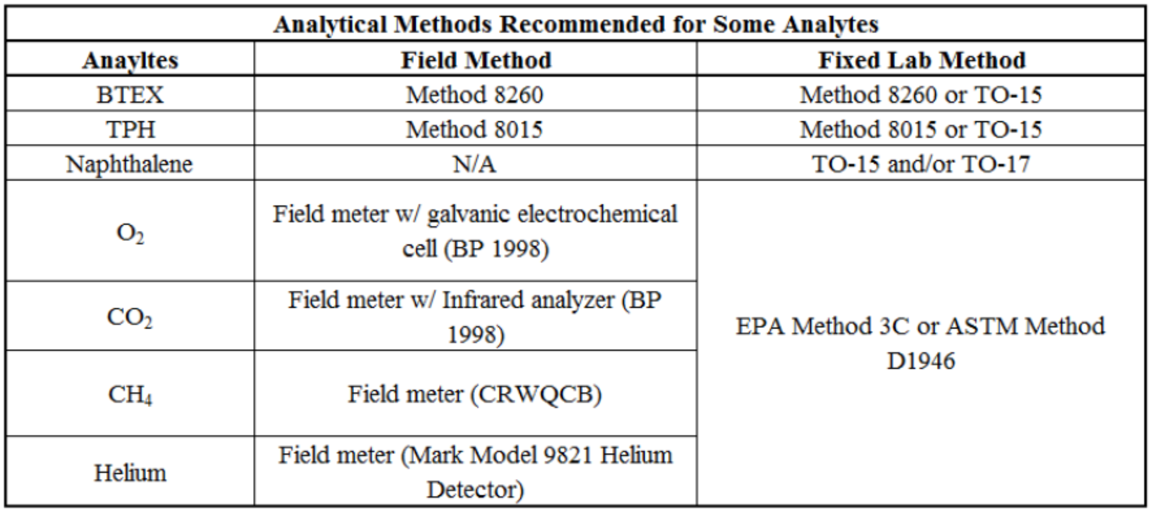
Naphthalene must be analyzed in all cases, and when using TO-15 (for sub-slab vapor, indoor air or outdoor ambient air), the laboratory must be notified of this request prior to ordering the Summa^{TM} canisters from the laboratory. In method

(a)



Sample Matrix	Indoor air	Outdoor air	Sub-slab soil vapor	Near-slab soil vapor
Analyte Required	All COCs no fixed gases	All COCs no fixed gases	All COCs and fixed gases	All COCs and fixed gases

(b)



Analytical Methods Recommended for Some Analytes

Anayltes	Field Method	Fixed Lab Method
BTEX	Method 8260	Method 8260 or TO-15
TPH	Method 8015	Method 8015 or TO-15
Naphthalene	N/A	TO-15 and/or TO-17
O_2	Field meter w/ galvanic electrochemical cell (BP 1998)	EPA Method 3C or ASTM Method D1946
CO_2	Field meter w/ Infrared analyzer (BP 1998)	
CH_4	Field meter (CRWQCB)	
Helium	Field meter (Mark Model 9821 Helium Detector)	

Table 4 **(a) Required analytes for different samples and (b) recommended analytical methods used for several common analytes (Adapted from API 2005).**

TO-15 the detector (i.e. MS) can be operated in either the full scan mode (for standard method detection limit of 1 to 5 $\mu g/m^3$), or selected ion monitoring (SIM) mode to improve the method detection limit (< 1 $\mu g/m^3$) for a selected set of analytes. Sub-slab **soil vapor samples should not be analyzed in the SIM mode for two reasons:** One, it is not necessary as the risk-based soil vapor screening levels are generally higher than 5 $\mu g/m^3$ (Hartman 2006) and two, there is a potential for interference from the natural organic matter in the soil (EPRI 2005). **At this point, Chevron recommends using TO-15 method to do naphthalene sample collection and the lab conducting analysis should utilize certain procedures specified Appendix E in CAEPA's "Advisory Active Soil Gas Investigation" (CAEPA, 2012). Chevron does not recommend using TO-17 method due to the lack of the universal acceptance by most regulatory agencies.** Should the TO-17 method be required by the local agency, a detailed description of how soil vapor samples are to be collected in the field should be included with clear explanatory text and illustrative figures in work plan documents.

6.2 Fixed Gases

ASTM Method D1946, a gas chromatography/thermal conductivity detector (GC/TCD) method, is recommended for analysis of fixed gases, including O_2 and CO_2. For CH_4, ASTM Method D1946 can also be used, with a flame ionization detector (FID) in place of a TCD.

6.3 Data reporting

Soil vapor concentrations are reported in units of µg/L, $\mu g/m^3$, ppm_v, and ppb_v. Unlike concentration units for groundwater, these units are not directly interchangeable. The molecular weight (MW) of the compound in question is a factor in the conversion from units of parts per billion (ppb_v) to mass per unit volume ($\mu g/m^3$) as follows (API 2005) assuming temperature at 273 K and pressure at 1 atm.:

$$concentration\left(\mu g/m^3\right) = concentration\left(ppb_v\right) \times 0.04 \times MW$$

USEPA website also provides a useful conversion spreadsheet at:
http://www.epa.gov/athens/learn2model/part-two/onsite/ia_unit_conversion.html

Data are usually reported in table format, which is adequate for understanding and interpreting soil vapor concentrations over time and space. However, depth profiles for multi-level soil vapor sampling probes can be used in order to visualize changes in VOC concentrations and respiration/fixed gases over a given depth interval (as in Figure 12 particularly for assessing biodegradation of petroleum hydrocarbon vapors). Figure 12 shows the vertical soil vapor profiles for benzene vapors sourced from the smear zone or dissolved groundwater plume and oxygen suggesting that downward diffusion of oxygen from surface may have contributed to the significant attenuation of benzene over a 10-ft depth interval due to the aerobic biodegradation of benzene diffusing upward. On the other hand, if higher soil vapor concentrations are detected in the shallower probes than in the deeper probes, it is usually an indication of soil vapors sourced from hydrocarbon impacted soil in the vadose zone. Plotting data in visual formats often enhances the message that the text is providing.

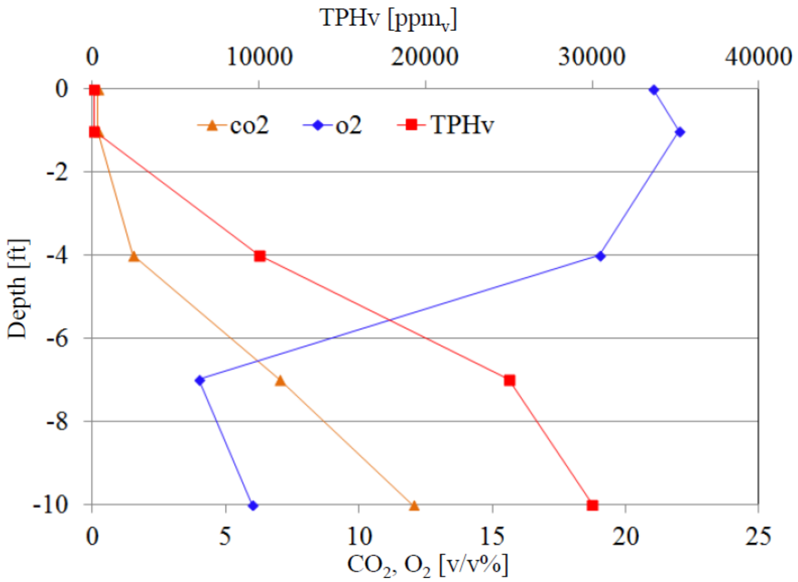


Figure 12. Vertical profile of TPHv, O_2, and CO_2.

7 REFERENCES

Air Toxics Ltd. Evaluating Leaks in a Soil Gas Sample Train
http://www.airtoxics.com/literature/AirToxicsLeakCheckStudy.pdf

Air Toxics Ltd. Guide to Air Sampling and Analysis, Canisters and Tedlar Bags
http://www.airtoxics.com/literature/AirToxicsLtdSamplingGuide.pdf

Air Toxics Ltd. Impact of Sampling Media on Soil Gas Measurements
http://www.airtoxics.com/literature/AirToxicsAWMA2006.pdf

American Petroleum Institute, 2005. Collecting and Interpreting Soil Gas Samples from the Vadose Zone: A Practical Strategy for Assessing the Subsurface-Vapor-to-Indoor-Air Mitigation Pathway at Petroleum Hydrocarbon Sites, Publication #4741.
http://www.api.org/ehs/groundwater/lnapl/soilgas.cfm

ASTM, D 5314-92, 2001. Standard Guide for Soil Gas Monitoring in the Vadose Zone.

California EPA, 2003. Advisory – Active Soil Gas Investigation. Jointly issued by the Regional Water Quality Control Board, Los Angeles Region and the Department of Toxic Substances Control.
http://www.dtsc.ca.gov/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf

California EPA, 2012. Advisory Soil Gas Investigations. Jointly issued by Department of Toxic Substances Control Los Angeles Regional Water Quality Control Board

San Francisco Regional Water Quality Control Board
http://www.dtsc.ca.gov/SiteCleanup/upload/VI_ActiveSoilGasAdvisory_FINAL_043012.pdf

California EPA 2011. Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Department of Toxic Substances Control. http://www.dtsc.ca.gov/AssessingRisk/upload/Final_VIG_Oct_2011.pdf

CSDDEH (County of San Diego Dept. of Environmental Health), 2002. Site Assessment and Mitigation Manual (SAM Manual).

Dawson, H. & 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, 29(1), 60-69.

DiGiulio, D. et al. 2006a Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air
http://www.epa.gov/ada/download/reports/600R05147/600R05147.pdf

DiGiulio, D., Paul C., Scroggins, B., Cody, R., Willey, R., Clifford, S., Mosley, R., Lee, A., Christensen, K., Costa, R., 2006b. EPA/600/R-06/111, Comparison of Geoprobe® PRT and AMS GVP Soil-Gas Sampling Systems with Dedicated Vapor Probes in Sandy Soils at the Raymark Superfund Site,
http://www.epa.gov/nrmrl/pubs/600R06111/600R06111.pdf

EPRI 2005. Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air http://mydocs.epri.com/docs/public/000000000001008492.pdf

Hartman, B., 2004. LUSTLine Bulletin no. 48, How to Collect Reliable Soil-Gas Data for Risk-Based Applications-Specifically Vapor Intrusion. Part 3-Answers to Frequently Asked Questions. http://www.neiwpcc.org/lustline/lustline_pdf/lustline_48.pdf

Hartman, B., 2006. LUSTLine Bulletin no. 53, How to Collect Reliable Soil-Gas Data for Risk-Based Applications-Specifically Vapor Intrusion. Part 4- Updates on Soil-Gas Collection and Analytical Procedures.
http://www.handpmg.com/documents/LL53.Blayne.pdf

Hartman, B., 2008. Results from EPA Research Programs on Sample Flow Rate, Purge Volume, Tubing Type, Tedlar Bags, and Temporal Variations On Soil Gas Concentrations, Presentation given to CA-EPA/DTSC, Los Angeles, CA.

Hayes, H., Benton, D., Grewal, S., Khan, N., 2005, “A Comparison between EPA Compendium Method TO-15 and EPA Method 8260 for VOC Determination in Soil Gas.

Paper #46., AWMA Symposium, San Francisco, CA.
http://www.airtoxics.com/literature/papers/Final_AWMA_TO15_8260.pdf

Health Canada. Soil Vapor Intrusion Guidance for Health Canada Screening Level Risk Assessment (For Vapor Intrusion Applications).

Interstate Technology and Regulatory Council (ITRC), 2007. “Vapor Intrusion Pathway: A Practical Guideline” (http://www.itrcweb.org/Documents/VI-1.pdf)

MA DEP 2002. Indoor Air Sampling and Evaluation Guide. Massachusetts Department of Environmental Protection, Boston, MA. April 2002.
http://www.mass.gov/dep/cleanup/laws/02-43 0.pdf

McAlary, T., and T. N. Creamer, 2006. The effects of Purge Rate and Volume on Sub-Slab Soil Gas Samples. Battelle. Remediation of Chlorinated and Recalcitrant Compounds. Monterey, CA. May 2006

Ouellette, G., 2004. Soil Vapor Sampling and Analysis-Lessons Learned Presentation, Inland Empire Analytical, PERF VI Forum, Brea.

State of New Jersey DEP, 2012. Vapor Intrusion Technical Guidance.
http://www.nj.gov/dep/srp/guidance/vaporintrusion/vig_main.pdf

State of New York DOH, 2005. Indoor Air Sampling And Analysis Guidance.
http://www.health.ny.gov/environmental/indoors/air/docs/guidance.pdf

State of New York DOH, 2006. Guidance for Evaluating Soil Vapor Intrusion in the State of New York
http://www.health.state.ny.us/environmental/investigations/soil_gas/svi_guidance/docs/svi_main.pdf

US EPA, 1999. Method TO-15. http://www.epa.gov/ttnamti1/airtox.html

US EPA, 2002. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance).
http://www.epa.gov/osw/hazard/correctiveaction/eis/vapor/complete.pdf

US EPA, 2006 SF_6 Emission Reduction Partnership for Electric Power Systems.

Additional Resources

http://www.epa.gov/oust/cat/pvi/index.htm
This website includes general information on vapor intrusion, along with information on VI guidiance documents from different states, and documents on different aspects of VI.